

**GROWTH AND BIOMASS PRODUCTION OF
DIFFERENT *EUCALYPTUS* SPECIES ON
RIVERINE SOILS OF PUNJAB**

Thesis

**Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of**

**MASTER OF SCIENCE
in
FORESTRY
(Minor Subject: Extension Education)**

By

**Harmandeep Singh
(L-2015-A-75-M)**

**Department of Forestry and Natural Resources
College of Agriculture
©PUNJAB AGRICULTURAL UNIVERSITY
LUDHIANA-141 004**

2018

CERTIFICATE I

This is to certify that the thesis entitled “**Growth and biomass production of different *Eucalyptus* species on riverine soils of Punjab**” submitted for the degree of **M.Sc.**, in the subject of **Forestry** (Minor subject: **Extension Education**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Harmandeep Singh (L-2015-A-75-M)** under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

(Dr. R.K. Garg)
Major Advisor
Professor of Forestry
Department of Forestry and Natural
Resources
Punjab Agricultural University
Ludhiana – 141 004

CERTIFICATE II

This is to certify that the thesis entitled, “**Growth and biomass production of different *Eucalyptus* species on riverine soils of Punjab**” submitted by **Harmandeep Singh (L-2015-A-75-M)** to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **Master of Science**, in the subject of **Forestry** (Minor subject: **Extension Education**) has been approved by the Student’s Advisory Committee along with External Examiner after an oral examination on the same.

(Dr. R.K. Garg)
Major Advisor

(Dr. K.S. Bangarwa)
External Examiner
Emeritus Professor
Department of Forestry
CCS Haryana Agricultural
University, Hisar

(Dr. R.I.S. Gill)
Head of the Department

(Dr. G.K. Sangha)
Dean, Postgraduate Studies

ACKNOWLEDGEMENT

This thesis is the end of my journey in obtaining my M.Sc. and I bow in front of the Almighty for the successful completion of my degree. The thesis has been kept on track and been seen through to completion with the support and encouragement of numerous people including my family, my friends, well wishers, colleagues and various departments of PAU.

*It cannot be argued with that the most influential person in my post graduate career has been my advisor, **Dr. Rakesh Kumar Garg**, Professor of Forestry, Department of Forestry and Natural Resources, whose passion, guidance, and discipline have been indispensable to my growth as a scientist and as a person over these past years. I feel privileged to express my deepest sense of gratitude towards him. I also thanks **Dr. Sanjeev Kumar Chauhan**, Head, Central Arid Zone Research Institute, Regional Research Station, Leh-Ladakh for his support throughout the research work.*

*I express my sincere thanks to **Dr. R.I.S Gill**, Head, Department of Forestry and Natural Resources for providing me the desired facilities in my research work.*

*I also express my sincere thanks to, **Dr. Sandeep Sharma**, Department of Soil Sciences, **Dr. Vipin Kumar Rampal**, Deputy Director, KVK Ropar, **Dr Sapna Thakur**, Department of Forestry and Natural Resources and **Dr. Harmeet Singh Saralch** who as members of my advisory committee provided me multifarious help and cooperation.*

*Language and words are inadequate to express my feelings of indebtedness and gratitude to my loving father **S. Jivan Singh**, mother **Hardeep Kaur**, brother **Gagandeep Singh** and sister **Ramandeep Kaur** for their love, untiring support and encouragement which enabled me to complete my work.*

*It is said "If friendship is your weakest point, then you are the strongest person in the world"...I owe special thanks to my friends: **Tarsem Singh, Narinderpal Singh Cheema, Gurpreet Singh, Sukhdeep Singh, Jagjot Singh** who have made my journey in these years an unforgettable one.*

*I am also thankful to the non teaching staff of Department of Forestry and Natural Resources especially **Mrs Kuldeep Kaur** for providing me the necessary facilities and help whenever required.*

Last but not the least I would like to thank all the people who contributed in some way to the work described in this thesis. All may not be mentioned but none is forgotten.

Date: _____

(Harmandeep Singh)

Title of the Thesis : Growth and biomass production of different *Eucalyptus* species on riverine soils of Punjab

Name of the student and Admission No. : Harmandeep Singh
(L-2015-A-75-M)

Major Subject : *Forestry*

Minor Subject : *Extension Education*

Name and Designation of Major Advisor : *Dr. Rakesh Kumar Garg*
Professor of Forestry

Degree to be Awarded : M.Sc. (Forestry)

Year of award of Degree : 2018

Total Pages of Thesis : 50 + VITA

Name of University : Punjab Agricultural University, Ludhiana – 141004,
Punjab, India

ABSTRACT

A field experiment entitled “Growth and biomass production of different *Eucalyptus* species on riverine soils of Punjab” was conducted at University Seed Farm of Punjab Agricultural University Ludhiana, Ludhiana during 2016-17. Five different species of *Eucalyptus* were studied to compare the growth and biomass production and to investigate the changes in soil physico-chemical properties after one year of harvesting of trees under riverine soils of Punjab. Different parameters for tree growth (tree height, collar diameter, DBH, canopy spread) and tree biomass (fresh stem weight, fresh branch weight, fresh leaf weight and bark biomass) were recorded. Soil parameters (soil pH, EC, soil organic carbon, bulk density, available N, P and K) were also observed. Results of the present study clearly indicated that the tree growth and biomass of clone was maximum in *Eucalyptus* 288 clone as compared to other four *Eucalyptus* species. Soil physico-chemical properties were better under tree plantation having organic matter in the form of litter fall as compared to the soil one year after harvesting of plantation. Soil pH, electric conductivity, soil organic carbon, available nitrogen, phosphorus and potassium decreased after one year of harvesting.

Keywords: *Eucalyptus*, Tree growth, Biomass, Soil physico-chemical properties

Signature of Major Advisor

Signature of the Student

ਖੋਜ ਗ੍ਰੰਥ ਦਾ ਸਿਰਲੇਖ	: ਪੰਜਾਬ ਦੀ ਦਰਿਆਈ ਮਿੱਟੀ ਉਪਰ ਸਫੈਦੇ ਦੀਆਂ ਵੱਖੋ-ਵੱਖਰੀਆਂ ਪ੍ਰਜਾਤੀਆਂ ਦਾ ਵਿਕਾਸ ਅਤੇ ਜੈਵਿਕ ਮਾਦੇ ਦਾ ਉਤਪਾਦਨ
ਵਿਦਿਆਰਥੀ ਦਾ ਨਾਮ ਅਤੇ ਦਾਖਲਾ ਨੰ.	: ਹਰਮਨਦੀਪ ਸਿੰਘ (ਐਲ-2015-ਏ-75-ਐਮ)
ਪ੍ਰਮੁੱਖ ਵਿਸ਼ਾ	: ਜੰਗਲਾਤ
ਸਹਿਯੋਗੀ ਵਿਸ਼ਾ	: ਪਸਾਰ ਸਿੱਖਿਆ
ਮੁੱਖ ਸਲਾਹਕਾਰ ਦਾ ਨਾਮ ਅਤੇ ਅਹੁਦਾ	: ਡਾ. ਰਾਕੇਸ਼ ਕੁਮਾਰ ਗਰਗ ਪ੍ਰੋਫੈਸਰ (ਜੰਗਲਾਤ)
ਡਿਗਰੀ	: ਐਮ.ਐਸ.ਸੀ.
ਡਿਗਰੀ ਮਿਲਣ ਦਾ ਸਾਲ	: 2018
ਖੋਜ ਪੱਤਰ ਵਿੱਚ ਕੁੱਲ ਪੰਨੇ	: 50 + ਵੀਟਾ
ਯੂਨੀਵਰਸਿਟੀ ਦਾ ਨਾਮ	: ਪੰਜਾਬ ਖੇਤੀਬਾੜੀ ਯੂਨੀਵਰਸਿਟੀ, ਲੁਧਿਆਣਾ - 141 004, ਪੰਜਾਬ, ਭਾਰਤ

ਸਾਰ

ਮੌਜੂਦਾ ਅਧਿਐਨ ਦੌਰਾਨ “ਪੰਜਾਬ ਦੀ ਦਰਿਆਈ ਮਿੱਟੀ ਉਪਰ ਸਫੈਦੇ ਦੀਆਂ ਵੱਖੋ-ਵੱਖਰੀਆਂ ਪ੍ਰਜਾਤੀਆਂ ਦਾ ਵਿਕਾਸ ਅਤੇ ਜੈਵਿਕ ਮਾਦੇ ਦਾ ਉਤਪਾਦਨ” ਸਿਰਲੇਖ ਅਧੀਨ ਪੰਜਾਬ ਖੇਤੀਬਾੜੀ ਯੂਨੀਵਰਸਿਟੀ ਦੇ ਲਾਢੋਵਾਲ ਸਥਿਤ ਬੀਜ ਫਾਰਮ ਵਿਖੇ 2016-17 ਦੌਰਾਨ ਖੇਤ ਤਜਰਬਾ ਕੀਤਾ ਗਿਆ। ਵਿਕਾਸ ਅਤੇ ਜੈਵਿਕ ਮਾਦੇ ਦੇ ਉਤਪਾਦਨ ਦਾ ਤੁਲਨਾਤਮਕ ਮੁਲਾਂਕਣ ਕਰਨ ਲਈ ਅਤੇ ਪੰਜਾਬ ਦੀ ਦਰਿਆਈ ਮਿੱਟੀ ਅਧੀਨ ਰੁੱਖਾਂ ਦੀ ਕਟਾਈ ਦੇ ਇੱਕ ਸਾਲ ਮਗਰੋਂ ਮਿੱਟੀ ਵਿੱਚ ਆਉਣ ਵਾਲੀਆਂ ਭੌਤਿਕ-ਰਸਾਇਣਕ ਤਬਦੀਲੀਆਂ ਦੀ ਜਾਂਚ ਕਰਨ ਲਈ ਸਫੈਦੇ ਦੀਆਂ ਪੰਜ ਵੱਖੋ-ਵੱਖਰੀਆਂ ਪ੍ਰਜਾਤੀਆਂ ਦਾ ਅਧਿਐਨ ਕੀਤਾ ਗਿਆ। ਰੁੱਖ ਦੇ ਵਿਕਾਸ ਦੇ ਵੱਖੋ-ਵੱਖਰੇ ਮਾਪਦੰਡਾਂ (ਰੁੱਖ ਦੀ ਉਚਾਈ, ਕਾਲਰ ਵਿਆਸ, ਡੀ.ਬੀ.ਐਚ., ਕੈਨੋਪੀ ਫੈਲਾਅ) ਅਤੇ ਰੁੱਖ ਦੇ ਜੈਵਿਕ ਮਾਦੇ (ਤਾਜ਼ੀ ਟਾਹਿਣੀ ਦਾ ਭਾਰ, ਤਾਜ਼ੀ ਸ਼ਾਖਾ ਦਾ ਭਾਰ, ਤਾਜ਼ੇ ਪੱਤੇ ਦਾ ਭਾਰ ਅਤੇ ਸੱਕ ਦਾ ਜੈਵਿਕ ਮਾਦਾ) ਦੇ ਆਂਕੜੇ ਦਰਜ ਕੀਤੇ ਗਏ। ਅਧਿਐਨ ਦੌਰਾਨ ਮਿੱਟੀ ਦੇ ਗੁਣ (ਮਿੱਟੀ ਦੀ ਪੀ.ਐਚ., ਬਿਜਲਈ ਸੰਚਾਲਕਤਾ, ਮਿੱਟੀ ਵਿੱਚਲੀ ਜੈਵਿਕ ਕਾਰਬਨ, ਬਲਕ ਘਣਤਾ, ਉਪਲਬਧ ਨਾਈਟ੍ਰੋਜਨ, ਫਾਸਫੋਰਸ ਅਤੇ ਪੋਟਾਸ਼ੀਅਮ) ਵੇਖੇ ਗਏ। ਮੌਜੂਦਾ ਅਧਿਐਨ ਦੇ ਨਤੀਜਿਆਂ ਤੋਂ ਇਹ ਸਪਸ਼ਟ ਹੋਇਆ ਕਿ ਸਫੈਦੇ ਦੀਆਂ ਬਾਕੀ ਚਾਰ ਪ੍ਰਜਾਤੀਆਂ ਦੇ ਮੁਕਾਬਲੇ ਸਫੈਦਾ 288 ਕਲੋਨ ਦੇ ਰੁੱਖ ਦੇ ਵਿਕਾਸ ਅਤੇ ਜੈਵਿਕ ਮਾਦਾ ਸਭ ਤੋਂ ਵਧੇਰੇ ਸੀ। ਜਿੰਨਾਂ ਥਾਵਾਂ ਤੇ ਜੈਵਿਕ ਮਾਦਾ, ਰਹਿੰਦ-ਖੂੰਹਦ ਦੇ ਡਿੱਗਣ ਨਾਲ ਉਪਲਬਧ ਸੀ ਉਹਨਾਂ ਥਾਵਾਂ ਤੇ ਲਗਾਏ ਗਏ ਰੁੱਖਾਂ ਹੇਠਲੀ ਮਿੱਟੀ ਦੇ ਭੌਤਿਕ-ਰਸਾਇਣਕ ਗੁਣ ਉਸ ਮਿੱਟੀ ਤੋਂ ਵਧੀਆ ਸਨ ਜਿਸ ਮਿੱਟੀ ਵਿੱਚ ਰੁੱਖਾਂ ਨੂੰ ਲਗਾਉਣ ਤੋਂ ਇੱਕ ਸਾਲ ਮਗਰੋਂ ਕੱਟਿਆ ਗਿਆ ਸੀ। ਰੁੱਖਾਂ ਦੀ ਕਟਾਈ ਤੋਂ ਇੱਕ ਸਾਲ ਬਾਅਦ ਮਿੱਟੀ ਦੀ ਪੀ.ਐਚ., ਬਿਜਲਈ ਸੰਚਾਲਕਤਾ, ਮਿੱਟੀ ਦੀ ਜੈਵਿਕ ਕਾਰਬਨ, ਮਿੱਟੀ ਵਿੱਚ ਉਪਲਬਧ ਨਾਈਟ੍ਰੋਜਨ, ਫਾਸਫੋਰਸ ਅਤੇ ਪੋਟਾਸ਼ੀਅਮ ਦੀ ਮਾਤਰਾ ਵਿੱਚ ਕਮੀ ਆਈ।

ਮੁੱਖ ਸ਼ਬਦ: ਸਫੈਦਾ, ਰੁੱਖ ਦਾ ਵਿਕਾਸ, ਜੈਵਿਕ ਮਾਦਾ, ਮਿੱਟੀ ਦੇ ਭੌਤਿਕ-ਰਸਾਇਣਕ ਗੁਣ

CONTENTS

CHAPTER	TOPIC	PAGE NO.
I	INTRODUCTION	1 – 4
II	REVIEW OF LITERATURE	5 – 17
III	MATERIAL AND METHODS	18 – 22
IV	RESULTS AND DISCUSSION	23 – 38
V	SUMMARY	39 – 40
	REFERENCES	41 – 50
	VITA	

LIST OF TABLES

Table No.	Title	Page No.
4.1	Growth performance of different <i>Eucalyptus</i> species	24
4.2	Fresh above ground biomass production (kg) of different <i>Eucalyptus</i> species	27
4.3	Fresh below ground biomass, total biomass and root to shoot ratio of different <i>Eucalyptus</i> species	28
4.4	Soil pH under different <i>Eucalyptus</i> species	30
4.5	Electric conductivity of soil for different <i>Eucalyptus</i> species	31
4.6	Soil organic carbon of different <i>Eucalyptus</i> species	32
4.7	Bulk density of soil in different <i>Eucalyptus</i> species	33
4.8	Available Nitrogen content in soil for different <i>Eucalyptus</i> species	34
4.9	Available P content in soil for different <i>Eucalyptus</i> species	35
4.10	Available K content in soil for different <i>Eucalyptus</i> species	37

LIST OF FIGURES

Fig. No.	Title	Page No.
1	Monthly meteorological data (Jan 2016-Dec 2016), Ludhiana	19
2	Mean annual increment of tree height different <i>Eucalyptus</i> species	25
3	Mean annual increment of DBH in different <i>Eucalyptus</i> species	26
4	Biomass partitioning of different <i>Eucalyptus</i> species	29
5	Soil pH under plantation and after one year of harvesting for different <i>Eucalyptus</i> species	30
6	Electric conductivity under plantation and after one year of harvesting for different <i>Eucalyptus</i> species	31
7	SOC under plantation and one year after harvesting for different <i>Eucalyptus</i> species	32
8	Bulk density of soil under plantation and one year after harvesting of different <i>Eucalyptus</i> species	34
9	Available N content under plantation and one year after harvesting for different <i>Eucalyptus</i> species	35
10	Available P content under plantation and one year after harvesting for different <i>Eucalyptus</i> species	36
11	Available K content under plantation and after one year of harvesting for different <i>Eucalyptus</i> species	37

CHAPTER I

INTRODUCTION

Eucalyptus, a fast growing tree belongs to family “Myrtaceae” and is native to Australia. *Eucalyptus* was introduced into sub-tropical countries to fulfill the requirement of timber and fuelwood for local peoples. It was introduced by Britishers in Tamil Nadu in 1843 for timber and food purpose (Troup 1932). The first *Eucalyptus* plantation was raised by forest department in 1877 at Malabavi, Tumkur, Karnataka (Kadambi 1944).

Eucalyptus hybrid is most common grown tree species in Punjab. The history of introduction of *Eucalyptus* in Punjab is quite old. A few species of *Eucalyptus* were planted in Punjab as early as 1860 by Director of Canals of Madhopur headworks situated on the river Ravi. In early sixties, *Eucalyptus* hybrid (Mysore gum) was planted on large scale. In northern western states especially in Punjab many farmers had started planting *Eucalyptus tereticornis* in their fields. Planting of *Eucalyptus* as an agroforestry tree species and tree outside the forests is catching up with introduction of new fast growing clones.

In the north Indian states such as Punjab, Haryana, Uttarakhand and Uttar Pradesh, *Eucalyptus* is grown under farm forestry and agroforestry systems. In Punjab, poplar and *Eucalyptus* trees growing outside the forests exceeds 28 million (Anon 2006). *Eucalyptus* being planted on large scale as it is not native to India because of its reach to grow fast and tolerate to unfavourable climates which involves the factors like : coppicing, indeterminate growth, drought, lignotubers, insect resistance, fire and tolerate low fertility and soil acidity. *Eucalyptus* species having high density, makes it desirable for fuelwood and charcoal production, pulp, sawn wood and paper manufacturing (Rockwood *et al.* 2008).

It has nearly perfect architecture to suit many afforestation requirements. The characteristics like straight and clean bole, small and light crown, self pruning, strong tap root system and fast growth made them popular with the forest department as well as farmers. It also yield valuable economic products such as charcoal, methyl alcohol, acetic acid, and cellulose for the manufacture of rayon and cellophane, oil, tannin and their direct anti-malarial value. Leaves and bark serve various pharmaceutical purposes (Penfold and Willis 1961).

