

**EVALUATION OF CARBON SEQUESTRATION ABILITY OF
NEEM (*Azadiractha indica*, A.Juss.) AND PONGAMIA
(*Pongamia pinnata* (L.) Pierre.)**

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**EVALUATION OF CARBON SEQUESTRATION ABILITY OF
AZADIRACTHA INDICA AND *PONGAMIA PINNATA***

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**AFFECTIONATELY DEDICATED TO MY BELOVED
PARENTS**

(A.B.NINGE GOWDA, V.R.HEMAVATHI),

BROTHER

(MADHU) & TO MY

GURU (Dr.K.T.PRASANNA)

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CERTIFICATE

This is to certify that the thesis entitled “**Evaluation of carbon sequestration ability of *Azadiractha indica* and *Pongamia pinnata***” submitted in partial fulfillment of the requirement for the degree of **Master of Science (Agriculture) in Environmental Science** to the University of Agricultural Sciences, Bengaluru is a bonafide record of research work carried out by **Mr. Manu, A.N.** during the period of his study in the University under my guidance and supervision, no part of the thesis has been submitted for the award of any degree, diploma, associateship, fellowship or other similar titles.

Bengaluru
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ABSTRACT

Carbon dioxide is a dominant greenhouse gas in the atmosphere. Increased atmospheric CO₂ is attributable mostly to fossil fuel combustion and deforestation worldwide. With the increasing deforestation, planting programmes of woody perennials on degraded lands, marginal agricultural lands, etc is intensified and emphasized. Trees fix carbon dioxide during photosynthesis. During metabolic activities part of carbohydrates are used and excess carbon will be stored as biomass. With the increase in the age of the tree, there will be an increase in biomass with a relative increase in carbon stock.

Carbon is sequestered by the plant photosynthesis and stored as biomass in different parts of the tree. In the present study conducted to evaluate the potential of carbon sequestration in *Azadiractha indica* and *Pongamia pinnata* as influenced by age, selecting the plantation of three age class viz., 2 year, 5 year and 10 year respectively. The mean carbon sequestration rate in neem and pongamia across ages was 0.01,0.96,2.16t/ha and 0.04,0.40,1.75t/ha respectively. Based on the gas exchange studies, it was found that the mean photosynthetic rate in neem and pongamia across ages (2 and 5 year) was 11.84, 12.00 μ moles m⁻²sec⁻¹ and 9.455, 12.63 μ moles m⁻²sec⁻¹ respectively. Similarly the stomatal conductance, inter cellular carbon dioxide rate, transpiration rate was higher in pongamia across ages compared to neem. Water use efficiency and *in vivo* Carboxylation efficiency across 2 and 5 years was found higher in neem compared to and pongamia respectively.

Thus the results clearly indicate that rate of growth in neem is slow in initial stages but later growth enhances leading to the sequestering of more carbon than pongamia. The studies conducted elsewhere using other important forestry species showed that neem and pongamia are comparable in growth and carbon uptake.

Signature of the student

(Major Advisor)

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LIST OF ACRONYMS

cm	Centimeters
mts	Meters
t	Tone
Mt	Metric tones
Mg	Mega grams (X 10 ⁶ grams)
Gg	Gega grams (X 10 ⁹ grams)
Tg	Tera grams (X 10 ¹² grams)
Pg	Peta grams (X 10 ¹⁵ grams)
ha	Hectare
m.ha	Million hectare
yr	year
C	Carbon
Gt	Giga tone (X 10 ⁹ tones)
m ³	Meter cube
m ²	Square meter
\$	Dollar
°C	Degree Celsius
C	Carbon
mm	Millimeter
N	North
E	East
MSL	Mean Sea Level
Cm ³	Cubic centimeter

INTRODUCTION

I.INTRODUCTION

It is generally accepted that forests can play a critical role in capturing and storing large amounts of carbon from the atmosphere and can thus contribute to reducing the buildup of atmospheric carbon dioxide. Despite their relatively fast growth, it has been suggested that tropical plantations are a small sink of atmospheric carbon because they occupy a relatively small area in relation to other vegetation types and land uses worldwide (Brown *et al.*, 1986). The area of plantations annually planted in the tropics is currently, 10% of the simultaneously deforested area, and tree planting currently compensates for 0.3% (at most) of the carbon released by deforestation (Bruenig 1996). To have a significant impact as a global Carbon sink, plantations would need to be established on an unprecedented scale (Sedjo 1989, Myers and Goreau 1991, Houghton 1996). However, rates of reforestation and afforestation worldwide are likely to grow over the next decades as many countries seek to compensate for the loss of natural forests, and thus the role of plantations in sequestering may also increase (Gladstone and Ledig 1990, Rotmans and Swart 1991, Houghton 1996). Several exotic and indigenous tree species growing in a variety of tropical environments should be tested with respect to their rates of growth and biomass accumulation, especially those that produce good quality timber, which results in longer-term storage of the fixed carbon.

Global warming is amongst the most dreaded problems of the new millennium. Carbon emission is supposedly the strongest causal factor for global warming. So, increasing carbon emission is one of today's major concerns, which is well addressed in Kyoto Protocol. Trees are amongst the most significant elements of any landscape, both due to biomass and diversity. Their Key role in ecosystem

dynamics is well known. However, it is paradoxical that the vegetation has undergone destruction and degradation in the modern times due to industrial and technological advancement achieved by human society. This advancement has resulted in emission of carbon in the ecosystem. Therefore, there is need to address environmental issues related to them. Trees are important sinks for atmospheric carbon i.e. carbon dioxide, since 50% of their standing biomass is carbon itself (Ravindranath *et al.*, 1997).

Afforestation and other forest management options to sequester Carbon in tropical latitudes may fail unless they address local economic, social, environmental, and political needs of people in the developing world (Cairns and Meganck 1994, Houghton 1996). Tree plantations are a source of cash, savings, and insurance for the individual farmers (Chambers and Leach, 1990).

On the other hand; fast growing tropical tree plantations incorporate considerable amounts of nutrients in their biomass over a relatively short period of time. Site fertility declines can limit sustained plantation forestry in tropical regions: soil fertility can be decreased through excessive removal of living biomass, particularly if nutrients in tree crowns are lost through harvest or site preparation (Jorgensen and Wells 1986, Perry and Maghembe 1989). This can be particularly serious when plantations are established on soils that are inherently poor. Therefore, examination of the role of tropical plantations as Carbon sinks necessitates integrative approaches to evaluate not only the rates of Carbon sequestration by different tree species, but also their design and management to minimize potential deleterious effects on ecosystem nutrients and to make plantations economically, socially, and environmentally sound land use Options.

Neem and Pongamia trees are grown commercially in plantations to extract chemicals or alkaloids from the seeds and leaves. Azadirachtin has been promoted as a new insecticide that is considered more 'Environment friendly' than synthetic insecticides. Plantations have been established in tropical to subtropical regions of the world, including semi-arid and wet tropical regions, from sea level to about 700 m elevation (NRC 1992). Those advocating the planting of Neem as a commercial crop cite a wide range of potential benefits. Some go as far as saying Neem is 'a tree for solving global problems' (NRC 1992).

Amongst the many species, which can yield oil as a source of energy in the form of bio-fuel, *Pongamia pinnata* has been found to be one of the most suitable species in India being widely grown, it is N₂-fixing tree, not browsed by animals and oil is non-edible. The fast growing nature, capacity to adapt and thrive well in different agro climatic conditions had led to the use of pongamia for afforestation programme in India.

With the above information in background, the present study was conducted with the following objectives;

1. To assess the carbon stock present in the wood of *Azadirachta indica* and *Pongamia pinnata*.
2. To assess photosynthetic ability of *Azadirachta indica* and *Pongamia pinnata*.
3. To compare the species based on their growth behavior and carbon sequestration ability.

REVIEW OF LITERATURE

II. REVIEW OF LITERATURE

2.1 Global Climate Change

Although we are currently concerned about global warming caused by anthropogenic activities, the Earth's climate has fluctuated many times in the past in response to natural mechanisms of climate change. Such changes in global climate have also occurred over much longer time scales, from hundreds to millions of years. In fact the current global warming trend which began at the end of the 19th century spans only a tiny fraction of the Earth's climatic history. Taking a longer perspective on climate variability can help us gain a better understanding of the global climate and of the evolution of the climate today and in the future.

The overall state of the global climate is largely determined by balance between energy the Earth receives from the Sun and the heat which the Earth releases back to space, called the global energy balance. Many causes of climate change involve processes that alter the global energy balance. The enhanced greenhouse effect is a potential cause of climate change because the extra quantities of greenhouse gases put into the air by mankind trap more heat in the atmosphere. This upsets the global energy balance and causes a rise in global surface temperature. Although most scientists agree that global warming is the result of the enhanced greenhouse effect, natural processes can also upset the global energy balance in this way, causing similar rises in global temperature. A change in the amount of energy received by the sun for example has often been proposed as the cause of global warming. The challenge facing scientists is to establish beyond doubt a link between global warming and man-made greenhouse gas pollution.

Unlimited human demand has resulted in over exploitation of natural resources. There are many evidences to show the increasing consumption of fossil fuels, population growth, industrialization and forest clearance, which is strongly correlated with the increasing global CO₂ concentration (Rotty and Maryland, 1986; Bazzaz, 1990, Bowes, 1993). There will always be uncertainty in understanding a systems complex as the world's climate. However there is now strong evidence that significant global warming is occurring. The evidence comes from direct measurements of rising surface air temperatures and subsurface ocean temperatures and from phenomena such as increases in average global sea levels, retreating glaciers, and changes to many physical and biological systems. It is likely that most of the warming in recent decades can be attributed to human activities (IPCC, 2001). This warming has already led to changes in the Earth's climate.

The existence of greenhouse gases in the atmosphere is vital to life on Earth. In their absence average temperatures would be about 30 centigrade degrees lower than they are today. But human activities are now causing atmospheric concentrations of greenhouse gases including carbon dioxide, methane, troposphere ozone, and nitrous oxide to rise well above pre-industrial levels. Carbon dioxide levels have increased from 280 ppm in 1750 to over 375 ppm today higher than any previous levels that can be reliably measured (i.e. in the last 420,000 years). Increasing greenhouse gases are causing temperatures to rise; the Earth's surface warmed by approximately 0.6° C over the twentieth century. The Intergovernmental Panel on Climate Change (IPCC) projected that the average global surface temperatures will continue to increase to between 1.4° C and 5.8° C above 1990 levels, by 2100.

2.2 Climate change negotiation

During the last quarter of the 20th century there was a buzz of research activities. This was largely to understand the influence of increased carbon dioxide concentration on plant response. The consensus that clearly emerged from these studies is that, there is an unprecedented increase in carbon dioxide concentration in the atmosphere and will bring about changes in the biosphere. In the light of these studies consolidation of views at global level was felt very urgent in reaction and the following developments started taking place.

2.3 Genesis of UNFCC

Increasing scientific evidence of human interference with the climate system, coupled with growing public concern over global environmental issues, began to push climate change onto the political agenda in the mid-1980s. Recognizing the needs of policymakers for authoritative and up-to-date scientific information, the World Meteorological Organization (WMO) and the UN Environment Programme (UNEP) established the Intergovernmental Panel on Climate Change (IPCC) in 1988. In 1990, the IPCC issued its First Assessment Report, confirming that human-induced climate change was indeed a threat and calling for a global treaty to address the problem.

In May 1992 international climate change negotiators agreed to the United Nation Framework Convention on Climate Change (UNFCC) which was signed at earth summit held at Rio de Janeiro (Anon., 1992). The main objective of the convention was stabilization of Green house gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with climate

system. The convention has given targets, to industrialized countries and economies in transition, to reduce their respective green house gas emissions to their 1990 level by 2000, but it was not very effective.

2.4 Genesis of Kyoto protocol

When they adopted the Convention, governments knew that its commitments would not be sufficient to seriously tackle climate change. At COP 1 (Berlin, March/April 1995), in a decision known as the Berlin Mandate, Parties therefore launched a new round of talks to decide on stronger and more detailed commitments for industrialized countries. After two and a half years of intense negotiations, the Kyoto Protocol was adopted at COP 3 in Kyoto, Japan; on 11 December 1997. This has been a landmark achievement in the international climate change negotiations, well known as Kyoto protocol. Under this protocol, developed countries are required to reduce their collective, carbon dioxide to at least 5.2 percent below their 1990 emission levels by 2012. Recognizing the need of the developing and least developed countries to have more industries for their development, the protocol does not bind these countries by any emission reduction targets during the first commitment period i.e. 2008-2012 (Anon., 1996).

2.5 Carbon sequestration

Plants absorb carbon from the atmosphere in the process of photosynthesis, some part of absorbed carbon is released back into the atmosphere and the remaining portion is stored in the form of biomass. In this natural process the sequestered carbon dioxide will be converted into biomass. But trees, in general, are considered as major sink of carbon because they retain carbon for longer duration, and also believed to be a closed system with little leakage. Therefore carbon sequestration is basically withholding carbon in some safe form other

than the gaseous form in the atmosphere and as long possible. The carbon absorbing capacity is high in the initial stages of plant when growth rate is high and it declines towards maturity.

A massive tree- planting program will have to be accompanied by a parallel effort to stop further deforestation. Globally large areas of already deforested lands remain available for reforestation (i.e. they have not been taken up for permanent settlement by human communities); there could be 5-7.6 million km² deforested lands available for productive use (Myers and Goreau, 1991)

If we consider that a fast growing tree plantation produces 20 ton biomass per ha per year, then it can sequester 10 ton of atmospheric carbon per ha per year (because roughly half the plant growth is made of carbon). Therefore, to fix 1Gt (Giga ton) of carbon from the atmosphere we need to plant trees on 100 million ha (1millionkm²) per year. In addition to reforestation of natural forested areas, we should concentrate on afforestation of marginal lands; water shed area, and urban areas. With a little care the trees grown under these areas can be made to sequester a huge amount of carbon as they continue grow.

For a successful evergreen revolution we need to involve all sections of the society including the farmers. In Costa Rica money grows trees says one of the recent issues of New Scientist (Pearce., 1998). The American and Norwegian businesses are about to pay farmers there to plant trees on their land. The farmer's job is to let the trees grow! The companies will pay the farmers \$10 for every tone of carbon that tree absorb from the atmosphere during photosynthesis. In turn, the companies will get certificates (carbon credits) declaring that they have paid for CO₂ to be removed from the atmosphere. This kind of strategies must be developed in all developing countries where

pollutants from industries are reaching the atmosphere at an alarming rate.

Enhancing carbon sequestration through different land use options to mitigate global warming is being undertaken in a big way in many countries. Optimal use of land and other natural resources for sustainable Management to create carbon sinks are major aims of this exercise by the governments and many other agencies working towards this goal.

2.6 Carbon sequestration and Indian scenario

Bhadwal and Singh (2002) have attempted to predict the carbon sequestration scenario in India from the year 2000, as base year, to a Situation during the year 2050 through a model developed by World Resources Institute. The authors have looked at carbon Sequestration potential in three scenarios, namely the economically feasible, the business as usual (BAU) and the potential scenario. The results depict a rosy picture of the country, indicating there would be a two-fold increase in the rate of annual carbon sequestration from 5.273 billion tons (bt) during the Year 2000 to over 10.5 bt/year in BAU, 11.92 bt/year and 12.21 bt/year in potential Scenario.

Ravindranath *et al.* (1997) estimated flows from the foresters are projected the same for the year 2011 (Table 2.1). They projected the future carbon flows in two separate conditions i) business as usual ii) favorable scenario. In the former condition, they assumed that the existing carbon absorption and release by forests remain same, where as in latter case they assumed that the condition are modified to help the carbon absorption from the atmosphere like, increased short term and long term forestry projects, increased productivity of forest, more

and more use of nonconventional energy sources instead of biomass plants, advanced stoves for household etc.

In the same study, they also estimated the net emission of carbon from the forest sector of India. For the year 1986 the gross emission from deforestation in that year, plus committed emission from deforestation in the preceding years, was estimated to be 64×10^6 t of carbon. The carbon sequestration (or net woody biomass accumulation in trees for long term storage) from the area brought under tree plantations and the existing forest area under forest succession was estimated to offset the gross carbon emission in India, leading to no net emission of carbon from the forest sector. Medium term projections for India (for the year 2011) show that under a business as usual scenario at current rates of afforestation, projected carbon emission would continue to be balanced by sequestration.

**Table 2.1: Carbon flows-current and future scenarios in India
(10⁶t)**

Carbon flux	1986	2011 Business as usual	2011 Favorable scenario
Carbon storage			
-Forest			
Vegetation	4179	4179	4186
Soil	5399	5399	5399
-Plantation	-	850	1181
-Perennials	-	75	3000
-Natural regeneration	-	-	1096
Total	9528	10503	14856
Carbon uptake			
-Forest	68.7	68.87	68.87
-Natural regeneration	-	00.23	09.38
-Afforestation	-	27.00	37.50
-Reforestation	-	-	75.00
Total	68.7	96.10	190.75

(Source: Ravindranath *et al.*, 1997)

2.7 Biomass accumulation & carbon sequestration in trees

Mahendranath Subedi (2004) conducted above ground biomass studies of *Quercus semecarpifolia* in temperate forests of Nepal. Above ground tree layer biomass was found to be 479.17, 357.53, 462.60, 358.02, 272.15 and 304.21 t/ha from east to west directions in temperate forest respectively.

Deva Kumar *et al.* (2007) conducted a study on the comparative assessment of biomass production in three different landscapes. Biomass production was highest in coffee plantations (468 t/ha) and least in the natural forests (94.5 t/ha).

Vijay Rawat and Negi (2004) revealed that *Eucalyptus tereticornis* biomass varied from 11.9 t/ha in three year old plantation to 146 t/ha in 9 year old plantation in moist regions. In dry tropical region it varied 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 cooler areas as compared to warmer areas. Where water is not the limiting factor comparatively higher mean annual temperature of around 25°C seems to produce higher biomass.

Roy *et al.* (2006) reported that eight year old trees of *Melia azedarch* planted in single line (2m apart) at Indian Grass land and Fodder Research Institute (IGFRI), Jhansi. The trees contributed a total biomass production of 21.11 t/ha of which 66, 24 and 10 per cent were contributed by minor timber, firewood and fodder respectively.