Eucalyptus plantations was also encouraged by centre as well as state governments through various schemes to meet the demands of inhabiting people by generating small timber, firewood, poles, etc. *Eucalyptus*, being accepted as an good farm forestry species, was raised on canal sides, field bunds and on marginal agricultural lands. Forest departments of most states, under different schemes, distributed seedlings of free of cost of different species

including *Eucalyptus*. National Forest policy (1988) envisaged that the industry requirements be met through plantation practices. Management of government forests should be done for ecological purposes and meeting the requirements of local peoples.

Farm forestry not only provides multiple outputs of tree/crop based products to meet the needs of local people and industries but also facilitates the amelioration of environment and reduce the pressure on traditional factors. In addition, it is thought to maximize soil organic carbon through the addition of litter fall (Schroth and Sinclair 2003; Young 1989), check soil erosion (Schultz *et al.* 2004; Escobar *et al.* 2002), increase land productivity (Noble *et al.* 1998) and diversify the farm income (Seobi *et al.* 2005). Several studies have shown that trees often improve the productivity of systems and also provides opportunities to create carbon sinks (Montagnini 2004; Dixon 1995; Nair *et al.* 2009; Jose 2009; Sharma *et al.* 2012; Singh and Pandey 2011). Farm forestry is most alternate way to minimize the affect of land degradation and to bring about sustenance of soil resources and eco-restoration (Dhyani and Chauhan, 1995).

According to Forest Survey of India area under forest and tree cover is 24.39% of overall geographical area of country (ISFR 2017). Minimum required area with forests is 33% out of total area of country. Punjab state, an intensively cultivated agriculture state, has about 84 percent of geographical area under crops. The situation of forest and tree cover is very dismal with only 3459 sq km as 6.17 percent of total geographical area out of which forest cover is 3.65 % with 1837 sq km area (ISFR 2017). Thus there exists a wide void between demand and supply of fuel wood, timber and other products.

The average productivity of *Eucalyptus* clones is about 20 to 25 m³ ha⁻¹ yr⁻¹ in un-irrigated conditions. Whereas, many farmers achieved maximum growth rate of 50-58 m³ ha⁻¹ yr⁻¹ making farm forestry an financially attractive land use option (Piare Lal 1994). Various things are need to improve in quality of produce and reductions in per unit production costs that is possible with use of true to type, uniform and genetically improved planting stock of *Eucalyptus* (Piare Lal 2001).

The farming of clonal *Eucalyptus* is one of alternatives for diversifying agriculture as the productivity and profitability of clonal plantation is very high compared to seed route plantations. The productivity of seed route plantation was 6-10 m³ ha⁻¹yr⁻¹ as compared to clonal plantations which ranges from 20 to 44 m³ ha⁻¹yr⁻¹ ((Lal and Kulkarni 1992).

Biomass studies are costly and time-consuming process, thus, restricted to small areas and small sample trees through destructive method (Ketterings *et al.* 2001; Fehrmann and Kleinn 2006). Regression model is most commonly method used by many researchers

(Djomo *et al.* 2010 and Henry *et al.* 2010) to estimate the biomass and carbon in forests. This is probably due to increasing pressure placed on forests by the community for different forest products, search for renewable source of raw materials, etc. In addition to the productive role, the growing concern of well being of forest ecosystems has resulted in the appearance of numerous publications on forest biomass throughout the world including India (George 1977, Chaturvedi, 1983, Negi 1984) but in most of the studies only above ground biomass has been estimated.

Eucalyptus has of high growth rate which requires more soil nutrients demand to grow (Camara *et al.* 2000). The nutrients absorption by *Eucalyptus* trees is essential to their development and reproduction. Studies conducted over many years on the effects of *Eucalyptus* on soils properties (Poore and Fries 1985; Kindu *et al.* 2006) have shown that soil chemical properties can be affected by monoculture in two different ways viz. 1) depletion of nutrients into different tree components and 2) litter layer formed as a result of litter fall from one species.

Clonal forestry refers to planting of vegetatively propagated ramets. The clonal identity of these ramets is maintained, from the recognized and tested ortets for commercial production of trees. Existing natural forests of India are failing to meet the increasing demand for timber, firewood and other wooden products due to the poor growing stock of forests, reduced increments, insufficient monetary and scientific inputs, intolerable biotic pressures and severe degradation of forest resources (Lal 2010). The clonal planting stock from genetically superior ramets result in higher productivity (Libby and Rauter 1984).

The brief description of different tree species, *Eucalyptus cameldulensis* common name long-beak *Eucalyptus* belongs to family Myrtaceae. It is important for apiculture due to nector production, fuelwood, pulp and paper production. Timber is suitable for many structural applications, for example poles, railway sleepers, floorings, posts, heavy construction and ship building. Bark produce a gum used as dye. Leaves are rich source of oil of medicinal uses. Another species *Eucalyptus tereticornis* common name *Eucalyptus*, Safeda belongs to family Myrtaceae. It is major source of pollen and nector for honey bee, fuelwood, good quality pulp for paper production.

Bet or flood plain soils are *Khadar* soils that flood periodically of different choes, rivers or streams or choes of Punjab. They are found in the form of elongated belts on both sides of the channels like that of Ravi, Satluj, Ghagghar and Beas. Colour ranges from pale to yellowish brown. The soils are very deep and well drained and have different textures with low and uneven organic matter in general. Depending upon the source of alluvium, the Soils are calcareous and non-calcareous depending upon alluvium soil.

Inspite of its known importance in practical use and potential short rotation valuable species for agroforestry and block plantations. The study was conducted with the following objectives:

- i. Comparison of growth and biomass of different *Eucalyptus* species.
- ii. To know the soil properties changes under different species.

CHAPTER II

REVIEW OF LITERATURE

Research reports on biomass production in different tree species of *Eucalyptus* are available and also their soil nutrition activities literature is reviewed under following headings:

2.1 Tree Growth and biomass production

2.2 Soil physico-chemical properties

2.1 Tree Growth and biomass production

South and South east Asia occupies 25.6 million hectares of planted forests that represents 8.7% of their total forest area across the world (FAO 2010) with most of these forests (90%) are in China, India, Indonesia, Malaysia, Thailand and Vietnam (Harwood and Nambiar 2014). The most planted tree in the world is *Eucalyptus*, a genus of more than 500 species (Demel 2000). *E. hybrid*, a form of *E. tereticornis* (Mysore gum) has been favoured and the most outstanding out of 170 species that were tried in India (Bhatia 1984). (Rawat and Negi 2004) *Eucalyptus tereticornis* is most widely planted species in India including Punjab. The strongest ecological factor for determining the primary production is climate. Depending on length of growing period and precipitation, country has been divided into six agro ecological zones and available data on biomass production has been stratified into different agro ecological zones. In moist regions from three year old plantation to 9 year old plantation biomass varies from 11.9 t/ha to 146 t/ha. It varies from 5.65 t/ha in 5 year plantation to 135.5 t/ha in 9 year old plantation in dry tropical region. Biomass accumulation was more in cool areas as compared to warm areas in dry tropical regions. Higher mean annual temperature of around 25°C seems to produce higher biomass as water is not the limiting factor. The share of leaf biomass was observed high in dry region. In dry tropical region, root to shoot ratio was also high.

The growth and biomass of three important energy plantation tree species viz. *Acacia auriculiformis*, *Cassia siamea* and *Eucalyptus hybrid* was studied by Oraon *et al.* (2016) in three districts (Deoghar, Ranchi and East Singhbhum) of Eastern plateau and hill region of Jharkhand, India. The comparison of growth performance in terms of survival percent, plant height, diameter and total biomass of tree were done at the age of four years. Among three species, *Eucalyptus hybrid* was better as compared to other two species in terms of survival, growth and biomass. Growth performance (height and diameter) of *Eucalyptus hybrid* was found better as compared to other species. The tree height and diameter of *Eucalyptus hybrid* was recorded maximum 11.42m and 9.14cm followed by *Acacia auriculiformis* (5.54m and

4.69cm) and *Cassia siamea* (5.03m and 3.85cm). The data for fresh biomass of different above ground parts (bole, branches, leaves and barks) and below ground parts (roots) were also collected. The result indicated that *Eucalyptus hybrid* (average 307.69 kg/tree) had maximum fresh biomass as compared to other two species, whereas below ground maximum fresh biomass obtained by *Acacia auriculiformis* (average 19.33 kg/tree) followed by *Cassia siamea* (average 14.61 kg/tree) and the minimum fresh biomass of root obtained by *Eucalyptus hybrid* (13.45 kg/tree).

Local *Eucalyptus* species (*E. camaldulensis*, *E. tereticornis* and *E. urophylla*) recorded mean height of 18.40 m (*E. urophylla* with a mean height of 12.05 m) performed comparatively poorer than the clones. Maximum height was recorded in *Eucalyptus hybrid* (11.25 m) followed by *E. grandis* (10.90 m) and *E. tereticornis* (10.35 m). *E. pelleta* recorded the lowest height (9.10 m) Balozzi Kirongo *et al.* (2010)

The study conducted by Karthick and Pragasan (2014) aims to determine the stand density, basal area and above ground biomass of two plantations, *Eucalyptus* plantation and mixed species plantation in the campus of Bharathiar University, Coimbatore, Tamil Nadu, India. Tree density was high at site of mixed species plantation i.e. 468 stems/ha than site of *Eucalyptus* plantation 320 stems/ha. Whereas, in case of basal area, the fast growing *Eucalyptus* tree plantation site had greater value 9.42 m²ha⁻¹ than site mixed species plantation 8.67 m² h⁻¹. Also, site *Eucalyptus* plantation had greater above ground biomass value 41.78 t/ha when compared to mixed plantation which had 34.47 t/ha. It concludes that *Eucalyptus* plantation is fast growing plantation in Bharathiar University when compared to mixed species plantation, having more biomass density.

The growth comparison of eight year old *Eucalyptus* clones (*E. urophylla* × *E. grandis* clones 3229, 30-1 and *E. urophylla* clone U6) was evaluated and revealed that, *Eucalyptus* clones showed high growth rate during the first three years. Zhongmian *et al.* (2009) observed the significant differences among the 3 *Eucalyptus* clones in plant height, diameter and volume growth. These indexes were positively correlated with the increasing age. Clone 3229 showed best growth followed by 30-1, while the U6 grew worst.

The growth and productivity of *Eucalyptus* species on degraded land from 2003 to 2010 were investigated at Main Agricultural Research Station, University of Agricultural Sciences, Dharwad. The experiment consisted of five *Eucalyptus* species viz., *E. hybrid*, *E. grandis*, *E. tereticornis*, *E. Dandeli* and *E. pelleta* clones planted with 2 x 2 m space in randomized block design with four replications. Patil *et al.* (2012) studied and found that parameters for growth viz., current annual increment in height, tree height and CAI in DBH and MAI in height, diameter at breast height (DBH) were significantly higher in *E.*

tereticornis and *E. hybrid* comparing to that of *E. pelleta*. *E. hybrid* and *E. tereticornis* has maximum volume as compared to *E. pelleta*.

The study for the growth performance of different *Eucalyptus* clones and the seedlings were reported and found that all clones performed equally well at this site as compared to the local landraces, the shortest height was found in *E. camaldulensis* (11.99 m) and *E. tereticornis* (11.58 m), whereas maximum height was recorded in Clone GC14 (17.15 m). In the case of DBH, there were significant differences in DBH in year three at $p < 0.001$. Oballa *et al.* (2005) found that the clones and species like GC15, GC581, GC14 and GC642 were best in performance among others. *E. tereticornis* and *E. camaldulensis* did not performed good due to unfavorable conditions.

Study was conducted by Rawat *et al.* (2012) in 4 Forest Divisions of Punjab namely Amritsar, Hoshiarpur, Ludhiana and Patiala. Biomass (t/ha) was estimated through complete harvesting of 23 *Eucalyptus* trees of various ages (18-30 years), density (232-740 trees/ha), diameter (12.7 cm to 49.75cm) and height (14.4 to 41.5 m). Total biomass ranged from 112.98 t/ha to 531.09 t/ha and the productivity ranged from 3.77 t/ha. Biomass of various plant components ranged as; leaf biomass (1.08 kg/tree to 29.95 kg/tree), twig biomass (1.62 to 31.92 kg/tree), branch biomass (6.36 to 151.56 kg/tree), bark (8.32 to 168.77 kg/tree), bole biomass (55.88 to 1911.41 kg/tree), root biomass/below ground biomass (BGB) (9.36 to 397.20 kg/tree).

The comparison for eleven *Eucalyptus* species and hybrids of *E. grandis* (seedling collected from Bhadrachalam and Saharanpur), *E. tereticornis*, *E. alba*, *E. torrelliana*, *E. urrophylla* and hybrid clones of 266, 348, 413, 471 for their morphological characteristics in north Indian condition were studied by Dutt and Tyagi (2011). They found that the *E. grandis* of Bhadrachalam and Saharanpur origins gave significantly better performance comparable to other *Eucalyptus* species.

Eucalyptus tereticornis clones cultivated on shallow medium soil under dry land conditions were evaluated for five years and compared with the seedling growth (Ilorkar *et al.* 2016). Among the clones ITC-413 attained maximum and significant height (6.62 m) followed by ITC-71 (6.33 m) and ITC-316 (6.32 m). ITC-413 and ITC-71 were at par while the lowest height was recorded by ITC-136 (5.26 m). Maximum mean annual height increment (MAI) was observed in ITC-413 (1.324 m). With reference to diameter at breast height (DBH) maximum DBH was attained by ITC-413 (20.13 cm) followed by ITC-316 (16.32 cm) and ITC-71 (15.23 cm). The lowest DBH was attained in ITC-286 (7.12 cm). Maximum mean annual DBH (MAI) was produced by ITC-413 (4.026 cm). *Eucalyptus* clones ITC-413, ITC-316 and ITC-71 suggest their suitability for cultivation under local dry land conditions.

Kumar *et al.* (2010) found significant variations for diameter at breast height, clear bole height and tree height in *E. tereticornis* (Sm.). The genetic gain for clear bole height and height increased substantially with increase in age of trees. Clone 17 attains maximum DBH over other genotypes for second and third year followed by clones 11 and 14. Clone 5 showed an upward trend for DBH and maintained its superiority for CBH as the age of tree increased. Similarly, clone 11 changes its rank from ninth to eighth to third in case of diameter at breast height and from ninth to fourth to second for clear bole height at the age of one, two and three years. Clones 10 and 6 performed not well for all characters that were studied. Clone 5, 17 and 14 were found to be well developed for commercial purposes.

The productivity of clonal *Eucalyptus* is more than two to three times of the seed route plantations. The experimental trials carried out by Pragati Biotechnologies have indicated seven most productive clones with MAI ranging from 24 to 30 m³ ha⁻¹ yr⁻¹ at the age of four years. Some clones are reported to produce 30 to 36 m³ ha⁻¹ yr⁻¹. The analysis of data from private agroforestry farms revealed that clone 288 gave MAI of 48.79 m³ ha⁻¹ yr⁻¹ followed by clone 316 with MAI (33.70 m³ ha⁻¹ yr⁻¹) at the age of four and five years, respectively (Luna *et al.* 2009). The clonal plantations are a boon for the farmers (Sapra 2006). Many farmers in Punjab have achieved record growth rates of 50-58 m³ ha⁻¹ yr⁻¹ making farm forestry an economically attractive land use option with better returns compared to traditional crops (Piare Lal 2006).

The yield and growing stock of *Eucalyptus* plantations varies depending on edapho-climatic conditions, inputs and sites. The potential productivity around about 5 tons of biomass/ha/yr on an average, but the average production is somewhat 2.5 ton/ha/yr. Average yield from the private plantations is much high i.e., 20-25 m³h⁻¹yr⁻¹ (Saigal and Kashyap 2002) and 20-58 m³h⁻¹yr⁻¹ (Kulkarni 2008) which is 5-9 times higher than seed route plantations. The yield recorded from Government plantations so far is low probably due to increase in removing of trees by the peoples for their bonafide use.

Eighty six trees of *E. tereticornis* (forty from energy and forty six from boundary plantation) were harvested to develop allometric regression equation for predicting standing tree's above ground weight were studied (Rai *et al.* 2006). Diameter of trees ranged from 9.55 to 30.25 cm and 12.73 to 37.58 cm, biomass from 25.95 to 332.48 kg/tree and 69.34 to 777.6 kg/tree, and height from 11.7 to 29.35 and 10.80 to 25.40 m under energy and boundary plantations, respectively. It was interesting to observe that leaf biomass accumulation was almost same under both plantations, whereas bole biomass was slightly higher under energy than boundary plantation, although statistically differences were not significant.

A study was conducted to assess the comparative growth performance of various *Eucalyptus* clones (Lal 2005). Most outstanding clones were 413, 407, 411, 112, 72, 105 and 316 with MAI ranging from 25 to 30 at $\text{m}^3 \text{ha}^{-1} \text{yr}^{-1}$ at 3 years age. The clonal material derived from *E. tereticornis*, *E. camaldulensis* and *E. hybrid* have been tested by Lal *et al.* 2006 and reported good productivity of 2070, 295, 316, 288, 498, 286 and 2045 clones in Punjab. Somachai *et al.* (1991) investigate the study and found that the performance of *Eucalyptus* in Japan, have observed that the tree yielded about 44.9 t/ha year of biomass which was over 30% more than the yield from *Acacia mangrum* plantation of identical age.

Sinha *et al.* (2012) found significant differences while comparing different *Eucalyptus* clones with their morphological characteristics such as height and diameter. P 316 attained the height of 15.38 m as compared to P 411 with height of 12.36 m. Diameter at breast height (DBH) range varies from 12.19 cm to 9.22 cm in JKSC 08 and BCM 2045 respectively.

Clone no. 130 was found to be most promising by (Kumar and Bangarwa 2006) with highest mean performance for diameter at breast height, CAI of total heights, CAI of clear bole height, CAI of unforked height and MAI of DBH. Clone no.7 found to be well performing with the highest mean performance for clear bole height, unforked height and MAI of unforked height. Rawat and Negi (2004) concluded that in *Eucalyptus tereticornis* biomass varies from 11.9 t/ha in three year old plantation to 146 t/ha in nine year old plantation in moist regions. In dry tropical region, it varies from 5.65 t/ha in five year plantation to 135.5 t/ha in nine year old plantation.