Jana *et al.* (2009) conducted research in 6 year old trees of *shorea robusta*, *Albizzia lebbek*, *Tectona grandis*, and *Artocarpus integrifolia*. Study revealed that the annual carbon sequestration rate from ambient air were estimated at 8.97 t C ha⁻¹ by *Shorea robusta*, 11.97 t C ha⁻¹ by *Albizzia lebbek*, 2.07 t C ha⁻¹ by *Tectona grandis* and 3.33 t C ha⁻¹ by *Artocarpus integrifolia*. The percentage of carbon content (except root) in the aboveground biomass of *Shorea robusta*, *Albizzia lebbek*, *Tectona grandis* and *Artocarpus integrifolia* were 47.45, 47.12, 45.45 and 43.33, respectively. The total aboveground biomass carbon stock per hectare as estimated for *Shorea robusta*, *Albizzia*

lebbek, *Tectona grandis* and *Artocarpus integrifolia* were 5.22, 6.26, 7.97 and 7.28 t C ha⁻¹, respectively in these forest stands.

Verma *et al.* (2006) conducted a study in nine year old energy plantation consisting of *Eucalyptus tereticornis*, *Melia azedarch* and *Leucaena leucocephala* at four planting densities viz. 5000, 10000, 15000 and 20000 plants/ha. Above ground biomass computed on mean tree and per ha basis differed significantly with the species and density. The contribution of leaf, branch and stem to mean tree biomass irrespective of the species and plant densities varied from 4.11 to 5.21, 16.19 to 25.84 and 69.89 to 79.72 respectively.

To estimate the dry matter from the standing biomass of trees, generally the volume of the wood is multiplied by the density of the specific species of the wood. However density of all the species across the globe may not be available. In order to accumulate such issue IPCC has recommended to use 50 per cent of the fresh weight of that biomass (Anon, 1996, Ajay Kumar. and Singh., 2003).

After converting the volume of wood into biomass, the next step would be to find out the carbon content in the biomass. The carbon content of the different part of the plant has been found to vary to a certain extent. But in general 50% of the biomass is taken as carbon content for all the carbon estimation (Anon, 1996 and Mac Dicken, 1997).

Siva Kumar *et al.* (2000) focused on the potentials of rubber plantations in carbon sequestration and presented some economic models, which could form the basis for the smart partnership between land owners downstream manufactures and global multinationals for the purpose of sustainable rubber cultivation. Carbon sequestration from one hectare 27 year old stand of rubber tree was 72.36 tones.

The major portion was sequestered in the trunk and primary branch comprising of 21.6 and 18.9 tons respectively. The result showed that sequestration capacity among different organs, highest carbon sequestration of 88 per cent was found in the latex vessels, leaves and twigs have carbon content of 53.8 per cent other woody tissue is trunk and branches.

Udaya Morabad *et al.* (2006) quantified the carbon sequestration in harvested wood of Kodagu District in Karnataka for a period of 13 years (1992 to 2004). He found that totally $373.88 \times 10^9 \text{ m}^3$ (114.9 Gg 'C') of wood was removed from the district, out of which was 58.74 Gg 'C' was fixed in the form of wood products.

Significant difference was recorded in *Pongamia pinnata* seedlings at different growth intervals of 8, 16, 24th months observations. With respect to height, gbh, crown diameter during 16 and 24 month the mean crown height, girth and crown diameter was recorded as 3.1, 0.19, 1.5 m and 2.89, 0.24, 1.98m respectively and growth parameters like biomass yield, carbon sequestered during 8th 16th and 24th months were 4.23, 2.11, 8.06 and 4.03, 12.40, 6.20 tonnes of 'C'/ha respectively (Shivanna *et al.*, 2006).

2.8 Carbon stock present in Wood

Trees are the major sinks of CO₂ and many scientists have measured carbon content using different method. Elias and Polvin (2003) measured the carbon content in woods of 32 tropical broad leaved trees and found carbon content ranging from 44.4% to 49.4%. Lamblom and Savidge (2006) analyzed the heartwood of 19 conifers and 22 broadleaved trees and they reported that conifers (47.21%-55.20%) had somewhat higher carbon content than broadleaved species (46.27%-49.97%). These reports suggest that variations in Carbon

content between species should be taken into account for accurate evaluation of carbon sequestration in trees and forests.

Variations in carbon content in wood among 102 clones, selected from almost the entire natural distribution area, were investigated in *Larix kaempferi*. The average carbon content was 50.50%, 50.94%, and 50.80% in sapwood, heartwood, and whole wood, respectively. (Eitaro Fukatsu *et al.*, 2006). Negi, *et al.*, (2003) reported that wood, which constitutes maximum portion of total biomass, stored maximum amount of carbon. While comparing the different life forms, it was observed that the maximum carbon is stored in the order of conifers > deciduous > evergreen > bamboos. Thus it can be said that the conifers are more efficient in carbon sequestration.

Carbon content showed statistically significant variation among species, ranging from 48.4% to 51.0%. The volatile Carbon fraction was non-negligible, averaging 2.2%, and showed high variation among species. Studies found that wood Carbon content was appreciably higher in conifer than hardwood (angiosperm) species ($50.8 \pm 0.1\%$ vs. $49.5 \pm 0.2\%$, respectively). Wood carbon density (gC/cm^3) showed very high inter-specific variation, due to differences in wood specific gravity (Thomas *et al.*, 2007).

Fuel wood harvest and consumption in a sustainable manner and decay of wood will not make any net CO_2 contribution assuming that the system remains in equilibrium (Singh *et al.*, 1997).

2.9 Photosynthetic ability of trees

Wood production declines as forest age. Decrease in production has been attributed to higher respiration associated with increasing biomass but direct measurement fails to support this assumption. An alternate hypothesis is that growth decline is caused by reduced net photosynthesis. To test this hypothesis, (Yoder *et al.*, 1994) compared the net photosynthetic rate of foliage from trees that had seized height growth with foliage from actively growing mature trees. Results showed that net photosynthesis per unit area of one year old foliage from old *Pinus contorta* and *Pinus ponderosa* averaged 14-30% lower than the same aged foliage from younger trees. Computer simulation from previous study indicated that differences of this magnitude are sufficient to explain the lower wood production in old trees. In order to predict carbon sequestration of vegetation with the future rise in atmospheric CO₂ concentration and temperature, long-term effect of high CO₂ and high temperature on responses of both photosynthesis and transpiration of plants as a whole community to environmental parameters need to be elucidated (Tako *et al.*, 2001).

Voronin *et al.* (2001) reported that the positive correlation between CO₂ exchange in the leafy parts of branch and light intensity was observed in the afternoons. This signifies that, apart from light, no environmental factor limited photosynthesis.

As plants acclimate to growth in elevated $p\text{CO}_2$ (partial pressure of CO₂) they often fail to sustain the initial, maximal stimulation of net CO₂ uptake rate under optimal microclimate conditions (Gunderson and Wullschleger, 1994; Sage, 1994; Curtis, 1996; Drake, Gonzalez-Meler and Long, 1997). Rogers and Humphries (2000) demonstrated that this phenomenon could be attributed almost entirely to a decrease in the carboxylation capacity of Rubisco. Knowledge of

photosynthetic sensitivity and potential long-term photosynthetic acclimation responses to elevated CO₂ may be used to predict annual global carbon influx into terrestrial ecosystems (Luo *et al.* 1996) and improve models of forest ecosystem response to global climate change.

In fact, a doubling of atmospheric CO₂ partial pressure results in a 50 per cent reduction in the ratio of photorespiration to photosynthesis (Sharkey, 1988), thereby increasing net photosynthesis.

Reduction in photosynthetic capacity, often termed down regulation or photosynthetic adjustment, after long-term exposure to elevated CO₂ has been observed in trees (Lewis *et al.* 1996, Atkinson *et al.* 1997, Rey and Jarvis, 1998) and is often attributed to an imbalance in the source-sink relationship due to the accumulation of leaf carbohydrates (Webber *et al.* 1994, Van Oosten and Besford 1994, Jones *et al.* 1996, Cheng *et al.* 1998). Substantial production of carbohydrates induced by higher photosynthetic rates at elevated CO₂ partial pressure initiates a feedback mechanism that ultimately reduces photosynthetic capacity.

In two deciduous trees, *Castanea sativa* (El Kohen and Mousseau, 1994) and *Betula pendzda* (Rey and Jarvis, 1998), Photosynthetic adjustment to elevated CO₂ increased as the growing season progressed.

The large reduction in Photosynthetic capacity and associated Photosynthetic components observed in *Ponderosa pine* in late summer may be greater than the Photosynthetic adjustment expected earlier in the growing season. Nonetheless, photosynthetic adjustment was observed in *Betula pendula*, an indeterminate growth species, in mid-season (Rey and Jarvis 1998), further suggesting that at least

some degree of photosynthetic adjustment in *Ponderosa pine* probably occurred earlier in the growing season. (Hellmers and Strain, 1972) work on loblolly pine trees shows that the relationship between photosynthetic capacity and sink demand in loblolly pine trees is complex because this species produces from one to seven distinct flushes of needle cohorts in each growth season. Kramer and Kozlowski (1979) described the growth of pine trees as a system of sinks in competition for Photosynthate from a shifting source as ontology proceeds.