Kulkarni (2004) evaluated various clones of *Eucalyptus* and short listed the promising clones on the basis of growth performance and identified clones number 3, 6, 7, 10, 27, 71, 72, 99, 105, 115, 122, 128, 130, 175, 223, 265, 266, 271, 273, 274, 277, 284, 285, 286, 288, 290, 292, 316, 319, 405, 411, 412, 413, 417, 439 and 470 as the important commercial clones. Chaturvedi (1983) described that *Eucalyptus* can attain an average height of 16.50 m and 12.50 cm diameter (*E. hybrid*); in case of *E. grandis* it is 20.50 m and 15.01 cm, just in 6 years plantation on good sites. Under scientific management with the fertilizer and irrigation applications, an optimum size of 15cm diameter with 15m height will be achieved in 6 years (Patel 1982).

Upadhyaya and Soni (1997) conducted a study on information regarding growth parameters, pattern of organic matter distribution and contribution of various parts towards total biomass of five year old *Eucalyptus camadulensis* plantation grown in IGP area of Rajasthan. The tree height varied from 5 m to 20 m and girth at breast height ranged from 15 to 69 cm. Average girth and height of the plantation being 13.55m and 12.01 m, respectively.

The higher girth classes contained higher percentage of bole wood and utilizable biomass and less of non-utilizable biomass. The total biomass yield was 185.12 oven-dry t/ha, whereas, utilizable biomass was 147.19 oven-dry t/ha.

A study conducted by the planting of fourteen provenances of *E. tereticornis* Sm. and fifteen provenances of *E. camaldulensis* Dehnh. at Pudukottai, Tamil Nadu revealed significant differences for diameter at breast height at age of eight years (Kumaravelu *et al.* 1995).

Banerjee *et al.* (1986) studied and found that *E. camaldulensis* was superior in respect to above ground biomass (46.97 t/ha), below ground biomass (10.25 t/ha) and total standing biomass (57.22 t/ha) followed by *E. grandis* (36.32, 8.02 and 44.34 t/ha respectively), *E. tessellaris* (34.53, 7.54, and 42.07 t/ha respectively) and *E. brassiana* (31.25, 6.88 and 38.13 t/ha respectively) after four year plantation. *E. tereticornis* and *E. resinifera* showed poor performance in laterite areas of West Bengal.

The trials of 6 provenances of *Eucalyptus tereticornis* (including one local *Eucalyptus* hybrid), 8 provenances of *E. camaldulensis* and one provenance each of 2 other species, *E. brassiana* and *E. tessellaris*, at a site in Ferozepur Forest Division, Punjab were reported by Aulakh and Sandhu (1990). The highest basal area and annual increment were reported in Laura provenance of *E. tereticornis* (Dogra and Sharma 2005). Significant differences between species/provenances were observed in height and DBH, but not in volume. The best performances were by 5 of the *E. tereticornis* provenances (including the local hybrid), with 3 of the *E. camaldulensis* provenances.

Three experiments were conducted at Forest Divisions, Gurdaspur, Tarn-Taran and Ludhiana to estimate the production of *Eucalyptus* clones. Data was also collected from different private farms. At Ludhiana, clone 413 gave highest mean annual increment (MAI) of 28.80 m³/ha/year, over bark and 23.49 m³/ha/year, under bark, at age of three years. Clone 526 performs well at Gurdaspur with highest MAI (productivity) of 21.15 m³/ha/year, over bark and 17.25 m³/ha/year, under bark. Whereas, at Amritsar, clone 413 was most productive with MAI of 36.07 m³/ha/year, over bark and 29.42, m³/ha/year, under bark, at the age of 2.5 years. The present study revealed that clone 413 gave outstanding productivity over bark ranges from 28.80 m³ to 36.07 m³/ha/year. Clones like 2045, 526, 285 and 2070 also performed well. The analysis of data from private farms revealed that clone 288 gave MAI of 48.79 m³/ha/year over bark, followed by clone 316 with MAI (33.70 m³/ha/year) (Private farm at Hoshiarpur) at the age of four and five years, respectively. Though other clones under study had low productivity and were significantly higher than seed route plants. Clonal *Eucalyptus* gave two to six times more volume per hectare as compared to the seed plants (Luna *et al.* 2009).

The comparison for plantation of *E. camaldulensis* and *E. grandis* with sal forest and secondary brushwood were reported by Mathur *et al.* (1980) after clearing of sal forest. Both the number of species and the vegetation cover were greater in the *Eucalyptus* plantation and lesser in the sal forest. So were the amounts of litter above ground biomass and below ground biomass. The crown canopy (a measure of shading) were recorded as *Eucalyptus* 74.7%, brushwood 53.79% and sal 36.29%. These suggest better and richer vegetation under *Eucalyptus*.

The 18 years-old *Eucalyptus hybrid* plantation were raised in foot hills of Nainital and Bisht *et al.* (1989) reported that the total above ground parts of trees accumulated 110.0 t/ha biomass, of which the maximum biomass was produced by bole 70.6 to 81.9 percent, while other tree components produced more or less similar biomass. Cromer *et al.* (1976) reported percent contribution to above ground biomass by bole, leaf, bark and branch in 2 years old *Eucalyptus globulus* as 28-38%, 33-46%, 9% and 17-20%, respectively. They have further noticed that at 5 years, the above ground biomass contribution was 83% to total standing biomass and the balance biomass (17%) was contributed by tree roots.

Tandon *et al.* (1993) have studied mean diameter of *Eucalyptus hybrid* plantation in Haryana with respect to age 4, 6, 8 and 10 years. Mean diameter at these ages were 6.9, 9.2, 14.5 and 16.5 cm respectively. The study estimated above ground biomass and its distribution among various components in *Eucalyptus hybrid* plantation in Haryana at different ages. The above grounds biomass reported at 4, 6, 8 and 10 years age was 20.1, 34.6, 88.7 and 137.7 t/ha, respectively. The componential biomass at 10 years age by bole, bark, leaf, twig and branch were 77.7, 7.8, 2.5, 3.7 and 8.1%, respectively. The found that the biomass increases with increase in age of trees. Patel (1982) reported that the total biomass yield of 38072 kg/ha in *Eucalyptus tereticornis* out of which 24942 kg/ha was utilizable biomass contributed by wood, bark and branches amounting to 12898, 4435 and 7609 kg/ha, respectively. In total biomass, contribution of leaf, fruit and roots were 4761 kg/ha, 15 kg/ha and 56336 kg/ha respectively.

2.2 SOIL PHYSICO-CHEMICAL PROPERTIES

Eucalyptus have been raised successfully in diverse kind of soils such as recent alluvial soils (Punjab, Haryana and Uttar Pradesh), Tarai soils (Uttarakhand), (Rajasthan), deeply cut ravines (Rajasthan), red sandy and loamy soils (Bihar, Madhya Pradesh and Orissa), skeletal rocky and murrans soils, denuded hill slopes, red and yellow soils (Andhra Pradesh and Madhya Pradesh), black cotton soils (Gujarat, Karnataka and Maharashtra) and coastal alluvial soils (Tamil Nadu). Though grown on a diverse type of soils, its best growth is achieved in deep, fertile, well-drained loamy soil with adequate moisture. In Bhabar and

Tarai region of Uttarakhand, a bhabar soil with coarse texture and excessive boulder sub-soil, having deficient moisture supply is not found favourable for good growth.

Mineral nutrients are required to plants as well as forest trees to grow and live. Nutrients taken up by trees are eventually returned to soil through the litter, and decomposed as organic matter through the leaching and washing effects of rain on tree stem and foliage (Spurr & Barnes 1980). Knowledge of nutrient cycling is equally an essential prerequisite for understanding and predicting forest plantations tree species' effect on the environment (Turner *et al.* 1976; Landsberg 1986).

The impact of tree plantations on soil properties has been very much debated and no any complete consolidated view exist, partly due to fact that the impact is much dependent on variable site and forest conditions. Number of studies indicate the changes in soil properties that were influenced by tree species (Lemma 2006, Poore and Fries 1985; Malik and Fries 1985; Lemenih *et al.* 2004; Lugo 1990). The changes depend on stand age (Zhang *et al.* 2004; Jaiyeoba 2001; Binkley *et al.* 2004), biological factors (Burgess *et al.* 1993), and intensity of forest management (Zhang *et al.* 2007; Mendham *et al.* 2002; Shan *et al.* 2001). Trees improve the sites by changing the infiltration capacity, microclimate, physical structure, moisture regime and chemical properties of soil (Prinsely and Swift 1986). With the time, process such as nitrogen fixation, litter fall, crown expansion, nutrient cycling contribute to nutrient, root extension and organic matter build-up on top soil leads to biological chemical and physical improvement in critical rooting zone (Garg and Jain 1992; Evans 1992; Gill *et al.* 1987).

Nutrient demand by *Eucalyptus* is less than others because heartwood begins to form at approximately 4 years. After this, a significant proportion of nutrients in wood is recycled to other parts of the tree and soil. And quantities that are immobilized are kept to a low. *Eucalyptus* also contributes to intense decomposition of organic matter in soil - through roots, bark and leaves estimated at 7 tonnes per hectare per year, thus improves soil fertility.

Sehgal *et al.* 1971; Sindhu *et al.* 1977; Anand *et al.* 1977; Sharma and Dev 1985; Ibrahim *et al.* 1986 all conducted the studies on the flood plains soils of Punjab showed that the soils are young and stratified with properties inherited from parent material. These soils developed on alluvium, vary widely with respect to texture, degree of profile development, drainage, salt and calcium carbonate content. According to Rigbelis and Nahas (2004), the most important soil nutrient supply to the forest soil environment is the one derived from litter decomposition by actions of organism under conditions of high air temperature and soil moisture content. Soil being one of the most complex and heterogeneous environments, contains significant microbial diversity (Tiedje *et al.* 1999).

Farm forestry not only provides multiple outputs of tree/crop based products to meet the needs of local people and industries but also facilitates the amelioration of environment and reduce the pressure on traditional factors. In addition, it is thought to increase the soil organic carbon through litter fall (Schroth and Sinclair 2003; Young 1989), check soil erosion (Schultz *et al.* 2004; Escobar *et al.* 2002), increase land productivity (Noble *et al.* 1998) and diversify the farm income (Seobi *et al.* 2005). Several studies have shown that trees often improve the productivity of systems and also provides opportunities to create carbon sinks (Montagnini 2006; Dixon 1995; Nair *et al.* 2009; Jose 2009; Sharma *et al.* 2012; Singh and Pandey 2011,). Farm forestry is thus the most viable option to tackle land degradation and to bring about sustenance of soil resources and eco-restoration (Dhyani and Chauhan, 1995).

The field experiment was conducted during 2012-13 at Agroforestry Research Centre, Haldi, of G.B. Pant University of Agriculture and Technology, Pantnagar (U. S. Nagar), Uttarakhand by Satyawali *et al.* (2017) to study the effect of different planting density of *Eucalyptus camaldulensis* and *Melia azedarach* on nutrient accumulation in soil with spacing of 3.0 m × 1.0 m, 3.0 m × 1.5 m, 3.0 m × 2.0 m and 3.0 m × 2.5 m. Maximum soil organic carbon content (1.73 and 1.79%) in *Eucalyptus* and *Melia*, respectively was recorded with greater planting density at 0-30cm depth, whereas, maximum NPK (356.6, 37.85 and 289.5 kg/ha, respectively) was obtained with wider spacing at the same depth. Annual litterfall affect the nutrient storage in soil which was found in the order: N>K>P. The nutrient shows the decreasing trend with increase in the depth of soil from 0-30 to 60-90cm. The nutrient (NPK) show significant relation with respect to planting density.

The study was conducted by Yitaferu *et al.* (2013) to find the effect of land use change from *Eucalyptus* to cropland on soil physico-chemical properties in Koga irrigation area, Amhara Region, Ethiopia. Soil samples were taken from four sites of three land uses (*Eucalyptus* land use changed to cropping, cropland and *Eucalyptus* woodlots) at 0-20, 20-40 and 40-60 cm depths. Result shows that except available P, sampled plots that were changed from *Eucalyptus* to cropland were found better in soil chemical properties (CEC, N, pH) and soil organic matter contents comparing to croplands. The comparison made to the other two land uses, it was found that total N was highest at *Eucalyptus* woodlots. Regarding soil physical properties (texture and bulk density), little or no difference was recorded among all land use types. The results of study showed and confirms that changing of land use from *Eucalyptus* to cropland is possible without any effect on soil properties and also without affecting productivity of lands to raise crops.

Bala *et al.* (2010) found that litter production varies with stem density and plantation age in *E. camaldulensis* being high in twelve year old plantation (6087 kg/ha). Minimum

production of litter was in four year plantation (2042 kg/ha). Conclusively, low rate of decomposition signifies slow rate of nutrient turnover.

Demessie *et al.* (2012) stated that the growing of exotic *Eucalyptus spp.* may lead to have less litter production and uneven nutrient release resulting in low soil productivity for long term. Through its litter decomposition, *Eucalyptus spp.* Plantation can improve the soil chemical, physical and biological properties.

The study was conducted by Ravina (2012) to find the impact of *Eucalyptus* plantations on pasture land as well as soil properties and carbon sequestration in Brazil. He also studied the soil properties and analyzed comprised SOC and nitrogen content, pH, cation exchange capacity (CEC), exchangeable cations and bulk density. The result found the increase in soil bulk density at 1.24 g cm^{-3} under *Eucalyptus spp.* plantation as compared to native forest of 0.66 g cm^{-3} within depth of 0-20 cm . It showed an increase in soil compaction and total SOC decrease with land use change to pasture. Higher pH and exchangeable cation concentrations show possible fertilization effects. The total nitrogen is not affected by the land use changes.

Pennington *et al.* (2001) observed a similar and significant change in soil properties after clear harvesting of *Eucalyptus* plantations in Australia. Range for soil bulk density varies from 0.58 Mg m^{-3} to 0.70 Mg m^{-3} and it was also noticed that there was a loss of 107 kg ha^{-1} of Nitrogen and 3850 kg ha^{-1} of Carbon content.

Baber *et al.* (2006) investigate the soil physico-chemical properties under agroforestry at two depths (0 to 15cm and 15 to 45cm), that were carried in Soil and Environmental Sciences Laboratory, North-West Frontier Province Agricultural University, Peshawar. Collection of samples from distance of 5, 10, 15 and 20m from the *Eucalyptus* trees. Soil samples were analyzed for various soil parameters viz. electrical conductivity (EC), pH organic matter, K, P and micronutrients (Cu, Zn, Mn and Fe). Result shows that soil pH of both depths were alkaline and EC of samples ranges from 0.08 to 0.35 dSm^{-1} whereas, organic matter content was low in both the depths. In micronutrients, Zn and Fe was deficient at both depths, Cu was marginal at 0-15cm and adequate at 15-45cm and Mn was deficient at 0-15cm and marginal at 15-45cm. The effect of distance on various soil properties EC, pH, K, P and organic matter decreases with distance from trees in surface soil, while in subsoil, organic matter and P decreased with distance whereas EC, K and pH. Conclusion of the study, defecting response for nutrients, alkaline and high pH and low organic matter were found in all soil samples. Soil organic and inorganic fertility may be recorded to avoid yield reduction and soil amended for reduction of pH and soil nutrients availability.

FAO (2011) studied and observe the increase in soil bulk density from 0.58 mg m⁻³ to 0.70 mg m⁻³ for *Eucalyptus spp.* plantations in Australia. Also FAO (2011) studied to compare the one to eight years old *Eucalyptus spp.* plantations and natural mixed broad leaved forest in the central Himalayas and result shows the total available nitrogen and available phosphorous decreased with reforestation of *Eucalyptus spp.*

The contents of soil organic matter were considerably high in *Eucalyptus spp.* soils as compare to pasture areas, which they attributed to the greater amount of residues produced by the *Eucalyptus spp.* plantation (branches, leaves, bark and especially roots) that remained in the soils of Brazil which were reported by Leite *et al.* (2010). He also found the large nutrient amounts are exported when *Eucalyptus spp.* plantation were cleared, causing a reduction in the soil nutrients content such as total nitrogen and available phosphorous.

Rhoades and Binkley (1996) found a decrease in soil pH which lowers from 5.9 to 5.0 after 8 years of *Eucalyptus saligna* establishment. Cao *et al.* (2010) also found decrease in soil pH between 0 to 10 cm depths of soil, which ranges from 4.2 to 4.5, in *Eucalyptus spp.* plantations in China.

On comparison of soil properties with depth 0- 30 cm under plantations of one to eight year old *E. tereticornis* and the natural mixed broadleaved forest in the subtropical zone of the central Himalaya. Sunita and Uma (1993) observed that organic carbon, N, P and K contents of soils in three, six and nine year old plantations of *E. tereticornis* is less than that of natural forest.

Bargali *et al.* (1993) noted that soil chemical properties like organic carbon, total nitrogen, phosphorus and potassium, decreased as a result of reforestation with *E. tereticornis* and further decreased with increasing age. Decrease in soil fertility due to short rotation *Eucalyptus* plantation was reported by Balagopalan (1992).

Only certain species of *Eucalyptus* are high extractor of soil nutrients and that entire genus should not be blamed on this count (George and Varghese 1990). Their experiments reveal that *E. globulus* takes up 184 Kg/ha/year of NPK and return as much as 102 Kg/ha/year to the soil while *E. hybrid* takes up 113 Kg/ha/year of NPK and returns only 31 Kg/ha/year to the soil. In other words only certain and not all species of *Eucalyptus* causes nutrient stress on the soil.

Nutrient requirements vary widely with different species (Cole and Rapp 1981). Likewise, much of the current environmental concern about short rotation forestry management revolves around nutrient removal from harvest (Heilman and Norby 1997). Various soil physical properties decreases with increasing age and soil chemical properties

like organic carbon, total N, P and K decreases as a result of reforestation with *Eucalyptus* and further decreases with increasing age. According to Lemenih *et al.* (2004), the soil pH marks decrease in *Eucalyptus* as comparing to adjacent natural forest and other exotic tree species.

Soil under trees has generally high organic carbon as compared to other land use systems because of continuous addition of litter fall by trees (Jha *et al.* 2003). Gill *et al.* (1987) observed higher organic carbon content in the plantation of *Acacia nilotica* than the *Eucalyptus* due to higher litterfall of *Acacia nilotica*. The litterfall added through different tree species affects the organic matter and nutrient content of soil depending upon the rate of decomposition of litterfall. The quality and quantity of litter produced by trees depend on the climatic conditions, age, species and spacing. Similarly, Kumar *et al.* (1998) observed lower content of OC under *Eucalyptus* among shisham, poplar, *Eucalyptus* and kikar in Haryana after 12 years of tree growth. Moreover high nutrient content and soil organic carbon can be noticed under tree as compares to the areas without trees (Singh and Sharma 2007).

The extent of improving the soil properties depends on the tree species, management practices and quality and quantity of litter and their decomposition rate (Jan *et al.* 1996). Leaf litter decomposition from *Eucalyptus* vegetation, results soil acidity that might affects intercrop yield. Increased organic matter content from leaf litter decomposition might have resulted in improving the soil water holding capacity, texture, porosity, essential nutrient and yield improvement of rabi and kharif crop. *Eucalyptus* plantation results in improvement in soil nutrient (N, P, K, and organic matter) as compared to natural soil. *Eucalyptus* plantation can ameliorate salinity and sodicity of soil by improving decreasing soil EC, pH and SAR (Nasim *et al.* 2007).

Kushalappa (1985) has reported an improvement in organic carbon, phosphorus, and potassium contents in the soil in *Eucalyptus* plantations thus providing a strong evidence that *Eucalyptus* monocultures are not detrimental to soil fertility. Poore and Fries (1985) believe that *Eucalyptus* may improve soil characteristics when planted on degraded or deforested sites by improving the structure of the surface soil by penetrating relatively impermeable layers of sub-soil, and by drawing up nutrients from depth. Moisture is more important than temperature in litter decomposition (Van den Driessche, 1984).

The total biomass in *Eucalyptus* plantation constituted 69% aboveground biomass and accumulated 42, 50, and 35% N, P, and K of total uptake amounting to 168, 47, and 104 kg ha⁻¹, respectively were investigated (George 1984).

Singh (1984) found that demand for nutrient by *E. tereticornis* was found to be 1594 kg of calcium, 100 kg of phosphorous and 217 kg of nitrogen per hectare per year. In low nutrient availability soils of Australia, follows the distribution and movement of nutrients within forest of *E. oblique* and demand raised for potassium, calcium and phosphorous per hectare, per year, to be 272 kg, 400 kg, and 36 kg respectively (Attiwell 1972).

CHAPTER III

MATERIAL AND METHODS

The present investigation entitled, “Growth and biomass production of different *Eucalyptus* species on riverine soils of Punjab” was carried out at the University Seed Farm, Ladhawal, Punjab Agricultural University, Ludhiana during the year 2016-17. The experimental details during the course of investigations are given in this chapter:-

3.1 EXPERIMENTAL SITE

3.1.1 Location

The experiments was conducted at University Seed Farm of Punjab Agricultural University Ladhawal, Ludhiana situated at an elevation of 223 m above mean sea level and lies at 30° 58' latitude and 75° 45' longitude, which represents the central agro-climatic zone of the Punjab.

3.1.2 Climate

The geographical location of Punjab is in the north-west of Indian sub-continent, with the western Himalaya in the north and the Thar Desert in the south. The periodic circulation of moist air masses from the south-west and north-west decide the occurrence of two wet periods each followed by a dry period. The south-western current of summer monsoons coming over Bay of Bengal brings the rains bearing depressions from July to September. From October to the end of June generally, dry conditions prevails except for few light showers received from north-western depressions during winter months.

In general, the climate is sub-tropical with a long dry season from late September to early June and wet season from July to early September. May and June are the hottest months with intensive evapo-transpiration losses, whereas, December and January are the coldest months. The area receives an average rainfall of 732 mm per annum and 80 per cent of total rainfall is received during July to September with an average of 37 rainy days. It is characterized by hot and dry early summers which are followed by a hot and humid monsoon period and cold winters. Mean maximum and minimum temperatures show considerable fluctuations during summer and winter. Maximum temperature of 45° C is common during summer and the minimum temperature of 1° C to 20° C. Frosts is also quite common during December to February. The mean monthly temperature ranges from 12.9° C (January) to 32.2° C (June). Average of meterological parameters for eight years is depicted in Fig. 1. The topography of the study area is plain and characterized inceptisol soils (USDA classification). The soils are deep, well drained, sandy loam in texture with low humus content and soil pH of 8.0 at experimental site. The irrigation is mainly by tube wells.

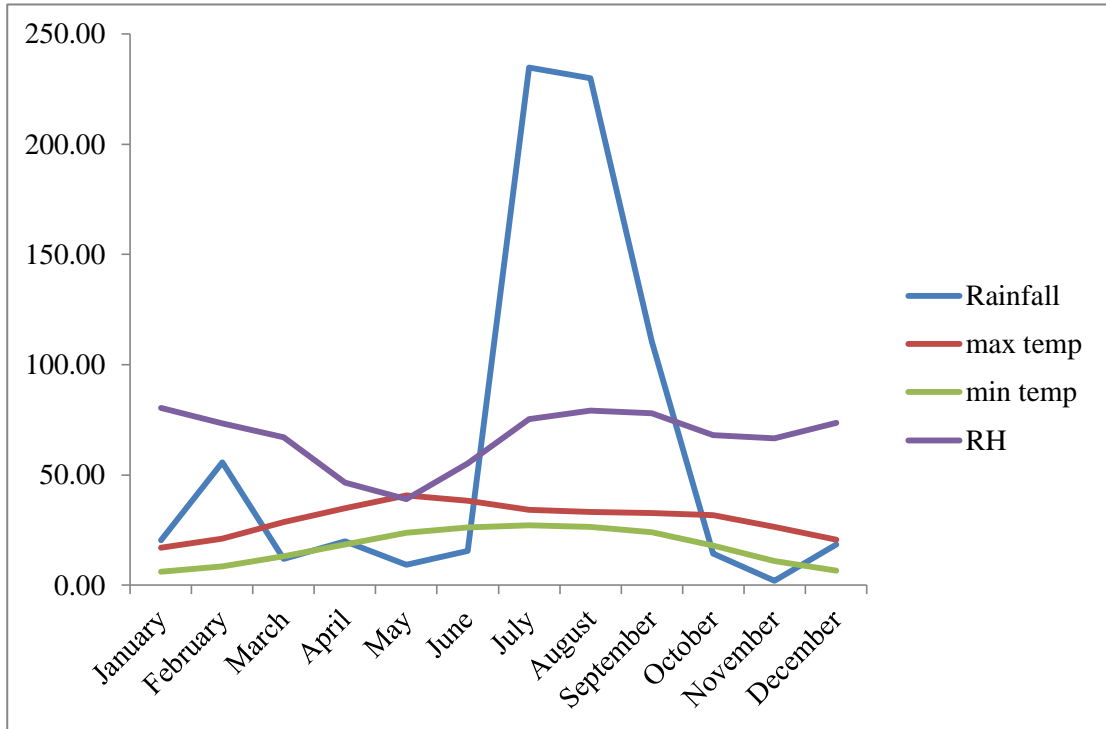


Fig. 1: Monthly meteorological data (Jan 2016-Dec 2016), Ludhiana (Source: School of Climate change and Agrometeorology, PAU)

3.2 EXPERIMENTAL DETAILS

3.2.1 Methodology

Five different species/sources i.e., *Eucalyptus tereticornis* (India), *E. tereticornis* (introduced from Australia), *E. tereticornis var tereticornis* (introduced from Australia), *E. camaldulunis var obusta* (introduced from Australia) and *Eucalyptus* clone (C288) raised during 2005 was assessed for their growth and biomass after harvesting. Data of six trees (2 trees per replication) were recorded for different parameters.

3.2.2 Observations recorded

3.2.2.1 Tree height

Six randomly selected trees from each replication were measured from ground level to the tip of the tree with the help of Ravi's multimeter for measuring tree height in meters.

3.2.2.2 Diameter at breast height (DBH)

Diameter at breast height of trees was measured by using tree caliper at 1.37 m above the ground level by selecting six trees randomly two per replication. Diameter was measured in centimeters.

3.2.2.3 Collar Diameter

Collar region of trees was measured in centimeters at a point above ground level where normal stem started with the help of measuring tape.

3.2.2.4 Canopy spread (m²)

Canopy spread was measured with the help of measuring tape in N-S and E-W directions of six randomly selected trees from each replication by following equation

$$\text{Canopy spread (m}^2\text{)} = \text{N-S} * \text{E-W}$$

Where:

N-S = Crown length in north-south directions

E-W = Crown length in east-west directions

3.2.2.5 Fresh stem biomass (kg)

Six randomly selected trees from each species (two trees per replication) were used to calculate the stem biomass. Selected trees were uprooted carefully by digging the soil around the selected trees. The stem was separated from the root and cut into small pieces, then weighed immediately on electronic weighing balance to get the fresh weight.

3.2.2.6 Fresh branch biomass (kg)

Six randomly selected trees from each species were used to calculate the branch biomass. Branches of selected trees were separated from the shoots and weighed immediately on electronic weighing balance in the field itself to get the fresh weight.

3.2.2.7 Fresh leaf biomass (kg)

Six randomly selected trees harvested from each species were used to measure the leaf biomass. Leaves were separated from branches of selected trees and weighed immediately on electronic weighing balance in the field itself to get the fresh weight.

3.2.2.8 Bark biomass (kg)

The bark portion, which was separated from sampled shoot discs at three different heights, was weighed on electronic weighing balance to get fresh bark weight. Individual disk measurements were used to find the bark biomass. The bark thickness was measured at the end of each section to the nearest millimetre using a metric tape at two perpendicular directions. Bark thickness values were determined by averaging the two measurements. The vertical variation of the bark proportion was calculated as the ratio of cross sectional basal area with and without bark. The bark were then dried in the oven (100±2°C) for approximately 48 hours and weighed to get the constant dry bark weight to calculate the total bark proportion.

Bark biomass:

$$B_{\text{odb}} = V_{\text{gw}} * \text{BV \%} * SG_{\text{gb}} * W$$

where

B_{odb} = oven-dry biomass of bark

V_{gw} = fresh weight of stem (green wood)

BV% = bark as a percentage of wood volume

SG_{gb} = basic specific gravity of bark (oven-dry mass of green volume)

W = weight of water (cubic foot)

3.2.2.9 Fresh root biomass (kg)

The root portion, which was separated from shoot was weighed on electronic weighing balance in the field itself to get the fresh root weight.

3.2.3 Soil properties

3.2.3.1 pH

The soil pH was determined in 1:2 soil-water suspension using an Elico-glass electrode pH meter (Jackson 1973) after equilibrating the soil with distilled water for half an hour using appropriate buffer.

3.2.3.2 Electrical conductivity ($dS m^{-1}$)

The soil electrical conductivity of collected samples was measured in soil-water suspension ratio of 1:2 with a conductivity meter (Elico) after equilibrating the sample for 24 hours with intermittent mixing and the samples were allowed to settle and then read on the conductivity meter (Richard 1954).

3.2.3.3 Bulk density ($Mg m^{-3}$)

For the determination of bulk density, fresh weight of each sample collected by soil core sampler was taken from depth (0-15 cm). The soil samples were taken with the help of cylindrical iron ring and dried in an oven at $105^{\circ}C$ for 24 hours or till the weight of the soil became constant. The ratio of dry soil mass of core and internal volume of the cylindrical ring (equivalent to bulk soil volume) is expressed. The units for bulk density of soil are $Mg m^{-3}$ (Blake and Hartage 1986).

$$\text{Bulk density (Db)} = Ms / Vt$$

Where,

Ms = mass of dry soil (Mg)

Vt = total volume of soils (m^3).

3.2.3.4 Organic carbon (%)

Total organic carbon was estimated by rapid titration method (Walkley and Black 1934). For this purpose, 2g soil sample was treated with 10 ml of 1N $K_2Cr_2O_7$, 20 ml of concentrated H_2SO_4 , 5g of sodium fluoride and 100 ml of distilled water. To this, 10 drops of diphenylamine indicator were added and it was treated with N/2 ferrous ammonium sulphate

till the colour of the solution changed from violet to bright green. The organic carbon was calculated from the amount of ferrous ammonium sulphate consumed in the titration.

3.2.3.5 Available N (kg ha^{-1})

Available N was estimated by alkaline-permanganate method given by Subbiah and Asija (1965). Five gram soil was treated with an excess of alkaline KMnO_4 and the ammonia, thus evolved is absorbed in a standard acid. The excess of the acid was titrated with a standard alkali using methyl red as indicator and from the volume of H_2SO_4 used for absorption of ammonia, the amount of nitrogen in the given soil sample was calculated.

3.2.3.6 Available P (kg ha^{-1})

The available phosphorous was determined by extracting the soil samples with 0.03 $\text{NH}_4\text{F} + 0.025\text{N HCL}$ (Bray and Kurtz 1945) and measuring the P content in the extract by calorimetric method using a spectrophotometer at 760 nm wavelength using ascorbic acid method.

3.2.3.7 Available K (kg ha^{-1})

Available potassium content was estimated by extraction with neutral normal ammonium acetate and determined on flame photometer (Mervwin and Peech 1950).

3.3 Statistical analysis

Data generated was analysed under CRD for making comparisons by using the CPCS software

CHAPTER IV

RESULTS AND DISCUSSION

The results of the present investigation recorded during 2016-17 are presented under the following these main headings:

4.1 Tree growth and biomass

4.2 Soil physico-chemical properties under plantation and after one year of harvesting

4.1 Tree growth and biomass parameters

4.1.2 Tree height (m)

The data on tree height of different *Eucalyptus* species is presented in Table 4.1. Tree height among species differed significantly. The tree height for different species ranged from 17.13 m to 21.30 m. The maximum height was recorded in *Eucalyptus* 288 clone (India) (21.30 m), which was closely followed by of *Eucalyptus tereticornis* (Australia) (20.43 m), whereas *E. tereticornis* var. *tereticornis* (Australia) showed minimum tree height i.e., 17.13 m, which was significantly at par with *E. camaldulensis* var. *obtuse* (Australia) (18.87 m).

Observations recorded in the present study are incongruent with Oballa *et al.*, (2005) investigating growth performance of different *Eucalyptus* clones and the seedlings in which it was reported that clones performed equally well as local landraces. The shortest height was found in *E. camaldulensis* (11.99 m) and *E. tereticornis* (11.58 m), whereas maximum height was recorded in Clone GC14 (17.15 m).

4.1.1 Diameter at breast height (cm)

For different species, diameter at breast height (DBH) varied significantly as evident from the data presented in Table 4.1. Maximum DBH was observed in case of *Eucalyptus tereticornis* (Australia) (88.83 cm), which was followed by *Eucalyptus* 288 clone (India) and *E. tereticornis* (India) having DBH of 88.17 cm and 87.50 cm respectively. Minimum DBH was observed in *E. camaldulensis* var. *obtuse* (Australia) (78.33 cm) and *E. tereticornis* var. *tereticornis* (Australia) (80.16 cm), respectively.

Similar significant differences were observed by Oballa *et al.*, (2005) in diameter at breast height in year three at $p < 0.001$. Clones like GC15, GC581, GC14 and GC642 were best in performance among others. *Eucalyptus tereticornis* and *Eucalyptus camaldulensis* did not performed good due to unfavorable conditions. The results found that *E. hybrid* having higher diameter at breast height (20.18 cm) to that of *E. tereticornis* (18.60 cm) Balozzi Kironko *et al.*, (2010). The results show that clonal performs better than that of species raised by seeds.

4.1.3 Canopy spread (m²)

Canopy spread of different species varied significantly as evident in data presented in Table 4.1 ranging from 32.74 m² to 42.21 m². The maximum canopy spread of tree species was in *Eucalyptus* 288 clone (India) (42.21 m²), which was statistically at par with *E. tereticornis* (India) (40.60 m²) and *E. tereticornis* (Australia) (36.77 m²). The minimum value for canopy spread was noticed in *E. tereticornis* var. *tereticornis* (Australia) (32.74 m²), followed by *E. camaldulensis* var. *obtusata* (Australia) (35.27 m²).

4.1.4 Collar diameter (cm)

The data for the collar diameter of different *Eucalyptus* species is depicted in table 4.1 ranging from 94.50 cm to 106.83 cm. *Eucalyptus* 288 clone (India) has maximum collar diameter (106.83 cm) followed by *E. tereticornis* (Australia) (105.0 cm) and *E. tereticornis* (India) (102.33 cm). Collar diameter for *E. tereticornis* var. *tereticornis* (Australia) (94.50 cm) was lowest of all and was slightly less than that of *E. camaldulensis* var. *obtusata* (Australia) having 96.0 cm.

Table 4.1: Growth performance of different *Eucalyptus* species

<i>Species</i>	Tree Height (m)	Collar diameter (cm)	DBH (cm)	Canopy spread (m²)
<i>Eucalyptus tereticornis</i> (India)	19.65	102.33	87.50	40.60
<i>Eucalyptus tereticornis</i> (Australia)	20.43	105.00	88.83	36.77
<i>E. tereticornis</i> var. <i>tereticornis</i> (Australia)	17.13	94.50	78.33	32.74
<i>Eucalyptus</i> 288 clone (India)	21.30	106.83	88.17	42.21
<i>E. camaldulensis</i> var. <i>obtusata</i> (Australia)	18.87	96.00	80.16	35.27
Critical Difference (CD)(at 5 % level)	1.70	7.08	7.87	5.04
Standard Error (S.E)	0.36	2.22	2.46	1.58

4.1.5 Mean annual increment of tree height

Data for mean annual increment of tree height of different tree species is presented in Fig.2. The maximum mean annual increment for height was recorded in *Eucalyptus* 288 clone (India) (1.94 m), which was significantly higher than other species. Mean annual increment in case of *E. tereticornis* (Australia) was 1.86 m. Minimum height annual increment (1.56 m) was recorded in *E. tereticornis* var. *tereticornis* (Australia), which was at par with *E. camaldulensis* var. *obtusata* (Australia) (1.72 m).

In contrast to the results, Patil *et al.* (2012) studied and found that *E. hybrid* and *E. tereticornis* performed well and were significantly higher in parameters viz., MAI in height, CAI in DBH, diameter at breast height current annual increment (CAI) in height, height as compared to *E. pelleta*.