The effect of leaf age on photosynthesis capacity, a critical parameter in the theory of optimal leaf longevity, was studied for two tropical pioneer tree species, *Cecropia longipes* and *Urera caracasna*, in a seasonally dry forest in panama. These species continuously produce short lived leaves (74 and 93d, respectively) during the rainy season (may-december) on orthotropic branches. However, they differ in leaf production rate, maximum no of leaves branch, light environment experienced by the leaves, leaf mass per unit area, and nitrogen content. Light saturated photosynthetic rates for marked leaves of known ages (± 1 wk) were measured with two contrasting schemes (repeated measurements vs. chronosequence within branch), which overall produced similar results. In both the species, photosynthetic rates and nitrogen use efficiency were negatively correlated with leaf age and positively correlated with light availability. Photosynthetic rates declined faster with leaf age in *Cecropia* than *Urera* as predicted by the theory.

2.10 Carbon dioxide and photosynthetic rate in trees

Plant tissue (including wood) is composed of about half carbon, all of which comes from carbon dioxide in the atmosphere. Photosynthesis rates tend to increase as carbon dioxide levels rise,

leading to an increase in dry weight, or biomass, of plants grown under elevated carbon dioxide levels. Compared to plants grown at existing carbon dioxide levels, plants “fertilized” by elevated levels of atmospheric carbon dioxide increase their photosynthesis rates (Norby *et al.*, 1999, Kimball *et al.*, 2002, Nowak *et al.*, 2004). Plants are always CO₂ limited for photosynthesis. CO₂ can enhance photosynthetic rate of C₃ plants over a wide range of concentration when all other environmental factors are optimum. Photosynthetic quantum efficiency of C₃ plants at all irradiation levels increases markedly with CO₂ (Ehleringer and Bjorkman, 1977). This indicates that growth responses may be enhanced at low light intensity and elevated concentrations of CO₂ as observed in wheat (Mac dowell, 1972). In species with C₄ metabolism there was little or no response of photosynthesis on quantum efficiency to an increase in CO₂ (Pearcy and Bjorkman, 1983).

2.11 Wood density

It is commonly accepted to speak of the weight of wood in terms of standard volume. Wood density is therefore defined as the mass per unit volume (kg/m³). It is an important factor that influences the strength of timber (Akpan, 1998). According to Desch (1992), different timbers vary in density from about 160 kg/m³ to 1250 kg/m³. Factors such as rate of growth, site conditions, and genetic composition are responsible for this variation. Due to this variation, knowledge about the density of wood species is required to enhance their optimum utilization.

2.12 Quantification of carbon in trees

Quantification of biomass in trees, in general, is not an easy task. Though there are some studies specific to certain species,

generally in natural forest it is still difficult. Never the less dynamic growth analysis approach has been quite useful in such cases and various models developed are in use. With the global initiative of UNFCCC generation of this information has become very important especially for the carbon trading purpose. Therefore, IPCC has come out with guidelines to employ protocols for such estimations. Employing such general guidelines not only help in maintaining uniformity across the globe but also easy to assess and these protocols are based on a large data base and scientifically developed. There are continuous efforts to further improve these methodologies.

2.13 Conversion factor for estimation of carbon content from biomass value

To estimate the carbon from the standing biomass of trees, a method generally followed. In this method, 50 percent of the fresh weight of the standing biomass is considered as the dry weight of that biomass (Anon., 1996). Therefore, 0.5 is used as factor and is multiplied with the standing biomass while estimating the carbon of the standing biomass. This is used by many workers (Ajay kumar and Singh, 2003).

2.14 Leaf area and its essential importance in growth analysis

Leaf area (LA) is an essential component to estimate plant growth through its incidence on crop physiology mechanisms (Ramesch and Singh, 1989; Portela, 1999; Bhatt and Chanda, 2003). It is used as a variable into Canopy photosynthesis models, training systems evaluation and pruning Practices (Gutirez and Lavín, 2000). In sweet cherry (*Prunus avium* L.), like in other crops, the measurement of LA, both expressed per tree or as Leaf Area Index (LAI), can be a time consuming process (Portela, 1999) and requires

sophisticated electronic instruments, which are expensive especially for developing countries (Bhatt and Chanda, 2003). Moreover, destructive methods may cause inconvenient for some investigations (Chirinos *et al.*, 1997).

Therefore, alternatives to estimate Leaf area on the field may be provided by practical and non-destructive methods (Gutirez and Lavín, 2000). For example, a rapid and non-destructive method to estimate LA is the use of equations that needs leaf dimensions (length and width) as inputs. These have been used for grapevine (Gutirez and Lavín, 2000; Williams and Martinson, 2003), Taro (Hsiu-Ying *et al.*, 2004), common bean (Bhatt and Chanda, 2003), Hyacinth bean (Singh, 1990), Banana (Potdar and Pawar, 1991) and Melon (Chirinos *et al.*, 1997). Such equations allow growers and researchers to estimate LA in relation to other factors like crop load, Drought stress and insect damage (Williams and Martinson, 2003).

It is known that the initial growth rate of seedlings mainly depends on the rapidity with which photosynthesizing area (leaf area) is expanding to generate sufficient photosynthates. Therefore giving emphasis on screening provenances/clones and exploiting existing generic variability for leaf area at nursery stage, and incorporating them in tree improvement programme could be a good approach. Leaf area estimations are also required for growth analysis such as leaf area ratio (LAR) to determine the seedling growth performance and for studying ecophysiology of tree seedlings under nursery situations (Kitajima, 1997). However the issue of estimating total leaf area plant is a practical problem, especially when a large no of provenances/clones are to be examined. To overcome such a difficulty, several methods have been devised for in situ determination of leaf area using regression equation is one of the methods used

(Schneirtr,1978) while some workers calculate leaf area by measuring the length and width of a leaf and multiplying by the product of fixed coefficient (Nanja reddy *et al.*,1995). Nataraja *et al.*, (2003) estimated leaf area of teak by using a constant factor 0.660. However in their study necessary validation was not incorporated as shape and size of teak leaves vary considerably according to the age of the plant.

MATERIAL AND METHODS

III. MATERIAL AND METHODS

India is the land of farmers and villages scattered all over and most often contiguous chain of villages has uniformity spread of green cover with selected trees with multipurpose use. Pongamia and neem are very common trees found in dry land agriculture of our state. Despite the persistent drought the pongamia and neem trees will flourish well in dry regions. In addition to biofuel, these trees provide other resources vital to farming community. Farmers should earn carbon credits for the trees and bushes maintained by them or new native species planted by farming community.

The present investigation was undertaken to estimate the quantity of carbon sequestered by *Azadirachta indica* and *Pongamia pinnata* in plantations. The photosynthetic ability in case of neem and pongamia were looked into by studying the various gas exchange characteristics using IRGA (Infrared Gas Analyzer). In addition to this regression equation or fixed co efficient was developed to estimate the variation of total leaf area across different age gradation. The materials used and method adopted in this study are presented in this chapter.

3.1 Study area

The present investigation was carried out at University of Agricultural Sciences- Bengaluru campus, which is situated at a longitude of 12°58¹ north, longitude of 17° 35¹ east and at an altitude of 930 m above MSL. The average annual rainfall of the experimental area was about 890.9 mm.

Soil of the experiment site:

The topography of the experimental site was fairly uniform with a gentle gradient towards western side. The soil of the experimental site was red sandy loam in texture.

The red sandy loam soil of the experimental site was acidic (pH 5.12-6.21) and normal with respect to salt content (electrical conductivity at 26°C was 0.11-0.16 dSm⁻¹). The organic content was 0.39 percent. The soil was slow in available nitrogen (192.91-254.56kg ha⁻¹), high in available P₂O₅ (117.24 -161.39 kg ha⁻¹) and medium in k₂O content (153.87-200.66 kg ha⁻¹).

Cultivation practices:

Silvicultural practices for neem and pongamia has not been developed in India, but package and practice prescribed by state forest department are followed with a spacing of 5m x 5m.

3.2 Studies carried out and observations recorded

- A. Above ground biomass estimation
- B. Gas exchange studies
- C. Wood density and moisture content
- D. Leaf area measurement

A. Above ground biomass estimation: Following parameters were recorded:

1. Tree height
2. Diameter
3. Canopy size
4. Biomass of branches

B. Gas exchange studies:

1. Photosynthetic rate
2. Stomatal conductance
3. Intercellular carbon dioxide concentration
4. Transpiration rate

C. Wood density and Moisture content:

D. Leaf area measurement:

1. Actual leaf area
2. Measured leaf area

3.3 Above ground biomass

To predict the above ground biomass, amount of carbon stored and the amount of CO₂ removed from atmosphere by *Azadirachta indica* and *Pongamia pinnata* species, twenty trees were randomly selected in each age gradations (2, 5 and 10 years) to estimate the above ground biomass and total carbon sequestered in *Pongamia pinnata* and *Azadirachta indica*. Collar diameter, height of individual trees and canopy size were recorded for 2 and 5 year age species. But for 10 year age species height and diameter at breast height were recorded (Chaturvedi. 1975).