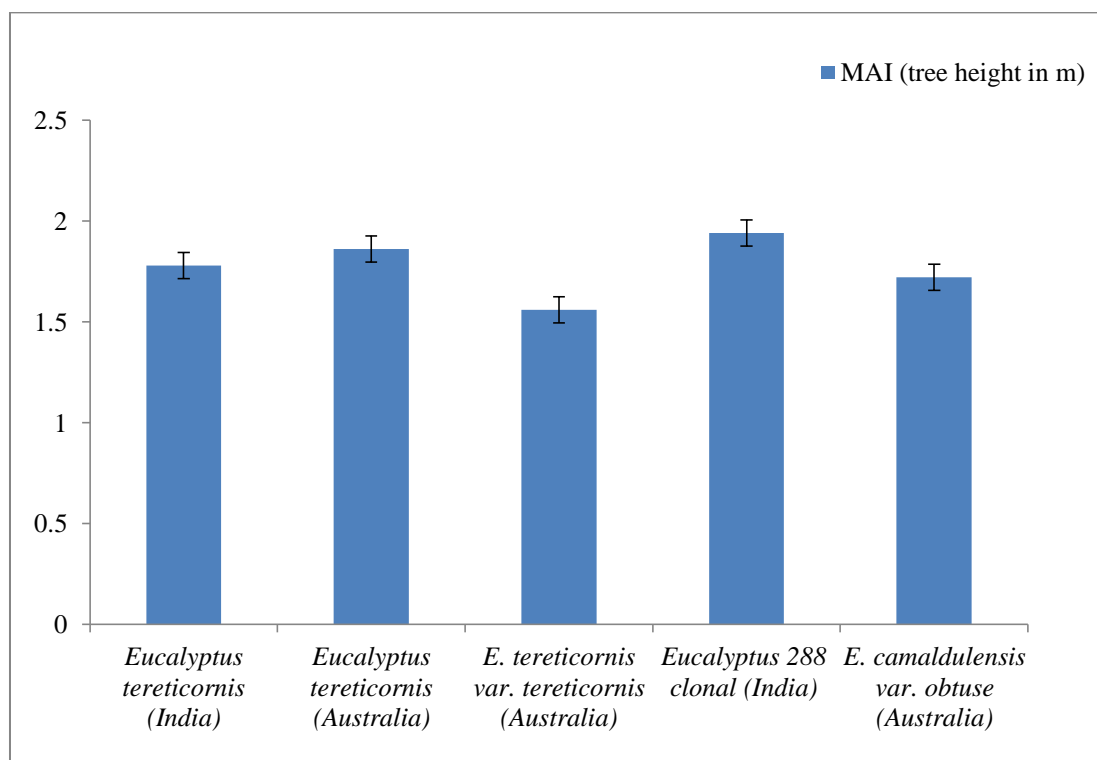


Fig. 2: Mean annual increment of tree height different *Eucalyptus* species

4.1.6 Mean annual increment for Diameter at Breast Height

The mean annual increment of diameter at breast height (DBH) varied significantly among different *Eucalyptus* species (Fig.3). The maximum mean annual increment of diameter at breast height was recorded in *Eucalyptus tereticornis* (Australia) (8.08 cm), which was statistically at par with *Eucalyptus* 288 clone (India) (8.02 cm) and *E. tereticornis* (India) (7.95 cm). Minimum annual increment for DBH was recorded by *E. tereticornis* var. *tereticornis* (Australia) (7.16 cm), which was at par with *E. camaldulensis* var. *obtuse* (Australia) (7.29 cm).

Kumar and Bangawa (2006) reported and found the significant differences for growth attributes among seven clones of *Eucalyptus* and found that, Indian clones had higher promising performance for DBH. Patil *et al.* (2012) found that the *E. hybrid* and *E. tereticornis* were significantly higher in MAI in height and DBH as compared to *E. pelleta*. Maximum MAI for diameter at breast height (DBH) was recorded in *E. tereticornis* and *E. hybrid*.

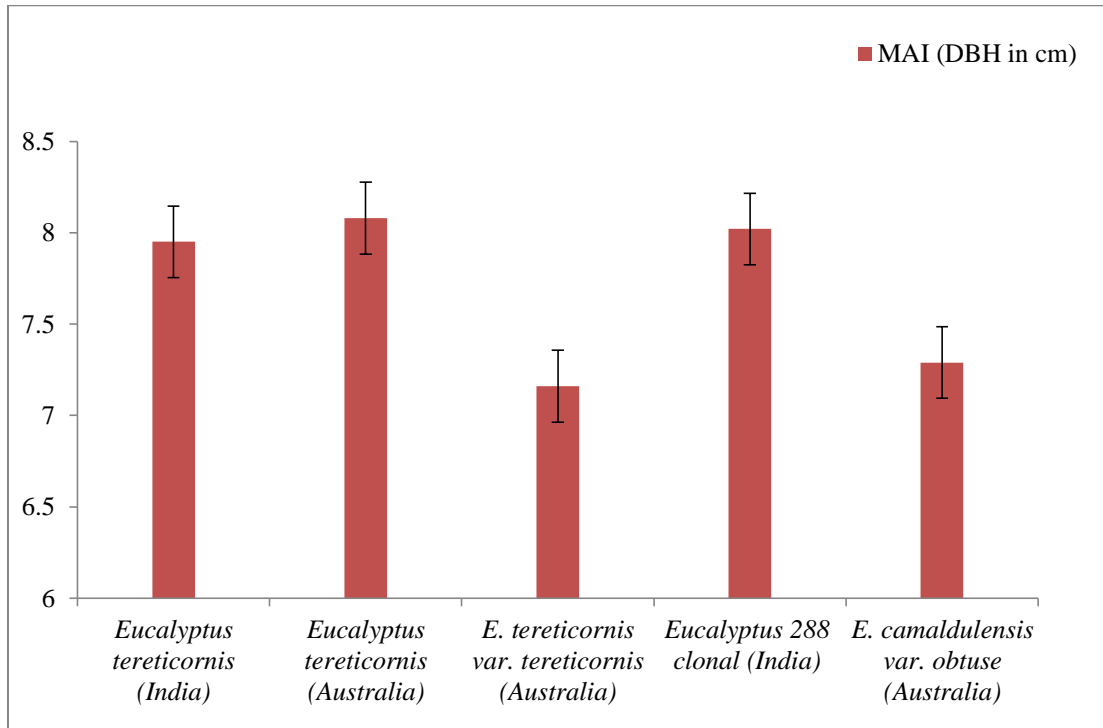


Fig. 3: Mean annual increment of DBH in different *Eucalyptus* species

4.1.4 Fresh above ground biomass (stem, branch, bark and leaf)

4.1.4.1 Fresh stem biomass

A perusal of the data (Table 4.2) clearly depicted that all the species of *Eucalyptus* varied significantly for stem biomass. Stem biomass ranged between 223.5 to 306.4 kg per tree. Maximum stem biomass was recorded in *Eucalyptus* 288 clone (306.4 kg/tree) which was statistically at par with *E. tereticornis* (Australian) (288.6 kg/tree) and significantly higher than others. *E. tereticornis* var. *tereticornis* (Australia) had minimum stem biomass having 223.5 kg per tree.

Variation in different components among 23 trees of *Eucalyptus* trees have been reported by Rawat *et al.* (2012) viz. leaf biomass (1.1 kg/tree to 29.9 kg/tree), branch biomass (6.4 to 151.6 kg/tree), bark (8.3 to 168.8 kg/tree), bole biomass (55.9 to 1911.4 kg/tree), root biomass/below ground biomass (BGB) (9.4 to 397.2 kg/tree)

4.1.10.2 Fresh branch biomass

Branch biomass of different *Eucalyptus* species varied significantly (Table 4.2). Maximum branch biomass was observed in case of *Eucalyptus* 288 clone (India) (101.6 kg/tree), which was statistically at par with *E. tereticornis* (Australian) (95.5 kg/tree) but significantly superior than other *Eucalyptus* species. Least performed species was *E. camaldulensis* var. *obtuse* (Australia) followed by *E. tereticornis* var. *tereticornis* (Australia) having 70.8 and 75.7 kg/tree of branch biomass, respectively.

4.1.10.3 Fresh leaf biomass

Data for leaf biomass Table 4.2 revealed that the leaf biomass varied significantly in different *Eucalyptus* species. Leaf biomass ranged between 29.7 to 39.9 kg per tree. The maximum leaf biomass 39.9 kg/tree was recorded in *Eucalyptus* 288 clone (India), followed by *E. tereticornis* (Australia) 34.6 kg/tree which was statistically and significantly better than other species. The minimum leaf biomass was recorded in *E. tereticornis var. tereticornis* (Australia) (29.7 kg) which was slightly less than that of *E. camaldulensis var. obtuse* (Australia) (30.9 kg).

Table 4.2: Fresh above ground biomass production (kg) of different *Eucalyptus* species

Species	Fresh Stem Biomass (kg/tree)	Fresh Branch Biomass (kg/tree)	Fresh Leaf Biomass (kg/tree)	Fresh Bark biomass (kg/tree)	Total fresh aboveground biomass (kg/tree)
<i>E. tereticornis</i> (India)	276.1	85.8	31.9	58.8	456.7
<i>E. tereticornis</i> (Australia)	288.6	95.5	34.6	63.4	482.2
<i>E. tereticornis var. tereticornis</i> (Australia)	223.5	75.7	29.7	50.7	379.7
<i>Eucalyptus</i> 288 clone (India)	306.4	101.6	39.9	76.0	524.0
<i>E. camaldulensis var. obtuse</i> (Australia)	242.6	70.8	30.9	53.7	398.3
CD (at 5 % level)	16.6	5.4	5.5	5.2	
Standard Error (S.E)	5.2	1.7	1.7	1.6	

4.1.10.4 Bark biomass

Significant variation was observed in bark biomass among different *Eucalyptus* species (Table 4.2). Bark biomass ranged between 50.7 to 76.0 kg per tree. Maximum bark biomass was recorded in *Eucalyptus* 288 clone (India) (76.0 kg/tree), which was significantly higher than other species. *E. tereticornis var. tereticornis* (Australia) (50.7 kg/tree) recorded minimum bark biomass.

Oraon *et al.* (2016) concluded that *Eucalyptus hybrid* (average 307.7 kg/tree) had maximum fresh biomass as compared to other two species *Acacia auriculiformis* and *Cassia siamea*, respectively. Karthick and Pragasan (2014) reported that *Eucalyptus* plantation had greater above ground biomass (41.8 t/ha) as comparing to that of mixed plantation (34.5 t/ha). Clone 288 gave MAI of bark biomass was 48.8 m³/ha/year and that of clone 316 (33.7 m³/ha/year) at the age of 4 and 5 years, respectively revealed from private farm (Luna *et al.* 2009).

4.1.10. Fresh below ground biomass

The observations pertaining to root biomass of different species are given in Table 4.3. It is apparent from the data that significant differences existed among species. Maximum root biomass was attained in *Eucalyptus* 288 clone (India) (129.4 kg/tree). It was statistically at par with the *E. tereticornis* (India) (105.01 kg/tree) and *E. tereticornis* (Australia) (99.6 kg/tree) but significantly higher than *E. tereticornis* var. *tereticornis* (89.6 kg/tree) and *E. camaldulensis* var *obtusa* (84.3 kg/tree).

Table 4.3: Fresh below ground biomass, total biomass and root to shoot ratio of different *Eucalyptus* species

Species	Below Ground Biomass (kg/tree)	Total Biomass (Below + Above ground) (kg/tree)	Root to Shoot ratio
<i>E. tereticornis</i> (India)	105.0	557.7	0.30
<i>E. tereticornis</i> (Australia)	99.6	581.8	0.27
<i>E. tereticornis</i> var. <i>tereticornis</i> (Australia)	89.6	469.3	0.32
<i>Eucalyptus</i> 288 clone (India)	129.4	653.4	0.33
<i>E. camaldulensis</i> var. <i>obtuse</i> (Australia)	84.3	482.6	0.27
CD (at 5 % level)	8.6	26.5	
Standard Error (S.E)	2.7	8.3	

ALB-above ground biomass BGB-below ground biomass

4.1.12 Total fresh above and below ground biomass

Perusal of the data in Table 4.3 revealed that the maximum total biomass (stem+ branch+leaf+bark+ root biomass) was recorded in *Eucalyptus* clone 288 (653.4 kg/tree), followed by *E. tereticornis* (Australia) (581.8 kg/tree), *E. tereticornis* (India) (557.7 kg/tree), and *E. camaldulensis* var. *obtuse* (Australia) (482.6 kg/tree). Minimum value for total biomass was observed in *E. tereticornis* var. *tereticornis* (Australia) (469.3 kg/tree). The root to shoot ratio for different species was as follows : *Eucalyptus* 288 clone, India (0.33), *E. tereticornis* var. *tereticornis* (Australia) (0.32), *E. tereticornis* (India) (0.30), *E. tereticornis* (Australia) (0.27) and *E. camaldulensis* var. *obtuse* (Australia) (0.27), with overall average of 23:77. The higher root to shoot ratio of 25:75 was observed in *Eucalyptus* 288 clone (India) indicating lower above ground biomass with a well developed root system.

Observations recorded in the present investigation in conformity with Cole and Rapp (1981), who found stem wood was the major component and its biomass was comprised

between 69% and 77% of total aboveground biomass. The observations in the present study were similar to the findings of Armson (1977) who observed that roots contribute approximately 20-25% of the total living biomass of trees, although this varies under different environmental conditions. Kaul *et al.* (2010) also recorded interspecies variation in biomass distribution in different components in *Eucalyptus*, *Sal* and *Teak* in the following order Stem > Root > Branches > Leaves.

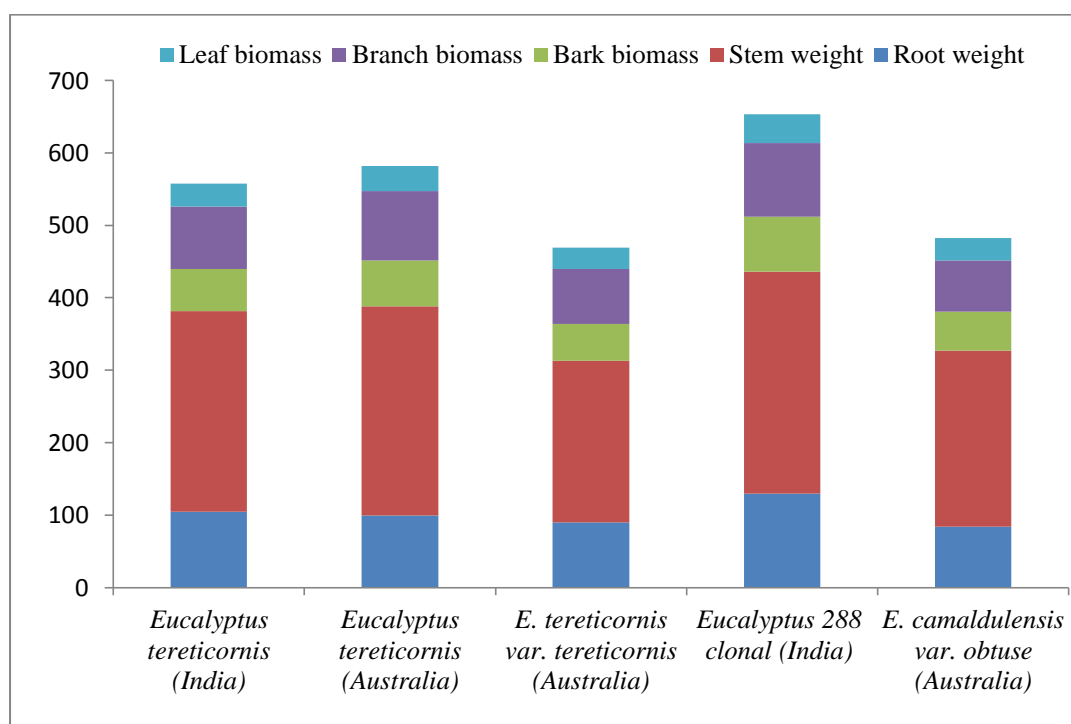


Fig.4: Biomass partitioning of different *Eucalyptus* species

4.2 Soil physio-chemical properties

Short rotation trees could affect the soil quality by causing changes in physical and chemical properties. Data are presented in following tables to depict important soil parameters i.e., soil pH, electrical conductivity, organic carbon, available nitrogen, phosphorus, potassium and bulk density in plantations of different fast growing *Eucalyptus* species and one year after harvesting.

4.2.1 Soil pH

Table 4.4 shows a non-significant impact of *Eucalyptus* species on soil pH. There was slight decrease in soil pH after one year of harvesting the trees. Soil pH ranged from 8.31 to 8.44, under plantation of various *Eucalyptus* species, whereas it ranged from 8.26 at plantation to 8.33 after one year of harvesting of plantation. Maximum decrease was noticed in *Eucalyptus* 288 clone plantation. Fig. 5 clearly indicates the decrease in pH of soil after one year of harvesting.

Observations were made in Andaman and Nicobar Islands and found the significant decrease in organic matter, soil pH, exchangeable potassium and extractable phosphorus in areas cleared for plantation Dagar *et al.* (1995).

Table 4.4: Soil pH under different *Eucalyptus* species

Species	Soil pH	
	Under plantation	After one year of harvesting
<i>Eucalyptus tereticornis</i> (India)	8.43	8.30
<i>Eucalyptus tereticornis</i> (Australia)	8.37	8.29
<i>E. tereticornis</i> var. <i>tereticornis</i> (Australia)	8.31	8.28
<i>Eucalyptus</i> 288 clone (India)	8.44	8.33
<i>E. camaldulensis</i> var. <i>obtuse</i> (Australia)	8.35	8.26
CD (at 5 % level)	0.04	0.03

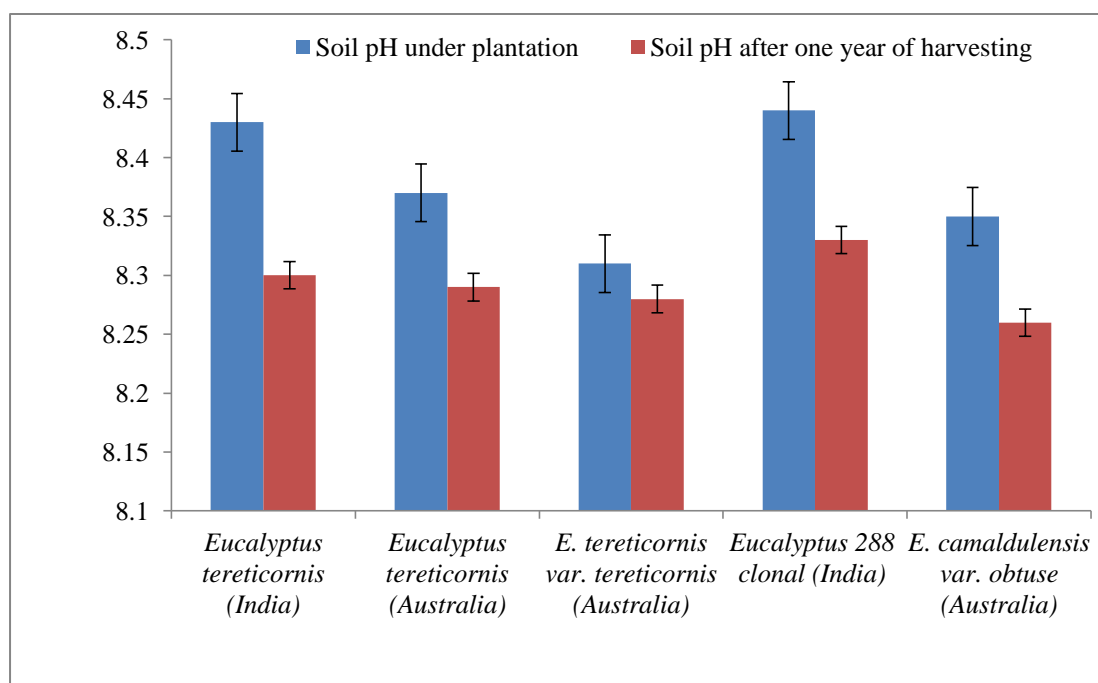


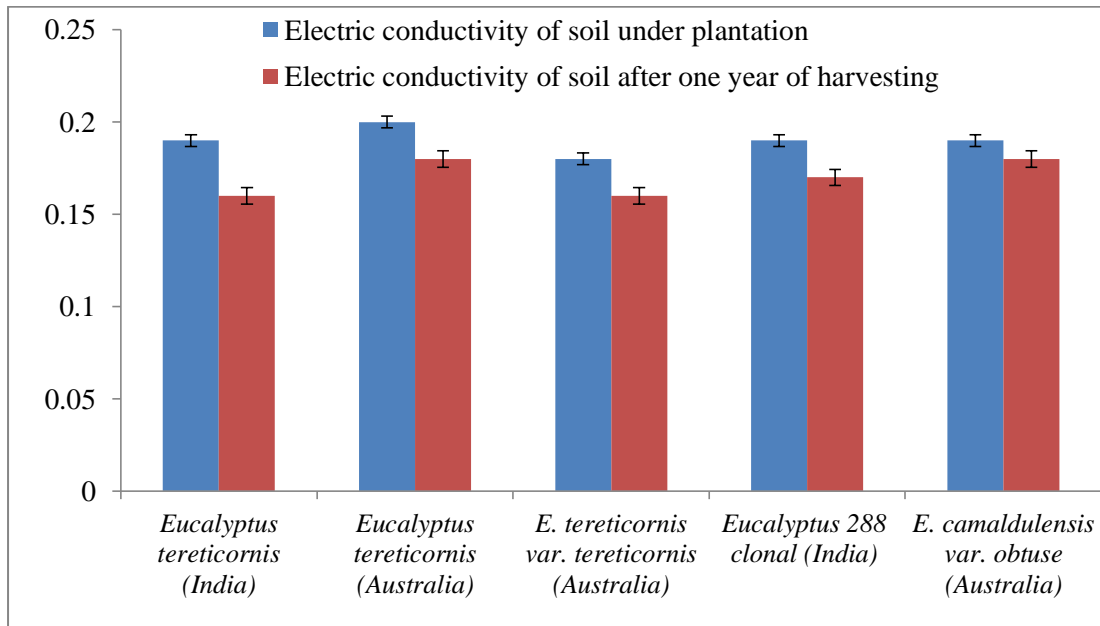
Fig. 5: Soil pH under plantation and after one year of harvesting for different *Eucalyptus* species

4.2.2 Electrical conductivity (dS/m)

Table 4.5 shows that there was not much variation in soil electric conductivity of soil. It ranged between 0.18 to 0.20 dSm⁻¹ under plantation and 0.16 to 0.18 dSm⁻¹ after one year of harvesting of plantation. Fig. 6 gives us clear view that there was very low decrease in electric conductivity after one year of harvesting and also standard error is provided.