In order to know the proportion of biomass added by different tree component like (primary branch, secondary, tertiary etc and leaves) to the tree, length and diameter of the each branch of individual species were recorded in 5 year age in both species. In each individual species number of leaves was counted and leaf area was calculated. Volume of these species was estimated by recording height and diameter using the formula $V = \pi d^2 / 4 * h$ (Chaturvedi. 1975).



Plate 3.1 An overview of two year old neem plants



Plate 3.2 An overview of two year old pongamia plants



Plate 3.3 An overview of five year old neem trees



Plate 3.4 An overview of five year old pongamia trees



Plate 3.5: An overview of ten year old neem trees



Plate3.6 An overview of ten year old pongamia trees

Destructive sampling was done in 5 year age of both the species to estimate the biomass; both fresh weight and oven dry weight were recorded. Wood densities of both the species were estimated according to the Indian standards (IS). Based on the obtained value of wood density of each species, biomass was estimated by using the formula.

$$\text{i.e. Biomass} = V \times W.D$$

Where,

V= Volume

WD= Wood density

1. Tree height: Height of the twenty randomly selected trees of neem and pongamia in each age gradation (2, 5 and 10 years) was measured using measuring tape (20 m).

2. Stem Diameter: Collar diameter was measured for 2 and 5 year old plants using Calliper and for 10 years age class tree species, diameter was measured at the breast height (DBH).

3. Canopy size: In order to measure the canopy size, Length and width of the crown of twenty randomly selected trees of neem and pongamia were measured by using measuring tape (20 m).

4. Biomass of branches: In order to estimate the biomass added to whole tree by the individual branches, each branch (primary, secondary and tertiary) of individual tree species of neem and pongamia were measured by taking its length and diameter using calliper and tape.

3.4 Gas exchange characteristics

All the gas exchange parameters were measured using portable (IRGA) (Li- COR 6400, Nebraska, USA)

3.4.1 Description of portable photosynthesis system

A portable photosynthesis system (IRGA) (Li-COR 6400, Nebraska, USA) was used for recording gas parameters. Since the instrument operates in an open system, it is possible to maintain steady state CO₂ Concentration and relative humidity in the leaf chamber.

3.4.2 Recording gas exchange parameters: The top fully expanded leaf was clamped to leaf chamber and held perpendicular to the incident light. Relative humidity was maintained at a steady state level equal to the ambient RH to stimulate a condition very similar to that of an ambient air. By altering the flow rates of dry air, it is possible to maintain desirable RH in the leaf chamber. Recording of data was done at saturated light intensities. Keeping in mind the possible diurnal variations of A and g_s all observations were made between 9 am and noon on a bright sunny day.

The instrument gives the following gas exchange parameters.

1. Photosynthetic rate (A) μ moles m⁻² sec⁻¹
2. Stomatal conductances (g_s) mol m⁻² sec⁻¹
3. Transpiration (E) m moles m⁻² sec⁻¹
4. Intercellular CO₂ concentration (c_i) ppm



Plate 3.7: Infrared Gas Analyzer

5. Vapour pressure deficit (VPD) milli bars.

All gas exchange traits were measured under growth conditions by maintaining VPD between 20-30 milli bars. Leaf was clamped in the leaf chamber and once A and gs value were stabilized the data were recorded. IRGA was used to measure the gas exchange parameters like photosynthetic rate, stomatal conductance, intercellular carbon dioxide rate and transpiration. By using the formula ' A/c_i ' *in vivo* carboxylation efficiency was estimated and similarly instantaneous water use efficiency was also calculated using formula ' A/g_s '.

3.5 Estimation of wood density and moisture content

It is commonly accepted to speak of the weight of wood in terms of standard volume. Wood density is therefore defined as the mass per unit volume (Kg/m^3). It is an important factor that influences the strength of the timber. In this research estimation of wood density of neem and pongamia species was carried out to know the biomass added by the each species at different age class.

Plantation of neem and pongamia of five year age was chosen for this experiment. The population consists of 20 trees each, Out of this number, one tree each in both the species were selected and felled. Trees were separated into different components after felling (i.e., branches, trunk, leaves etc.) initial weight of all those components were taken in the field and later they were brought to lab for further work. Therefore due to variation of density along tree trunk, felled tree was divided into three sections and totally six samples were taken from the tree trunk of neem and pongamia. Each wood specimen were cut to sizeable dimension of 2.5 cm x 2 cm x 2 cm for the test in accordance with IS: 1708 (part-1). Prior to density determination, the moisture contents of the test pieces were determined. This was done

by recording wet weight of the samples and thereafter oven drying the wood samples at a temperature of $103^{\circ}\text{C} \pm 2^{\circ}\text{C}$ for 24 hours. After the wood samples have dried, weight of the samples were recorded at the regular interval, using the electronic weighing balance until a constant mass was obtained for each of the wood samples. The moisture content of the wood samples was then determined based on their oven dry weights, using the equation:

$$\text{MC} = \frac{W_1 - W_0}{W_0} \times 100$$

Where: MC=Moisture content of the wood samples (%)

W_1 = Weight of the wood sample at test in gms before drying,
and

W_0 = Oven dry weight of the wood sample in gms.

There after specimens were cut to standard sizes of 6 cm x 2 cm x 2 cm (IS: 1708). Based on these standard sizes their masses were recorded using the electronic weighing balance. In the same vein, the volume of wood specimen in terms of their length, width and height were also measured using a pair of callipers. Densities of the wood samples were then calculated with the equation:

$$\text{Specific gravity at test} = \frac{W_1}{V_1}$$

Where,

W_1 = Weight in gms of test specimen.

V_1 = Volume in cm^3 of test specimen

3.6 Leaf area measurement

Leaf area measurement of tree is a time consuming process and requires sophisticated electronic instruments. The objective of this study was to develop a simple, accurate, non-destructive and time saving predictive model for leaf area (LA) estimation in neem and pongamia. In this study, tree of five year age class of neem and pongamia were selected for recording this parameter. In each population of neem and pongamia, 100 leaves ($n=100$) were selected randomly and detached from the tree. Leaf length (L) was measured as a straight line from the apex to the base of the leaf blade and leaf width (W) was measured across the widest portion of the blade at right angle to the length. The total leaf area was recorded using graphical method and expressed as m^2 . The measured leaf area and product of length and width of leaf was used to develop regression equation (Snedecor and Cochran, 1987) to calculate leaf area. Fixed coefficient (FC) was calculated by using the following formula:

$$FC = (LA / P)$$

Where,

LA= Measured leaf area, and

P = Product of leaf length and width.

3.7 Carbon content

The volume of wood of each species was multiplied with the density of that particular species to obtain the biomass of the tree. In the present study density of the tree was estimated based on the Indian standard (IS: 1708 (part 2)-1986. Standing biomass of the tree species was calculated by using volume and wood density of the

species. Carbon content of wood was taken as 50 percent of the dry weight of the wood (Anon., 1996).

3.8 Analysis of data

The data on growth, volume, biomass and carbon sequestered was analyzed by one Factor Complete randomized Design (One way ANOVA). The data were analyzed using programme on Agreis software and along with that correlation studies were done to know the relationship between the growth parameters in both the species using SPSS Software.

EXPERIMENTAL RESULTS

IV. EXPERIMENTAL RESULTS

Global warming is amongst the most dreaded problems of the new millennium. Carbon emission is supposedly the strongest causal factor for global warming. So, increasing carbon emission is one of today's major concerns, which is well addressed in Kyoto Protocol. Worldwide there are many works done regarding the sequestering ability of different tree species under different climatic condition. Sequestering ability of tree species reported by researchers from all over the world reveals that carbon sequestering ability of tree species varies from species to species, climatic condition and with different age class.

The results of the study conducted to evaluate the carbon sequestration ability of *Azadirachta indica* and *Pongamia pinnata* at different age classes (2, 5 and 10 years) in GKVK, Bengaluru is presented here. The study was carried out,

1. To assess the carbon stock present in the wood of *Azadirachta indica* and *Pongamia pinnata*.
2. To assess photosynthetic ability of *Azadirachta indica* and *Pongamia pinnata*.
3. To classify the species based on their growth behavior & carbon sequestration ability.

In addition, support studies were conducted to develop Regression equation (RE) and a fixed coefficient (FC) to calculate the Leaf Area (LA) of *A. indica* (neem) and *P. pinnata* (pongamia) trees grown in natural conditions.

4.1 Assessing the carbon stock present in the wood of *Azadirachta indica* and *Pongamia pinnata*.

The carbon sequestration assessed based on the data of growth performance of *A. indica* and *P. pinnata* viz., total height (m), diameter(m), volume (m³), above ground biomass (t/ha),etc are presented in this chapter.

4.1.1 Total height (m)

Between the two species, *A. indica* (neem) and *P. pinnata* (pongamia), the total height across 2 year age plants was found maximum in pongamia (0.80m) followed by neem (0.51m). The total height across 5 year age trees was found maximum in neem (2.86 m) followed by pongamia (1.73m). The total height of 10 year age trees was found to be maximum in neem (4.67m) followed by pongamia (4.07m). The growth of tree with respect to height in two species *A. indica* (neem) and *P. pinnata* (pongamia) was found significant. The effect of age on height growth was significant among all age groups (Table 4.1 and 4.2).