Table 4.5: Electric conductivity of soil for different *Eucalyptus* species

Species	Soil Electric conductivity (dS/m)	
	Under plantation	One year after harvesting
<i>Eucalyptus tereticornis</i> (India)	0.19	0.16
<i>Eucalyptus tereticornis</i> (Australia)	0.20	0.18
<i>E. tereticornis</i> var. <i>tereticornis</i> (Australia)	0.18	0.16
<i>Eucalyptus</i> 288 clone (India)	0.19	0.17
<i>E. camaldulensis</i> var. <i>obtusata</i> (Australia)	0.19	0.18
CD (at 5 % level)	NS	NS

**Fig. 6: Electric conductivity under plantation and after one year of harvesting for different *Eucalyptus* species**

4.2.3 Soil Organic carbon (%)

Soil organic carbon (SOC) is the most commonly measured quality parameter which affects the potential soil productivity. Input of litter and their decomposition are the main factors determining the organic carbon content of soils. The quantity of litter and its quality influence the organic carbon and can vary over time and with species, age and geometry of planting. The organic carbon at 0-15 cm soil depth in table 4.6 ranged from 0.64 to 0.77 per cent under plantation and from 0.57 to 0.68 per cent one year after harvesting of plantation. It further reveals that soil organic carbon under tree species *E. tereticornis* (India) (0.77 %) and *E. camaldulensis* var. *obtusata* (Australia) (0.75 %) was highest than under other *Eucalyptus* species.

Table 4.6: Soil organic carbon of different *Eucalyptus* species

Species	Soil organic carbon (%)	
	Under plantation	One year after harvesting
<i>Eucalyptus tereticornis</i> (India)	0.77	0.68
<i>Eucalyptus tereticornis</i> (Australia)	0.65	0.59
<i>E. tereticornis</i> var. <i>tereticornis</i> (Australia)	0.70	0.60
<i>Eucalyptus</i> 288 clone (India)	0.64	0.57
<i>E. camaldulensis</i> var. <i>obtuse</i> (Australia)	0.75	0.63
CD (at 5% level)	0.03	0.03

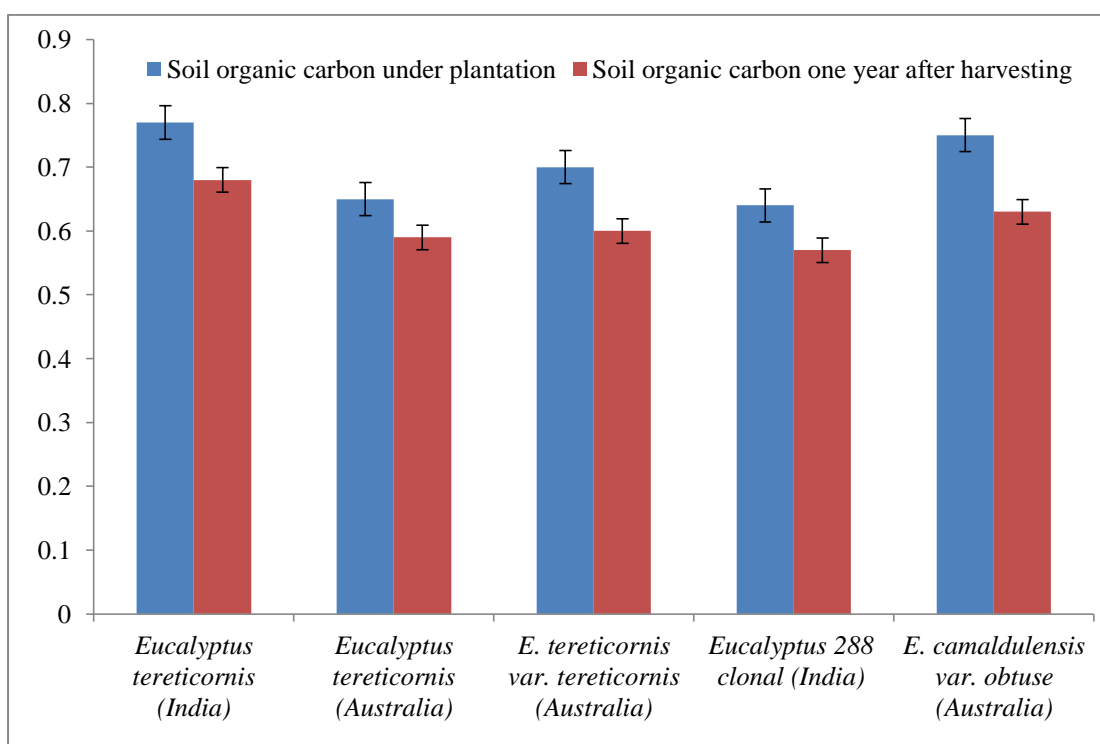


Fig. 7: SOC under plantation and one year after harvesting for different *Eucalyptus* species

Similar observations were made by Johnson and Curtis (2001) and found the small decreases in soil organic carbon when using harvest systems that remove large amounts of biomass (such as whole tree harvesting). Singh and Sharma (2007) reported that on account of recycling of organic matter, higher organic carbon percentage was observed in the soil under plantations. The higher amount of organic carbon under agroforestry system may be due to addition of litter. Soil under trees is a major store house of organic carbon in comparison to

other land use systems because of continuous addition of litter fall by trees. The higher build up of organic carbon on surface layers of soils under different tree species may be attributed to the regular accumulation of litter fall of tree species on soil surface and fine roots turnover. The subsequent decomposition of litter fall and its incorporation into soil with time might have helped in raising the organic matter status of soils.

Trees harvesting results in immediate physical site disturbance, resulting in short-term changes in soil organic carbon of the soil (Rab 1994; 1996). Moreover high nutrient content and soil organic carbon can be noticed under tree as compares to the areas without trees (Singh and Sharma 2007).

4.2.4 Bulk density (Mg m^{-3})

It is evident from the data presented in table 4.7 that there was a significant difference in bulk density of soil under plantation comparing to soil after one year of harvesting. Bulk density ranged between 1.20 to 1.31 Mg m^{-3} under plantations and 1.22 to 1.33 Mg m^{-3} after one year of harvesting. There was slight increase in bulk density after one year of harvesting of plantation as compared to the soil under plantation.

Pennington *et al.* (2001) observed a similar and significant change in soil properties after clear harvesting of *Eucalyptus* plantations in Australia. Range for soil bulk density varies from 0.58 Mg m^{-3} to 0.70 Mg m^{-3} and it was also noticed that there was a huge loss of 3850 kg ha^{-1} of Carbon and 107 kg ha^{-1} of Nitrogen content. Stockfisch *et al.* (1999) have observed that bulk density increased with depth due to compaction. This increase is largely because of decreasing organic matter content and reduced aggregation with depth. Shirani *et al.* (2002) also reported a significant decrease in surface layer bulk density of the manured fields. Observations were made in Andaman and Nicobar Islands and found increase in soil bulk density harvested for commercial plantations (Dagar *et al.* 1995).

Table 4.7: Bulk density of soil in different *Eucalyptus* species

Species	Bulk density (Mg m^{-3})	
	Under plantation	One year after harvesting
<i>Eucalyptus tereticornis</i> (India)	1.28	1.30
<i>Eucalyptus tereticornis</i> (Australia)	1.31	1.33
<i>E. tereticornis</i> var. <i>tereticornis</i> (Australia)	1.22	1.26
<i>Eucalyptus</i> 288 clone (India)	1.28	1.29
<i>E. camaldulensis</i> var. <i>obtuse</i> (Australia)	1.20	1.22
CD (at 5 % level)	0.03	0.04

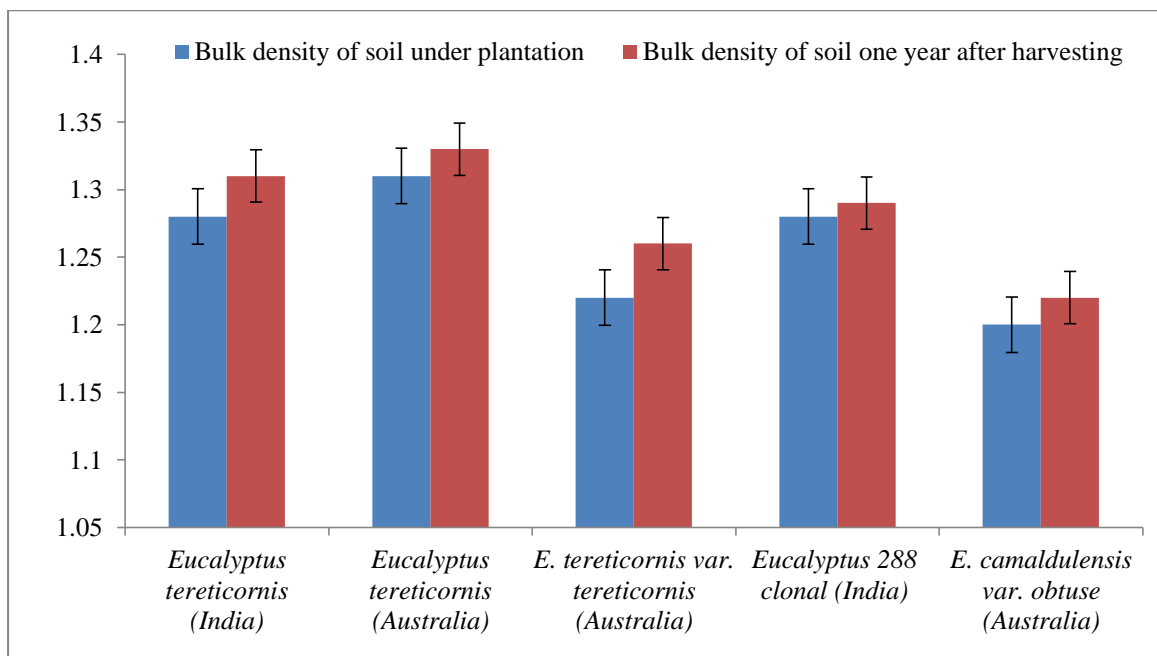


Fig. 8: Bulk density of soil under plantation and one year after harvesting of different *Eucalyptus* species

4.2.5 Available N (kg ha^{-1})

As shown in Table 4.8, higher available N content in soils was recorded at 0-15 cm depth i.e. 65.1 to 76.5 kg ha^{-1} under different *Eucalyptus* plantation and 59.6 to 66.9 kg ha^{-1} of N content after one year of the harvesting of plantation. The maximum available N content was found under *E. camaldulensis* var. *obtuse* (Australia) (76.5 kg ha^{-1}) followed by *E. tereticornis* (Australia) (75.5 kg ha^{-1}). Whereas, minimum available N was recorded under *Eucalyptus* 288 clone (India) (65.1 kg ha^{-1}). Fig. 9 indicates the decrease in available N content in soil after one year of harvesting.

Table 4.8: Available Nitrogen content in soil for different *Eucalyptus* species

Species	Nitrogen (kg ha^{-1})	
	Available N content under plantation	Available N content one year after harvesting
<i>Eucalyptus tereticornis</i> (India)	65.8	59.7
<i>Eucalyptus tereticornis</i> (Australia)	75.5	66.2
<i>E. tereticornis</i> var. <i>tereticornis</i> (Australia)	71.3	65.3
<i>Eucalyptus</i> 288 clone (India)	65.1	59.6
<i>E. camaldulensis</i> var. <i>obtuse</i> (Australia)	76.5	66.9
CD (at 5 % level)	3.87	3.43

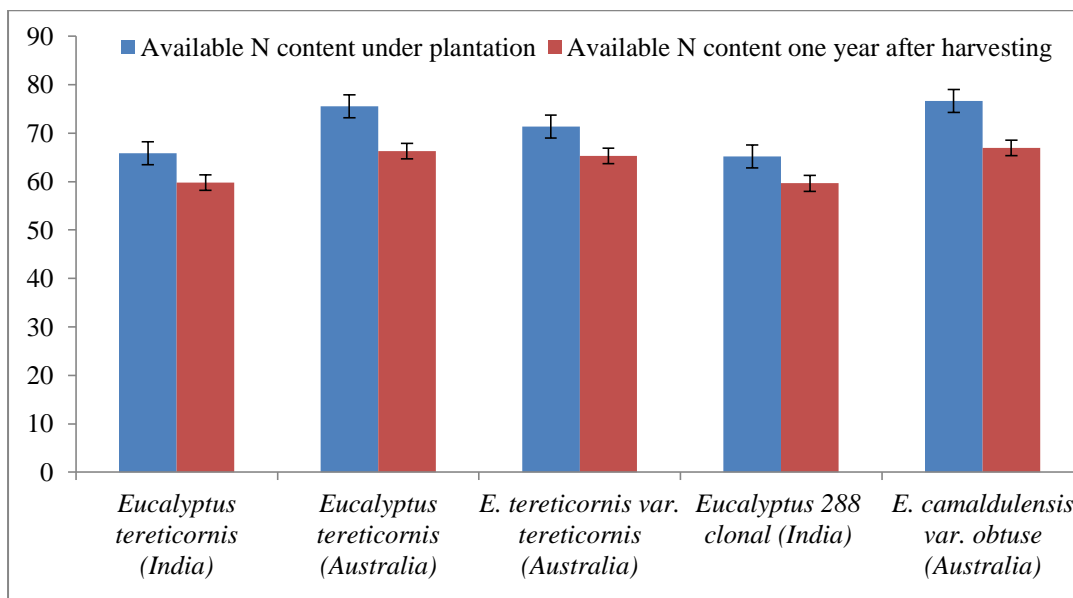


Fig. 9: Available N content under plantation and one year after harvesting for different *Eucalyptus* species

Pennington *et al.* (2001) observed a similar and significant change in soil properties after clear harvesting of *Eucalyptus* plantations in Australia and found the loss of 107 kg ha⁻¹ of N content and 3850 kg ha⁻¹ of C. Nutrient content were high in 0-15 cm horizon and decreased with increasing depth of the soil and this may be due to surface layer enrichment through nutrient cycling.

4.2.6 Available P (kg ha⁻¹)

The data presented in Table 4.9 showed significant difference in phosphorous range at 0-15 cm depth i.e., 11.0 to 18.8 kg ha⁻¹ under the various *Eucalyptus* species plantations. Available P after one year of harvesting of plantations was also recorded which ranged from 10.0 to 14.7 kg ha⁻¹.

Table 4.9: Available P content in soil for different *Eucalyptus* species

Species	Phosphorus (kg ha ⁻¹)	
	Available P content under plantation	Available P content one year after harvesting
<i>Eucalyptus tereticornis</i> (India)	13.8	11.4
<i>Eucalyptus tereticornis</i> (Australia)	11.0	10.0
<i>E. tereticornis</i> var. <i>tereticornis</i> (Australia)	17.2	13.9
<i>Eucalyptus</i> 288 clone (India)	12.2	10.6
<i>E. camaldulensis</i> var. <i>obtuse</i> (Australia)	18.8	14.7
CD (at 5 % level)	1.58	1.68

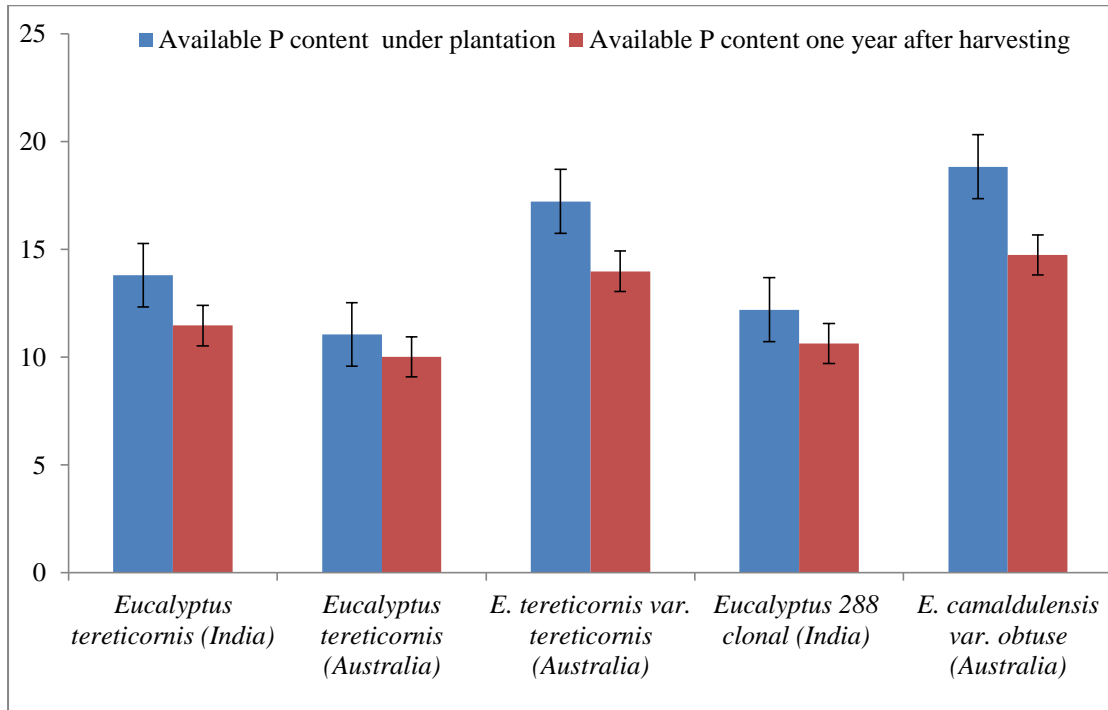


Fig. 10: Available P content under plantation and one year after harvesting for different *Eucalyptus* species

The maximum content of available P was recorded under *E. camaldulensis* var. *obtuse* (Australia) (18.8 kg ha⁻¹) followed by *E. tereticornis* var. *tereticornis* (Australia) (17.2 kg ha⁻¹) which is statistically and significantly better than other species. Minimum content of available P was found in *E. tereticornis* (Australia) (11.0 kg ha⁻¹).