Significantly higher total height was recorded in *A. indica* at 5 and 10 year age and *P. pinnata* at 2 year age.

4.1.2 Stem Diameter (m)

The diameter across 2 year age plants was found maximum in *P. pinnata* (0.015m) followed by *A. indica* (neem) (0.011m). The diameter across 5 year age trees was found maximum in neem (0.055m) followed by pongamia (0.044m). The diameter across 10 year age trees was found maximum in neem (0.065m) followed by pongamia (0.060m). The diameter of both the species were found significant. The

effect of age on diameter was significant among all age class (Table 4.1- 4.2).

Significantly maximum stem diameter was observed in *A. indica* at 5 and 10 year age and *P. pinnata* at 2 year age.

4.1.3 Volume (m³)

The volume across 2 year age trees of both the species was found maximum in *P. pinnata* (0.0003m³) followed by neem (0.0001m³). The volume across 5 year age trees was found maximum in neem (0.007m³) followed by pongamia (0.002m³). The volume across 10 year age trees was found maximum in neem (0.017m³) followed by pongamia (0.012m³). The volume of both the species was found significant and the effect of age on volume was significant among in all ages (Table 4.1- 4.2).

Significantly maximum volume was reported in *A. indica* at 5 and 10 year age and *P. pinnata* at 2 year age

4.1.4 Wood density and moisture content of the species

Wood density of the both the species were estimated and based on the results, it was found that density of *P. pinnata* (696.58kg/m³) was more compared to density of *A. indica* (626.21kg/m³). According to Desch (1992), different timbers vary in density from about 160 kg/m³ to 1250 kg/m³. Hence density of pongamia is more compared to neem, it might be because certain factors like rate of growth, site conditions, and genetic composition of the species and within the provenance of same species.

Moisture content of the *P. pinnata* (82.48%) in oven dry method was found to be more compared to neem (52.75%). Similarly in air dry

method the moisture content of *P. pinnata* (71%) was more compared to neem (42%) because in 5 year aged plants formation of heartwood will be less and most of the tissue is attributed to the components of cortex and parenchyma cells in the middle part of the stem that facilitates more moisture content in pongamia than neem. (Table 4.3)

4.1.5 Above ground biomass (t/ha)

The results of the above ground biomass across 2 year age trees was found maximum in *P. pinnata* (0.09 t/ha) followed by neem (0.03 t/ha). The above ground biomass across 5 year age trees was found maximum in neem (1.93 t/ha) followed by pongamia (0.81t/ha). The above ground biomass across 10 year age trees was found maximum in neem (4.33 t/ha) followed by pongamia (3.50 t/ha). (Fig 4.1)

4.1.6 Carbon sequestration (t/ha)

Pongamia of 2 year age trees was found to have higher capacity of sequestering carbon (0.04t/ha) compared to neem (0.01t/ha). The carbon sequestration across 5 year age trees was found maximum in neem (0.96t/ha) followed by pongamia (0.40t/ha). The carbon sequestration across 10 year age trees was found maximum in neem (2.16t/ha) followed by pongamia (1.75t/ha). (Fig 4.2).

Table 4.1 Height, diameter, and volume, of *Pongamia pinnata* in relation to age class.

	Pongamia				
Age (yr)	Height (m)	Diameter (m)	Volume (m³)	Biomass (t/ha)	Carbon (t/ha)
2	0.804	0.015	0.000	0.090	0.045
5	1.739	0.044	0.002	0.816	0.408
10	4.070	0.060	0.012	3.500	1.750
Mean	2.204	0.039	0.005	1.469	0.734
F- value	*	*	*	*	*
S.Em±	0.164	0.003	0.001	0.339	0.169
CD (5%)	0.328	0.007	0.002	0.678	0.339

*Significant at 5% level

Table 4.2 Height, diameter, and volume, of *Azadiractha indica* in relation to age class.

	Neem				
Age (yr)	Height (m)	Diameter (m)	Volume (m³)	Biomass (t/ha)	Carbon (t/ha)
2	0.510	0.011	0.0001	0.031	0.015
5	2.863	0.055	0.0077	1.938	0.969
10	4.601	0.065	0.0173	4.335	2.167
Mean	2.658	0.044	0.0084	2.101	1.050
F-value	*	*	*	*	*
S.Em ±	0.197	0.005	0.0022	0.539	0.269
CD (5%)	0.394	0.010	0.0043	1.079	0.540

* Significant at 5%level

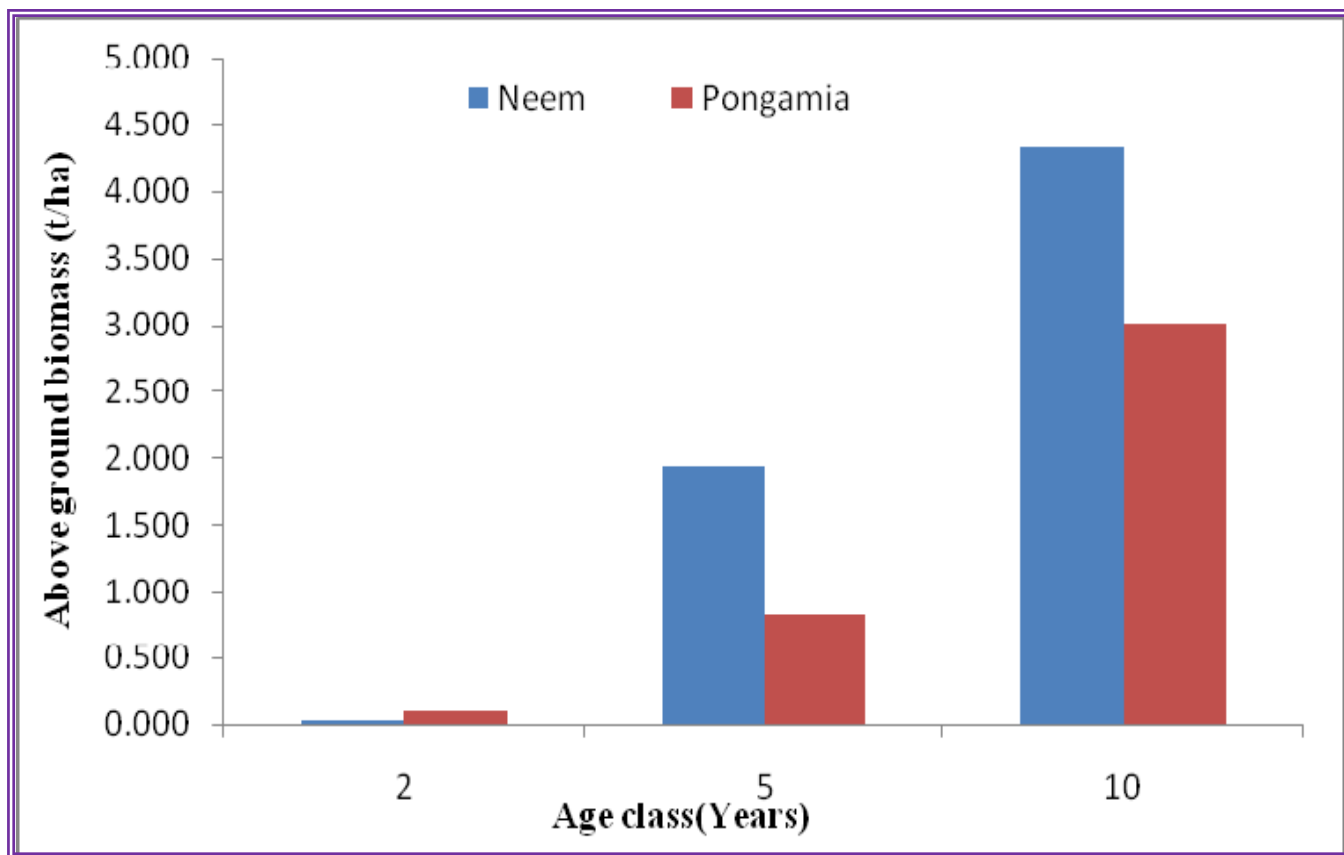


Fig 4.1 Mean above ground biomass (t/ha) of *Azadiractha indica* (neem) and *Pongamia pinnata* (pongamia) in relation to age clas

Table 4.3 Wood density and moisture content of *Azadiractha indica* and *Pongamia pinnata*.

Species	Density of wood (kg/m³)	Moisture content (%)
Neem	626.21	52.75
Pongamia	696.58	82.48

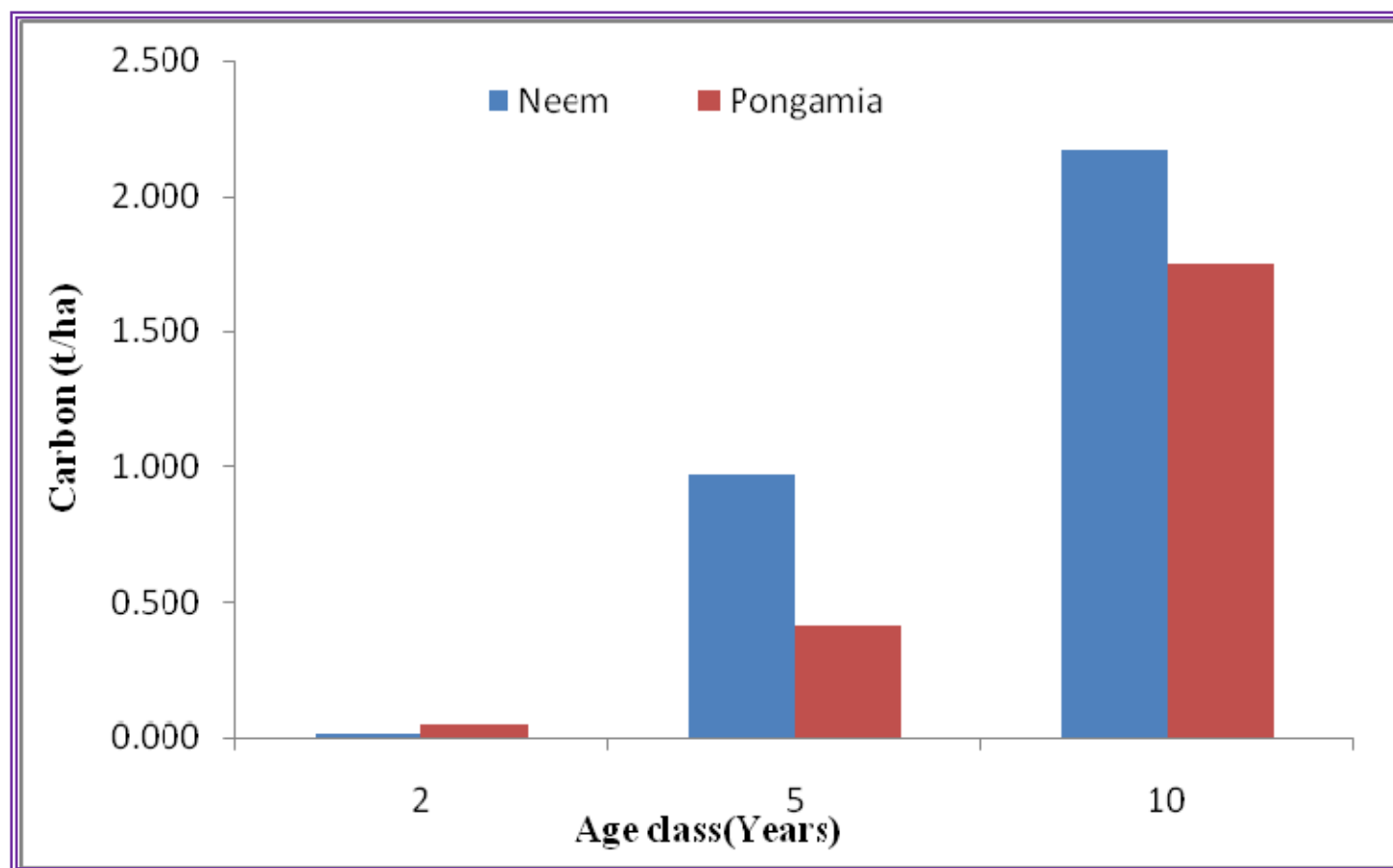


Fig 4.2 Mean Carbon (t/ha) of *Azadiractha indica* (neem) and *Pongamia pinnata* (pongamia) in relation to age class.

4.2 Gas exchange characteristics of *Azadiractha indica* (Neem) and *Pongamia pinnata* at different age class.

The gas exchange characteristics Viz., A, gs, Ci, and Tr of *A. indica* (neem) were studied at different age class. Based on the results obtained it was found that in 2 year age neem plants mean photosynthetic rate was ($11.84 \mu\text{mol m}^{-2}\text{s}^{-1}$) and at 5 year the photosynthetic rate was ($12.00 \mu\text{mol m}^{-2}\text{s}^{-1}$) Among two age group photosynthetic rate was found non significant.

Similarly mean stomatal conductance ($0.132 \text{ mol m}^{-2} \text{ s}^{-1}$) at 2 year old was more compared to stomatal conductance ($0.130 \text{ mol m}^{-2} \text{ s}^{-1}$) at 5 year, Mean intercellular carbon dioxide concentration rate (229.7 ppm) at 5 year was more compared to intercellular carbon dioxide concentration (209.55 ppm) at 2 year, Mean transpiration rate ($3.07 \text{ m moles m}^{-2}\text{s}^{-1}$) at 5 year age was more compared to the transpiration rate ($2.84 \text{ m moles m}^{-2}\text{s}^{-1}$) at 2 year and all these parameters were found non significant. (Table 4.4)

Photosynthetic rate (A), stomatal conductance (gs), Intercellular carbon dioxide rate (Ci) and transpiration rate (E) of *P. pinnata* was studied at 2 and 5 year age class. Based on the results obtained, it was found that in 5 year aged trees, the mean photosynthetic rate ($12.63 \mu\text{mol m}^{-2}\text{s}^{-1}$) of pongamia was more compared to photosynthetic rate ($9.45 \mu\text{mol m}^{-2}\text{s}^{-1}$) at 2 year age and photosynthetic rate was found to differ significantly.

Similarly mean Stomatal conductance ($0.301 \text{ mol m}^{-2} \text{ s}^{-1}$) at 5 year age trees was more compared to Stomatal conductance ($0.200 \text{ mol m}^{-2}\text{s}^{-1}$) at 2 year old, and they are found to be significantly different ($P < 0.005$). Mean intercellular carbon dioxide concentration rate (307.9 ppm) at 5 year aged trees was more compared to

intercellular carbon dioxide concentration (301 ppm) at 2 year, and they were found non significant. Mean transpiration rate ($6.00 \text{ m moles m}^{-2} \text{ s}^{-1}$) at 5 year age trees was more compared to the transpiration rate ($4.11 \text{ m moles m}^{-2} \text{ s}^{-1}$) at 2 year and all those parameters are found to be significantly different ($P < 0.005$). (Table 4.5)

4.3 To classify the species based on their growth behavior & carbon sequestration ability

Among two species *A. indica* and *P. pinnata*, the total height across 2 year old plants was found maximum in pongamia (0.80m) followed by neem (0.51m). The total height across 5 year age trees was found maximum in neem (2.86m) followed by pongamia (1.73m). The total height of 10 year age trees was found to be maximum in Neem (4.67m) followed by pongamia (4.07m). The height growth with respect to two species was found significant statistically. The effect of age on height growth was significant among all age groups.

Significantly maximum total height was reported in *Azadirachta indica* at 5 and 10 year age and *P. pinnata* at 2 year age class.

Diameter in *A. indica* and *P. pinnata*, across 2 year old plants was found maximum in *P. pinnata* (0.015m) followed by neem (0.011m). The diameter across 5 year age was found maximum in neem (0.055m) followed by pongamia (0.044m). The diameter across 10 year age was found maximum in neem (0.065m) followed by pongamia (0.060m). The diameter with respect to two species *A. indica* and *P. pinnata* was found significant. The effect of age on diameter was significant among all age class.

Table 4.4 Gas exchange parameter readings of *Azadiractha indica* (neem) at different age class.

Neem				
Age (yrs)	A	gs	Ci	E
2	11.84	0.132	209.5	2.848
5	12.00	0.130	229.7	3.078
F value	NS	NS	NS	NS
SEm±	4.116	0.051	71.38	1.038
CD at 5% level	11.42	0.143	198.20	2.88

NS-Non significant

Note:

Photosynthetic rate (A) $\mu\text{mol m}^{-2}\text{s}^{-1}$

Stomatal conductance (gs) $\text{mol m}^{-2}\text{s}^{-1}$

Intercellular carbon dioxide rate (Ci) ppm

Transpiration rate (E) $\text{m moles m}^{-2}\text{s}^{-1}$

Table 4.5 Gas exchange parameter readings of *Pongamia pinnata* at different age class.

Pongamia				
Age(yrs)	A	gs	Ci	E
2	9.455	0.200	301	4.11
5	12.63	0.301	307.9	6.00
F value	*	*	NS	*
SEm±	0.111	0.014	3.953	0.396
CD at 5% level	0.309	0.038	10.976	1.099

* Significant

NS : Non significant

Note:

A: Photosynthetic rate ($\mu\text{mol m}^{-2}\text{s}^{-1}$)

gs: Stomatal conductance ($\text{mol m}^{-2}\text{s}^{-1}$)

Ci : Intercellular carbon dioxide rate (ppm)

E: Transpiration rate ($\text{m moles m}^{-2}\text{s}^{-1}$)

Significantly maximum diameter was reported in *A. indica* at 5 and 10 year age and *P. pinnata* at 2 year age class.

Similarly in *A. indica* and *P. pinnata*, the Volume across 2 year old plants was found maximum in *P. pinnata* (0.0003m³) followed by neem (0.0001m³). The volume across 5 year age trees was found maximum in neem (0.007m³) followed by pongamia (0.002m³). The volume across 10 year age trees was found maximum in neem (0.017m³) followed by Pongamia (0.012m³). The volume with respect to two species *A. indica* and *P. pinnata* was found significant. The effect of age on volume was significant among all age class.

Significantly maximum Volume was reported in *A. indica* at 5 and 10 year age and *P. pinnata* at 2 year age class.