4.2.7 Available K (kg ha⁻¹)

The data presented for available potassium in Table 4.10 showed significant difference in potassium content of soil. Available K in surface layer (0-15 cm) ranged between 80.6 to 102.6 kg ha⁻¹ under plantation of *Eucalyptus* species. After harvesting of trees after one year of plantation, available k was found ranging from 73.5 kg ha⁻¹ to 96.2 kg ha⁻¹. Therefore, it can be concluded that available potassium content under plantation was more than in soil after one year of harvesting. The available K content was the highest under *E. camaldulensis* var. *obtuse* (Australia) (102.6 kg ha⁻¹ and *Eucalyptus* 288 clone (India) (95.3 kg ha⁻¹) and lowest under *E. tereticornis* var. *tereticornis* (Australia) (80.6 kg ha⁻¹).

All these results are in agreement with the findings of Swamy *et al.* (2006) as well as Singh and Sharma (2007). They noticed that higher organic carbon (OC) and available nitrogen, phosphorus and potassium content were observed in the soil under agroforestry plantation than at site without trees. Due to accumulation and decomposition of litter fall on the surface layer of soil there is high availability of N, P and K which leads to mineralization and releases organic N

and P from the litter into soil. Litter fall increases the potassium content of soil through decomposition process that's why the surface layer of soil under trees has high content of potassium.

Table 4.10: Available K content in soil for different *Eucalyptus* species

Species	Potassium (kg ha ⁻¹)	
	Available K content under plantation	Available K content one year after harvesting
<i>Eucalyptus tereticornis</i> (India)	88.6	79.1
<i>Eucalyptus tereticornis</i> (Australia)	85.2	78.3
<i>E. tereticornis</i> var. <i>tereticornis</i> (Australia)	80.6	73.5
<i>Eucalyptus</i> 288 clone (India)	95.3	86.9
<i>E. camaldulensis</i> var. <i>obtus</i> (Australia)	102.6	96.2
CD (at 5% level)	3.82	2.94

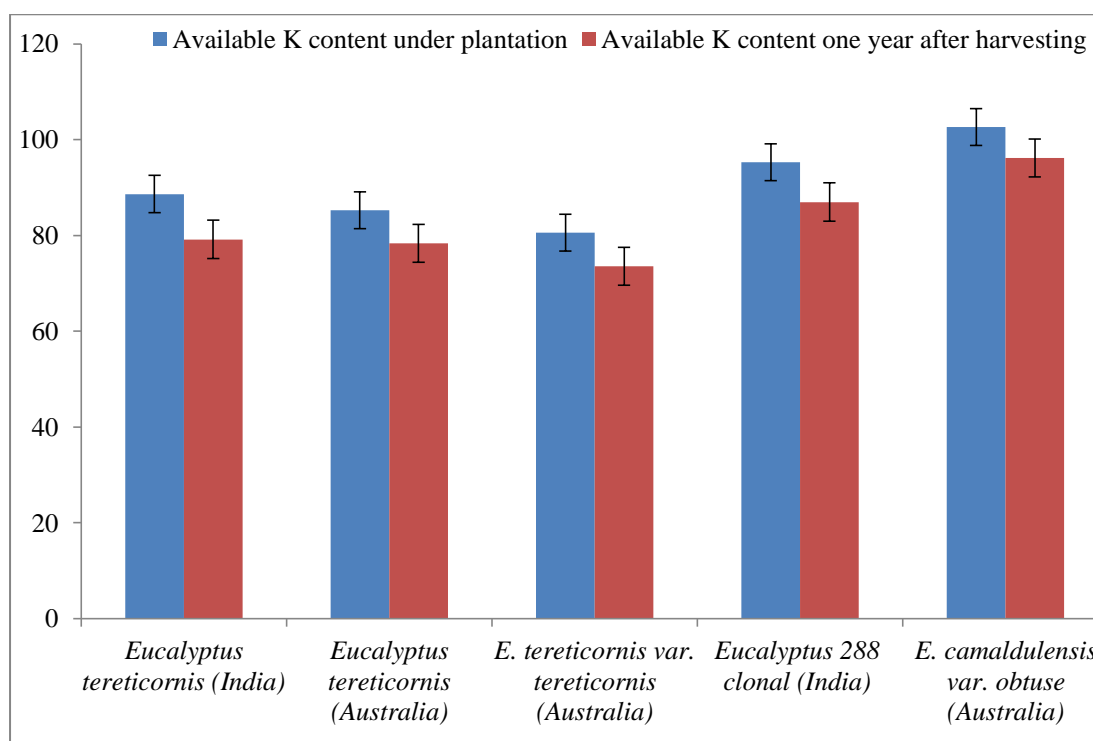


Fig. 11: Available K content under plantation and after one year of harvesting for different *Eucalyptus* species

Fig. 11 gives us a clear view about the K content in soil, as it shows the decrease in k content in soil after one year of harvesting comparing to that of under plantation and also the standard error is provided.

The differences in available nutrient content under different species might be due to variation in nutrient concentration of litter, total litter production and varying rates of mineralization in these species. Garg (1997) as well as George and Kumar (1998), presumably due to release of nutrient by leaf litter in soil and variation under different species is also due to quality and quantity of litter produce by respective species.

CHAPTER V

SUMMARY

Eucalyptus is native to Australia and other names of the tree are “gum tree”, “safeda or nilgiri”. *Eucalyptus tereticornis* and *Eucalyptus grandis* are mainly grown species (Dwivedi 2004). *Eucalyptus*, a quick growing genus with narrow crown and straight bole, has been widely planted along roads, canals, alongside railway tracks and within and on field boundaries due its adaptability to varying site conditions and ease of establishment. More availability of organic matter and nutrients under trees is due to the continuous litter fall and also leftover of roots which improves soil fertility. Exotic plantation species have the characteristics of fast growth rate and thereby take up nutrient at a fast rate from the soil, leading to reduced soil fertility. There is need, therefore, for a rapid decomposition of litter from these exotics to balance rapid nutrient depletion from the soil and avert soil degradation.

Though, *Eucalyptus* can survive at various sites and even in soils having low nutrient composition, however, provided with adequate (improved) nutritional status, it responds positively towards this status. Introduction of this genes into highly nutritious environments, particularly in soils of having high nitrogen and phosphorous, has witnessed marked increase in vigour and thus productivity. So, it is clear from this observation that productivity largely depends upon the nutritional status of the soil. *Eucalyptus* could positively impact soil fertility through decayed litter in areas where the land has been previously degraded by intensive agriculture. Genetically superior clonal planting stock offers many distinct advantages compared to seedlings obtained from normal seed such as it has all desirable genetic qualities of the mother plant, immediate capture of genetic gains to exploit natural variation or hybrid vigour through cloning is possible, very high productivity and far better quality of timber and pulpwood from clonal plantations compared to normal seed based plantations.

The present investigation entitled “Growth and biomass production of different *Eucalyptus* species on the riverine soils of Punjab” is an attempt in this direction, where study was designed to evaluate the growth and biomass potential. In addition, study investigates changes in soil properties under different tree species. The six tree species (two per replication) were evaluated for various parameters i.e., growth and biomass production. The observations were also recorded for soil chemical and physical parameters.

The significant variation was recorded among the species for all parameters. *Eucalyptus* 288 clone (India) registered maximum value for tree height, whereas *E. tereticornis* (Australia), *Eucalyptus* 288 clone (India) and *E. tereticornis* (India) were having maximum diameter at breast height (dbh). *Eucalyptus* 288 clone (India) showed higher values for canopy spread and collar diameter. For fresh stem biomass, *Eucalyptus* 288 followed by

E. tereticornis (Australia) and *E. tereticornis* (India) was found superior than the other remaining two *Eucalyptus* species. *Eucalyptus* 288 having maximum values for fresh branch biomass, fresh leaf biomass, and bark biomass followed by *E. tereticornis* (Australia). Hence the overall, fresh above ground biomass and fresh belowground biomass was maximum in *Eucalyptus* 288 clone (India).

In partitioning of tree biomass, stem, root, branch, leaf and bark biomass contributed 48.72 %, 18.51 %, 15.64 %, 6.09 % and 11 %, respectively out of the total biomass (above ground biomass + below ground biomass). On an average root : shoot ratio was 0.30 and proportion of above ground biomass was 77 percent of total biomass.

After one year of harvesting, there was decrease in soil pH, electric conductivity and soil organic carbon whereas bulk density increased as compared to the soil under plantation. Significant decrease was noticed for available nitrogen, phosphorus and potassium content in soil after one year harvesting of *Eucalyptus* species as compared to the soil under plantation.

Conclusion: Results of present study clearly indicates the growth and total biomass was maximum in *Eucalyptus* 288 clone (India), followed by *E. tereticornis* (Australia), *E. tereticornis* (India), *E. camaldulensis* var. *obtus* (Australia) and minimum in *E. tereticornis* var. *tereticornis* (Australia) respectively. Biomass allocation among the given species was in the order- Stem > Root > Branch > Leaf > Bark. Soil physico-chemical properties were better under tree plantation having organic matter in the form of litter fall as compared to the soil one year after harvesting of plantation. Most significant changes observed were decrease in soil pH, soil organic carbon, electric conductivity, available N, P and K.

REFERENCES

- Alexander T G and Thomas P (1985) Physical properties of soils in relation to *Eucalyptus* growth. KFRI Report No. 27. Peechi, KFRI, pp. 11.
- Anand R R, Sehgal J L and Sharma P K (1977) Genesis and classification of some soils of Malwa alluvial plain. *Indian Natn Sci Acad* pp 43-44.
- Anon (2006) Report on inventory of trees outside forests (TOF) in Punjab. Forest survey of India, MoEF, Dehradun, pp 145.
- Armson K A (1977) Forrest Soils: properties and processes. University of Toronto Press, Toronto, pp 390.
- Attiwell P M (1972) On the cycling of elements in mature *Eucalyptus obliqua* forest. *Proc Aust Forest Tree Nutrition Conf* Canberra, pp 39-46.
- Aulakh K S and Sandhu S S (1990) Growth studies of some species and provenances of *Eucalyptus* in Punjab. *Ind For* **116**: 442-45.
- Baber S, Ahmad M F and Bhatti A (2006) The effect of *E. camaldulensis* on soil properties and fertility. Department of Soil and Environmental Sciences, North West Frontier Province Agricultural University, Peshawar, Pakistan
- Bala N, Kumar P, Bohra N K, Limba N K, Baloch S R, Singh B and Singh G (2010) Production and Decomposition of litter in plantation forests of *Eucalyptus camaldulensis* along canal command area in Indian Desert. *Ind For* **136**: 163-72
- Balagopalan M (1992) Impact on soils of growing *Eucalyptus* in Kerala. Seminar on Environmental Problems of Kerala. 2nd December. *Center for Water Resources Development and Management*. Kozhikode, Kerala.
- Balozi B Kirongo, Kimani G K, Kingiri S, Lazare E, Angela M, and Mbae M (2010) Five Year Growth and Survival of *Eucalyptus hybrid* Clones in Coastal Kenya. *JMHT* **16**: 1-9
- Banerjee B, Nandi A, Nath S and Banerjee S K (1986) Characteristics of the soils supporting quality I *E. tereticornis* in South Bengal. *Ind For* **112**: 762-71
- Bargali S S, Singh R P and Joshi M (1993) Efficiency of nutrient utilization in an age series of *E. tereticornis* plantations in the tarai belt of Central Himalaya. *J Tropical For Sci* **7**: 383-90.
- Bhatia C L (1984) *Eucalyptus* in India - its status and research needs. *Ind For* **110**: 91-96.
- Binkley D, Kaye J, Barry M and Ryan M G (2004) First rotation changes in soil carbon and nitrogen in *Eucalyptus* plantations in Hawaii. *Soil Sci Soc Am J* **68**: 1713-19

- Bisht Y P S, Sharma D and Pandey U M N (1989) Distribution of biomass in 18 year old *Eucalyptus hybrid* (*E. Tereticornis*) plantation. *J Tree Sci* **8**: 56-61.
- Blake G R and Hartage K H (1986) Bulk density. In: Klute A (Ed) *Methods of Soil Analysis, Part I*, Agron no. 9. Am Soc Agron Madi, USA.
- Bray R H and Kurtz L T (1945) Determination of total organic and available form of phosphorous in soil. *Soil Sci* **59**: 39-45.
- Burgess T I, Malajczuk N and Grove T S (1993) The ability of 16 ectomycorrhizal fungi to increase growth and phosphorus uptake of *E. globulus* Labill. and *E. diversicolor* F.Muell, *Plant and Soil* **153**: 155-64
- Camara C D, Lima W P and Vieira S A (2000) Clearcutting of a 50 years old growth *Eucalyptus saligna* plantation: impacts on water balance and water quality in an experimental catchment. IPEF, *Scientia Forestalis* **57**: 99–109
- Cao Y, Fua S, Zoub X, Cao H, Shaoa Y and Zhou L (2010) Soil microbial community composition under *Eucalyptus* plantations of different age in subtropical China. *Eur J Soil Biol* **46**: 128-35
- Chaturvedi A N (1983) General standard volume table for *Eucalyptus hybrid*. *Ind For* **12**: 9
- Cole R J and Rapp M (1981) *Elemental Cycling in Forest Ecosystems*. Cambridge University Press, London. pp. 341-409
- Cromer R N, Ranpack M, Clarke A R P and Cameron J N (1976) *Eucalyptus* plantation in Australia. The potential of intensive production and utilization. *OSLO Biomass studies, College of Life Science and Agriculture University Maine, Orono, USA* :31-39
- Dagar J C (1995) Agroforestry systems for Andaman and Nicobar Islands in India. *Int tree Crops J* **8**:107–28
- Demel Teketay (2000) Facts and experience on *Eucalyptus* in Ethiopia and elsewhere: ground for making wise and informed decision. Workshop on *Eucalyptus* Dilemma, 15 November 2000.
- Demessie A, Singh B R, Lal R, and Strand L T (2012) Leaf litter fall and litter decomposition under *Eucalyptus* and coniferous plantations in Gambo District, southern Ethiopia. *J Agric Onco* **62**: 467– 76
- Dhyani S K and Chauhan D S (1995) Agroforestry intervention for sustained productivity in north-eastern region of India. *Range Mgt Agrofor* **16**:79-85
- Dixon R K (1995) Agroforestry systems: sources or sinks of greenhouse gases? *Agrofor Syst* **31**: 99–116.

- Djomo A N, Adamou I, Joachim S and Gode G (2010) Allometric equations for biomass estimations in Cameroon and pan moist tropical equations including biomass data from Africa. *Forest Ecol Manag* **260**:1873-85
- Dogra A S and Sharma S C (2005) Performance of *Eucalyptus* species and provenances in South-West Punjab. *Ind For* **131**:3-16
- Dutt D and Tyagi C H (2011) Comparison of various *Eucalyptus* species for their morphological, chemical, pulp and paper making characteristics. *IJCT* **18**: 145-51
- Dwivedi A P (2004) A Text Book of Silviculture: International Book distributors, Dehradun.
- Escobar A G, Mackay A D, Hodgson J and Kemp P D (2002) Soil properties of a widely spread, planted poplar (*Populus deltoides*) pasture system in a hill environment. *Aus J Soil Res* **40**: 873-86
- Evans J (1992) Plantation Forestry in Tropics. Oxford University Press, New York.
- FAO (2010) Criteria and Indicators for Sustainable Wood fuels. FAO Forestry Paper 160. Food and Agriculture Organization of the United Nations, Rome.
- FAO (2011). *Eucalyptus* in East Africa: Socio-economic and environmental issues **46**: 1-42. Rome, Italy.
- Fehrmann L and Kleinn C (2006) General considerations about the use of allometric equations for biomass estimation on the example of Norway spruce in central Europe. *Forest Ecol Manag* **236**: 412-21.
- Garg V K (1997) Litter production and nutrient concentration under high density plantation in some fuel wood species grown on sodic soils. *Ind For* **123**: 1155-60.
- Garg V K and Jain R K (1992) Influence of fuelwood trees on sodic soils. *Can J For Res* **22**: 729-35
- George M (1977) *Organic productivity and nutrient cycling in Eucalyptus hybrid plantation*. PhD Thesis, Meerut University, Meerut, India.
- George M (1984) Nutrients removal from *Eucalyptus* plantations by harvesting wood. *Ind For* **110**: 61-67.
- George M and Varghese G (1990) Nutrient cycling in *Eucalyptus globulus* plantation. Litter production and nutrients return. *Ind For* **116**: 962-68.
- George S J and Kumar B M (1998) Litter dynamics and cumulative soil fertility changes in silvopastoral systems of a humid tropical region in central Kerala, India. *Int Tree Crops J* **9**: 267-82.
- Gill H S, Abrol I P, Samra J S (1987) Nutrient recycling through litter production in young plantations of *Acacia nilotica* and *E. tereticornis* in a highly alkaline soil. *Forest Ecol Manag* **22**: 1-2.

- Heilman P and Norby R J (1997) Nutrient cycling and fertility management in temperate short rotation forest systems. *Biomass and Bioenergy* **14**: 361-70.
- Henry M, Besnard A, Asante WA, Eshun J, Adu-Bredu S, Valentini R, Bernoux M and Saint-Andre L (2010) Wood density, phytomass variations within and among trees, and allometric equations in a tropical rainforest of Africa. *Forest Ecol Manag* **260** :1375-88.
- Ibrahim J M, Sehgal J L and Sharma P K (1986) Two dominant stages of pedogenic development in the soils of Bist. Dooab alluvial plain in Punjab. *J Indian Soc Soil Sci* **34**: 334.
- Ilorkar V M, Kausadikar P H, Khobragade Y R (2016) Growth Performance of Different Clones of *Eucalyptus tereticornis* under Dryland Conditions in Vidarbha Region, Maharashtra. *J Tree Sci* **35**: 27-29.
- Jackson M L (1973) Soil Chemical Analysis. Prentice Hall of India Pvt Ltd., New Delhi.
- Jaiyeoba I A (2001) Soil rehabilitation through afforestation: Evaluation of the performance of *Eucalyptus* and pine plantations in Nigerian savanna. *Land Degrad Dev* **12**: 183-94.
- Jan M N, Dimri B M and Gupta M K (1996) Soil nutrient changes under different ages of *Eucalyptus* monocultures. *Ind For* **122**: 55-60.
- Jha M N, Gupta M K, Saxena A and Kumar R (2003) Soil organic carbon store in different forests in India. *Ind For* **129**: 714-24.
- Johnson D W and Curtis P S (2001) Effects of forest management on soil C and N storage: meta analysis. *Forest Ecol Manag* **140**: 227-38.
- Jose S (2009) Agroforestry for ecosystem services and environmental benefits: an overview. *Agrof Syst* **76**: 1-10.
- Kadambi K (1944) A working plan for the Devarayadurga Group of Forests, Tumkur district, pp. 1942-51, Bangalore, Superintendent, Government Press
- Karthick A, Pragasan L (2014) Stand Structure and Above-ground Biomass of Two Tree Plantations at Bharathiar University, Coimbatore Environmental Ecology Lab, Department of Environmental Sciences, Bharathiar University, Coimbatore.
- Kaul M, Mohren G M J and Dadhwal V K (2010) Carbon storage and sequestration potential of selected tree species in India. *Mitig Adapt Strateg Glob Change* **15**: 489-510.
- Ketterings Q M, Coe R, Noordwijk M V, Ambagau Y and Palm C A (2001) Reducing uncertainty in the use of allometric biomass equations for predicting aboveground tree biomass in mixed secondary forests. *Forest Ecol Manag* **146**:199-209.

- Kindu M, Glatzel G, Tadesse Y and Yosef A (2006) Tree species screened on nitosols of central Ethiopia for biomass production, nutrient contents and effect on soil nitrogen. *Journal of Tropical Forest Science* **18**: 173-80.
- Kulkarni H D (2004) Clonal forestry for industrial wood production: Compendium on clonal forestry. Mettupalyam, Tamil Nadu Agricultural University, pp 92-113.
- Kulkarni H D (2008) Private farmer-private industry partnerships for industrial wood production: a case study. *Inter for Rev* **10**: 147-55.
- Kumar A, Luna R K, Parveen, Kumar V (2010) Variability in growth characteristics for different genotypes of *Eucalyptus tereticornis* (SM.). *J For Res* **21**: 487-91.
- Kumar R and Bangarwa K S (2006) Clonal evaluation in *E. tereticornis* Sm. *Environment and Ecology* **24**: 1188-91.
- Kumar R, Kumar A and Dhillon R S (1998) Morphological and physico-chemical characteristics of soils under different plantations in arid ecosystem. *Ind J For* **21**: 248-52
- Kumaravelu G, Stanley J, Rai R S V and Balan S (1995) Provenances of *E. camaldulensis* Dehnh and *E. tereticornis* Sm suitable to South Indian conditions - results of an IUFRO trial. *Ann For Sci* **3**: 9-133.
- Lal P (2005) Performance of *Eucalyptus* clones in Punjab. Proc. National Symposium on Exotics in Indian Forestry, held at Department of Forestry and Natural Resources, PAU, Ludhiana, from March, 15-18, 2005, pp 45.
- Lal P (2010) Clonal forestry in India. *Ind For* **136**: 17-37.
- Lal P and Kulkarni H D (1992) Sustainable development through application of clonal technology in forestry/agroforestry. Biodiversity implication for global food security, pp 205-13.
- Lal P, Dogra A S, Sharma S C and Chahal G B S (2006) Evaluation of different clones of *Eucalyptus* in Punjab. *Ind For* **132**:1383-90.
- Landsberg J J (1986) Experimental approaches to the study of effects of nutrients and water on carbon assimilation by trees. *Plant Physiol* **12**: 713-17
- Leite F P, Silva I R, Ferreira R, de Barros N F, and Neves L J C (2010) Alterations of Soil Chemical Properties by *Eucalyptus* Cultivation in Five Regions in the Rio Doce Valley. *Forest Ecol Manag* **1**: 821-31.
- Lemenih M, Gidyalew T and Teketay D (2004) Effect of canopy cover and understorey environment of tree plantations on richness, density, and size of colonizing woody species in southern Ethiopia. *Forest Ecol Manag* **194**: 1-10.

- Lemma B (2006) *Impact of exotic tree plantations on carbon and nutrient dynamics in abandoned farmland soils of southwestern Ethiopia*. Ph.D. Dissertation. Swedish University of Agricultural Sciences, Faculty of Natural Resources and Agricultural Sciences, pp. 1-42.
- Libby W J and Rauter R M (1984). Advantages of clonal forestry. *Forest Chron* **60**: 145-49.
- Lugo A E (1997) The apparent paradox of reestablishing species richness on degraded lands with tree monocultures. *Forest Ecol Manag* **99**: 9-19.
- Luna R K, Thakur N S and Kumar V (2009) Performance of clonal *Eucalyptus* in different agro-climatic zones of Punjab, India. *Ind For* **135**: 1455-64.
- Malik R S and Fries C (1985) *The Ecological effect of Eucalyptus*. Rome, FAO.
- Mathur H N, Jain N and Sajwan S S (1980) Ground cover and undergrowth in *Eucalyptus*, brushwood and sal forest - an ecological assessment. *Van Vigyan* **18**: 56-61.
- Mendham D S, Sankaran K V, Connell A M and Grove T S (2002) *E. globulus* harvest residue management effects on soil carbon and microbial biomass at 1 and 5 years after plantation establishment. *Soil Biol Biochem* **34**: 1903-12.
- Mervin H D and Peech M (1950) Exchangeability of soil potassium in the sand silt and clay fractions as influenced by the nature of the complementary exchangeable cations. *Soil Sci Soc Proc* **15**: 136-40.
- MOEFCC (2017) India state of forest report. Forest Survey of India.
- Montagnini F and Nair P K R (2004) Carbon sequestration: an underexploited environmental benefit of agroforestry systems. *Agrof Syst* **61**: 281-95.
- Nabiar E K S and Harwood C E (2014) Productivity of *Acacia* and *Eucalyptus* plantations in Southeast Asia. *Int Forest Rev* **16**: 249-60.
- Nair P K R, Kumar B M and Nair V D (2009) Agroforestry a strategy for carbon sequestration. *J Pl Nutr soil Sci* **172**: 10-23.
- Nasim M, Qureshi R H, Saqib M, Aziz T, Nawaz S, Akhtar J and Anwar-ul-Haq M (2007) Properties of salt affected soil under *Eucalyptus camaldulensis* plantation in field conditions. *Pak J Agri Sci* **44**: 401-14.
- Negi J D S (1984) Biological productivity and cycling of nutrient in managed and manmade ecosystems. Ph.D. Thesis, Garhwal Uni. Srinagar.
- Noble A D, Randell P J, Sparling G, Anderson L S, Adams M, Khanna P K, Roison R J, Saffina P G and Xu Z H (1998) How trees affect soils? *Ri Rdl Rbl* **16**: 124.
- Oballa P, Chagala Odera E, Wamalwa L, Oeba V, Mutitu E and Mwangi L (2005) The performance of *Eucalyptus hybrid* clones and local landraces in various agro ecological zones in Kenya.

- Oraon B C, Malik M S, Bijalwan A and Dobriyal M J R (2016) Growth and biomass of three important energy plantation tree species in Jharkhand state of India. *Ind For* **142**: 833-42.
- Patel V J (1982) Short rotation forestry scope, limitations and perspectives. In first convention and symposium , *Bioenergy Society of India* **10**: 14-16.
- Patil S J, Mutanal S M, Patil H Y, Shahapurmath Girish (2012) Growth and productivity of different *Eucalyptus* species on degraded land. *Karnataka J Agric Sci* **25**: 92-93
- Penfold A R and Willis J L (1961) *Eucalyptus* as Exotics. In: Polunin N (Ed.) *The Eucalyptus*, Leonard Hill, pp. 112.
- Pennington P, Laffan M, Lewis R and Otahal P (2001) Assessing the long-term impacts of forest harvesting broadcast burning on soil properties at the Warra LTER site. University of Melbourne, School of Forestry, *Tas forests* **13**: 291-301
- Piare Lal (1994) Economics and mass multiplication of forest trees. *Ind For* **120**: 85-96.
- Piare Lal (2001) Private sector forestry research: A success story from India. *Bois Et Forets Des Tropiques* **267**: 33-48.
- Piare Lal (2006) Clonal forestry in India. In Regional Consultation Workshop on Scope of Production Forestry for Carbon Sequestration, 7-8 December 2006, Dehradun, FSI.
- Poore M E D and Fries C (1985) The ecological effects of *Eucalyptus*. FAO Forestry Paper 59. FAO, Rome.
- Prinsely R J and Swift M J (1986) Amelioration of Soils by Trees: A Review of Current Concepts and Practices. *Commonwealth Science Council*, London, UK.
- Rab M A (1994) Changes in physical properties of a soil associated with logging of *E. regnans* forest in south eastern Australia. *Forest Ecol Manag* **70**: 215-29.
- Rab M A (1996) Soil physical and hydrological properties following logging and slash burning in the *E. regnans* forest of south eastern Australia. *Forest Ecol Manag* **84**: 159-76.
- Rai A P, Handa A K, Choudhari S and Uma (2006) Allometry for estimating above ground biomass of *E. tereticornis* under energy and boundary plantations in Central India. *Annals of Arid Zone* **45**: 175-82.
- Ravina M (2012) Impact of *Eucalyptus* plantations on pasture land on soil properties and carbon sequestration in Brazil. Swedish University of Agricultural Sciences.
- Rawat L, Kamboj S K and Kandwal A (2012) Site depletion and resource conservation in *Eucalyptus hybrid* plantation ecosystems of Punjab, India. *J Tree Sci* **31**: 92-101.

- Rawat V and Negi J D S (2004) Biomass production of *E. tereticornis* in different agro ecological regions of India. *Ind For* **130**:762-70.
- Rhoades C and Binkley D(1996) Factors Influencing Decline in Soil pH in Hawaiian *Eucalyptus* and *Albizia* plantations. *Forest Ecol Manag* **8**: 47-56.
- Richard L A (1954) Diagnosis and improvement of saline and alkali soils. USDA. Agricultural Handbook **60**: 107-08.
- Rigobelo and Nahas (2004) Seasonal fluctuations of bacterial population and microbial activity in soils cultivated with *Eucalyptus* and *Pinus*. *Sci Agric* **61**: 88-93.
- Rockwood D L, Rudie A W, Ralph S A, Zhu J Y and Winand J E (2008) Energy Product Options for *Eucalyptus* Species grown as short rotation woody crops. *Int J Mol Sci* **9**: 1361-78.
- Saigal S and Kashyap D (2002) The second green revolution : analysis of farm forestry experiences in western tarai regid of Uttar Pradesh and coastal Andhra Pradesh. Instruments for sustainable private sector forestry. Echotech Services (India) Pvt. Ltd., New Delhi, pp. 23-78.
- Sapra R K (2006) Clonal forestry with reference to *Eucalyptus* and poplar in Punjab and Haryana. In: Regional Consultation Workshop on Scope of Production Forestry for Carbon Sequestration, 7-8 December 2006, Dehradun, FSI
- Satyawali K, Chaturvedi S and Bisht N (2017) Effect of high density *E. camaldulensis* and *Melia azedarach* plantation on soil nutrients at different planting density. *Int J Chem Stud* **5**: 827-31.
- Schroth G and Sinclair F (2003) Tree crops and soil fertility: Concept and research methods. CABI Wallingford UK, pp. 464.
- Schultz R C, Isemhart T M, Simpokios W W and Colletti J P (2004) Riparian forest buffers in ecosystem- lessons learned from the Bear creek watershed, Central Iowa USA. *Agroforest Syst* **61**: 35-50.
- Sehgal L and De Coninck F (1971) Identification of clay mineral in Punjab soils. *J Indian Soc Soil Sci* **19**: 159.
- Seobi T, Anderson S H, Udawatta R P and Gantzer C J (2005) Influence of grass and agroforestry buffer strips on soil hydraulic properties of an Albaqualf. *Soil Sci Soc Am J* **69**: 893-901.
- Shan J, Morris L A and Hendrick R L (2001) The effect of management on soil carbon and plant carbon sequestration in slash pine plantations. *J Appl Ecol* **38**: 932-41.

- Sharma P K and Dev G (1985) Genesis of soils on different geomorphic surfaces in a riverine plain of Punjab. *J Indian Soc Soil Sci* **33**: 613.
- Sharma S C, Dogra A S and Chauhan S K (2012) Carbon sequestration potential of production forestry for mitigating impact of climate change. In: Paniwar P, Tiwari A K and Daothmal K S (Eds) *Agroforestry systems for resources conservation & livelihood security in lower Himalayas*, NIPA, New Delhi, pp. 253-72.
- Shirani H, Hajabbasi M A, Afuni M and Hemmat A (2002) Effects of farmyard manure and tillage systems on soil physical properties and corn yield in central Iran. *Soil Till Res* **68**: 101-08.
- Sindhu P S and Gilkes R J (1977) Minerology of soils developed on alluvium in Indo-Gangetic plain (India). *Soil Sci Soc Am J* **41**: 1194.
- Singh B and Sharma K N (2007) Tree growth and nutrient status of soil in a poplar (*Populus deltoides* Bartr.) based agroforestry system in Punjab, India. *Agrof Syst* **70**: 113-24
- Singh R P (1984) Nutrient cycle in *Eucalyptus tereticornis* plantations. *Ind For* **110**: 76-85.
- Singh V S and Pandey D N (2011) Multifunctional agroforestry systems in India: Science-based policy options. *Climate Change* and CDM cell, RSPCB, Jaipur, pp. 1-33.
- Sinha S K, Gupta S K, Jha S K, Jadeja D B (2012) Above ground biomass estimation of different *Eucalyptus* clones. Conference: An Evergreen Agriculture for Food Security and Environmental Resilience, February 2012, pp 84-85.
- Somachai T, Pongsak S and Kyoji Y (1991) Litterfall and productivity of *E. camaldulensis* in Thailand. *J Trop Ecol* **7**: 275-79.
- Spurr S H and Barnes B V (1980) *Forest Ecology*. 2nd ed. John Wiley & Sons, New York
- Stockfisch N, Forstreuter T and Ehlers W (1999) Ploughing effects on soil organic matter after twenty years of conservation tillage in Lower Saxony, Germany. *Soil Till Res* **52**: 91-101.
- Subbiah B V and Asija G L (1965) A rapid procedures for estimation of available nitrogen in soils. *Curr Sci* **25**: 259-60.
- Sunita M and Uma M (1993) Soil conditions as affected by various age groups of *Eucalyptus* and *Populus* plantations in Tarai region of U.P. *INSA* **59**: 67-70.
- 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. *Bioresour Technol* **97**: 57-68.
- Tandon V N, Rawat J K and Singh R (1993) Biomass production and mineral cycling in plantation ecosystems of *Eucalyptus* hybrid in Haryana. I. Biomass production and its distribution. *Ind For* **119**: 232-37.

- Tiedje J M, Asuming-Brempong S, Nusslein K, March T L & Flynn S J (1999) Opening the black box of soil microbial diversity. *Appl Soil Ecol* **13**: 109-22.
- Troup R S (1932) Exotic forest trees in the British Empire. Oxford Clarendon Press, pp. 259.
- Turner J W, Cole D W and Gessel S P (1976) Mineral nutrient accumulation and cycling in a stand of Red Alnus (*Alnus rubra*). *J Ecol* **64**: 965-71.
- Upadhyaya A K and Soni R G (1997) Growth, biomass production and dry matter distribution pattern of *E. camaldulensis* grown under irrigated conditions in IGNP Area of Rajasthan. *Ind For* **123**: 95-99.
- Van den Driessche R (1984) Nutrient storage, retranslocation and relationships of stress to nutrition. Nutrition of plantation forest, pp. 181-210.
- Walkley A and Black I A (1934) An examination of the digestion method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci* **37**: 29-38.
- Yitiferu B, Abewa A and Amare T (2013) Expansion of *Eucalyptus* Woodlots in the Fertile Soils of the Highlands of Ethiopia: Could It Be a Treat on Future Cropland Use? Amhara Agricultural Research Institute (ARARI), Bahr Dar, Ethiopia. *J Agric Sci* **5**: 97-107.
- Young A (1989) Agroforestry for Soil Conservation. CAB International, Wallingford, UK. pp. 276.
- Zhang H, Zhang G L and Zhao Y G (2007) Chemical degradation of Ferralsol (Oxisol) under intensive rubber (*Hevea brasiliensis*) farming in tropical China. *Soil Tillage Res* **93**: 109-16.
- Zhang X Q, Kirschbaum M U F, Hou Z and Guo Z (2004) Carbon stock changes in successive rotations of Chinese fir (*Cunninghamia lanceolata*) plantations. *For Ecol Manage* **202**: 131-47.
- Zhong Mian W, WenSheng W, YueMei Y, WuMing Q, ChuanMing Z and Yi R (2009) Growth comparison and reforestation economic evaluation of eight-year-old *Eucalyptus* clones. *Guangxi Academy of Agricultural Sciences* **40**: 1215-19.

VITA

Name : Harmandeep Singh
Father's name : S. Jiwan Singh
Mothers name : Smt. Hardeep Kaur
Nationality : Indian
Date of birth : 01.09.1992
Permanent home address
VPO Ugrahan, Teshil Sunam
District Sangrur, Punjab

Email : vickydhillon01@gmail.com

EDUCATIONAL QUALIFICATIONS

Bachelor's degree : B.Sc. Agriculture
University and year of award : Punjabi University, Patiala
2015
OCPA : 6.10/10.00
Master's degree : M.Sc. (Forestry)
University and year of award : Punjab Agricultural University, Ludhiana
2018
OCPA : 7.23/10.00
Title of Master's Thesis : Growth and biomass production of different
Eucalyptus species on riverine soils of Punjab