The results of above ground biomass across 2 year old plants was found maximum in *P. pinnata* (0.09t/ha) followed by neem (0.03t/ha). The above ground biomass across 5 year age trees was found maximum in neem (1.93t/ha) followed by pongamia (0.81t/ha). Above ground biomass across 10 year age trees was found maximum in neem (4.33t/ha) followed by pongamia (3.50t/ha). Similarly Carbon sequestration capacity in *A. indica* and *P. pinnata*, across 2 year age plants was found maximum in *P. pinnata* (0.04t/ha) followed by neem (0.01t/ha). The carbon sequestration across 5 year age trees was found maximum in neem (0.96t/ha) followed by pongamia (0.40t/ha). The carbon sequestration across 10 year age trees was found maximum in neem (2.16t/ha) followed by pongamia (1.75t/ha. (Table 4.6)

Table 4. 6 Classifying *Azadiractha indica* (neem) and *Pongamia pinnata* (pongamia) based on different growth parameters at different age class.

	Height(m)		Diameter(m)		volume(m ³)		Biomass(t/ha)		Carbon(t/ha)	
Age (yr)	Neem	Pongamia	Neem	Pongamia	Neem	Pongamia	Neem	Pongamia	Neem	Pongamia
2	0.51	0.80	0.01	0.015	0.0001	0.0003	0.03	0.09	0.01	0.04
5	2.86	1.73	0.05	0.044	0.0077	0.0029	1.93	0.81	0.96	0.40
10	4.60	4.07	0.06	0.060	0.0173	0.0126	4.33	3.50	2.16	1.75
Mean	2.65	2.20	0.04	0.039	0.0084	0.0053	2.10	1.46	1.05	0.73
F-value	*	*	*	*	*	*	*	*	*	*
S.Em±	0.19	0.16	0.005	0.003	0.0022	0.0012	0.5393	0.339	0.269	0.169
CD(5%)	0.39	0.32	0.010	0.007	0.0043	0.0024	1.0799	0.678	0.54	0.339

*Significant at 0.05 level

4.4 Contribution of trunk and branches to the total above ground biomass of *Azadiractha indica* and *Pongamia pinnata*

It was observed that in *A. indica* the contribution of trunk (29.94%) towards above ground biomass was more compared to the branches like primary (26.33%), secondary (16.25%), tertiary (8.02%), Quaternary (11.06%), pentanary (11.03%), and hexanary (0.36%). But in *P. pinnata* it was found that contribution of primary branch (29.79%) towards total above ground biomass was more compared to the trunk (15.44%) and rest of the branches like secondary (27.34%), tertiary (16.43%), quaternary (10.75%), and pentanary (0.25%) (Table 4.7).

4.5 Comparison of the *Azadiractha indica* (neem) and *Pongamia pinnata* (pongamia) based on their gas exchange characteristics

The results of gas exchange characteristics of *A. indica* and *P. pinnata* shows that mean photosynthetic rate of *A. indica* ($11.84 \mu\text{mol m}^{-2}\text{s}^{-1}$) at 2 year old plants, was more compared to the pongamia ($9.45 \mu\text{mol m}^{-2}\text{s}^{-1}$). Where as in 5 year old trees the photosynthetic rate of pongamia ($12.63 \mu\text{mol m}^{-2}\text{s}^{-1}$) was superior compared to the photosynthetic rate of neem ($12.00 \mu\text{mol m}^{-2}\text{s}^{-1}$) and it was found to differ significantly in pongamia across age class.

Stomatal conductance for both the species was assessed at 2 and 5 year old trees. Based on the result it was found that stomatal conductance of *P. pinnata* ($0.200 \text{ mol m}^{-2}\text{s}^{-1}$) at 2 year, 5 year ($0.301 \text{ mol m}^{-2}\text{s}^{-1}$) was more compared to the stomatal conductance of *A. indica* ($0.132 \text{ mol m}^{-2}\text{s}^{-1}$) at 2 year, 5 year ($0.130 \text{ mol m}^{-2}\text{s}^{-1}$) and statistically stomatal conductance in *P. pinnata* across ages was found

to be significantly different ($P < 0.005$) and in case of neem across ages, it was found non significant.

Similarly inter cellular carbon dioxide rate (C_i) was more in *P. pinnata* at 2 year old (301 ppm), 5 year old (307.9 ppm) compared to *A. indica* at 2 years (209.5 ppm), 5 years (229.7 ppm) and statistically the result was found to be differ significantly in case of pongamia across age class but in case of neem it was found non significant. Transpiration rate (E) was more in *P. pinnata* at 2 years ($4.11 \text{ mmol m}^{-2} \text{ s}^{-1}$), 5 years ($6.00 \text{ mmol m}^{-2} \text{ s}^{-1}$) compared to *A. indica* at 2 years ($2.84 \text{ mmol m}^{-2} \text{ s}^{-1}$), 5 years ($3.07 \text{ mmol m}^{-2} \text{ s}^{-1}$) and statistically the result was found to be significantly different ($P < 0.005$) in *P. pinnata* across age class and differ significantly. But in case of neem, it was found non significant (Table 4.8).

4.6 Comparison of water use efficiency, in vivo carboxylation efficiency, instantaneous water use efficiency in *Azadiractha indica* (neem) and *Pongamia pinnata* (pongamia) at different age class

It was observed that in 2 year old plants, in vivo carboxylation efficiency was maximum in neem ($0.056 \mu \text{ moles m}^{-2} \text{ s}^{-1}$) compared to pongamia ($0.031 \mu \text{ moles m}^{-2} \text{ s}^{-1}$). In 5 year old trees in vivo carboxylation efficiency was found to be maximum in neem ($0.052 \mu \text{ moles m}^{-2} \text{ s}^{-1}$) compared to pongamia ($0.041 \mu \text{ moles m}^{-2} \text{ s}^{-1}$). (Fig 4.3)

Instantaneous water use efficiency in 2 year old plants was found to be maximum in neem (89.69) compared to pongamia (47.2) and in 5 years instantaneous water use efficiency was found to be maximum in neem (91.85) compared to pongamia (41.96). (Fig 4.4)

4.7 Relationship between photosynthetic rate and stomatal conductance

The leaf photosynthetic characteristics are said to be a very good initial approach to study the response of plants to environmental conditions. In most plants there is strong positive relationship between photosynthesis and stomatal conductance.

In the present study relationship between photosynthetic rate and stomatal conductance rate were assessed in neem and pongamia. There was a positive relationship between the photosynthetic rate and stomatal conductance in case neem with an r value of ($r=0.91$) (Fig.4.5) and similarly in case of pongamia also there is a positive relationship between the photosynthetic rate and stomatal conductance as shown in the (Fig.4.6) ($r=0.75$).

4.8 Instantaneous water use efficiency and carboxylation efficiency in *Azadiractha indica* and *Pongamia pinnata*.

Based on the Photosynthetic rate, stomatal conductance and intercellular carbon dioxide concentration in two species, a few related physiological parameters were assessed. As estimated in neem A/c_i was ($0.056 \mu \text{ moles. m}^{-2}.\text{s}^{-1}$) in 2 year old plants as compared to ($0.052 \mu \text{ mols. m}^{-2}.\text{s}^{-1}$) in 5 year old trees. Similarly in pongamia the A/c_i was ($0.031 \mu \text{ mols. m}^{-2}.\text{s}^{-1}$) in 2 year old plants as compared to ($0.041 \mu \text{ mols. m}^{-2}.\text{s}^{-1}$) in 5 year old trees. (Fig.4.3)

The instantaneous water use efficiency calculated by A/g_s ratio was (89.69) in two year old plants of neem and it was (91.85) in 5 year old trees. Similarly in pongamia the A/g_s ratio in 2 year old plants was (47.27) and (41.96) in case of 5 year old trees as shown in the figure. (Fig. 4.4)

Table 4.7 Percentage contribution of trunk and branches to the total above ground biomass in *Azadiractha indica* (neem) and *Pongamia pinnata* (pongamia).

Neem		Pongamia	
Branches	Percentage (%)	Branches	Percentage (%)
Primary	26.33	Primary	29.79
Secondary	16.25	Secondary	27.34
Tertiary	8.02	Tertiary	16.43
Quaternary	11.06	Quaternary	10.75
Pentanary	11.03	Pentanary	0.25
Hexanary	0.36	Trunk	15.44
Trunk	26.94		

Table 4.8 Comparison of *Azadiractha indica* (neem) and *Pongamia pinnata* (pongamia) based on Gas exchange characteristics at different age class.

	Neem	Pongamia	Neem	Pongamia	Neem	Pongamia	Neem	Pongamia
Age (yrs)	A		gs		Ci		E	
2	11.84	9.455	0.132	0.200	209.5	301	2.848	4.11
5	12.00	12.63	0.130	0.301	229.7	307.9	3.078	6.00
F value	NS	*	NS	*	NS	NS	NS	*
S.Em±	4.116	0.111	0.051	0.014	71.38	3.953	1.038	0.396
CD @ 5%level	11.428	0.309	0.143	0.038	198.20	10.976	2.88	1.099

NS-non significant *Significant at 5% level

Note: Photosynthetic rate (A), Stomatal conductance (gs), Intercellular carbon dioxide rate (Ci),
Transpiration rate (E)

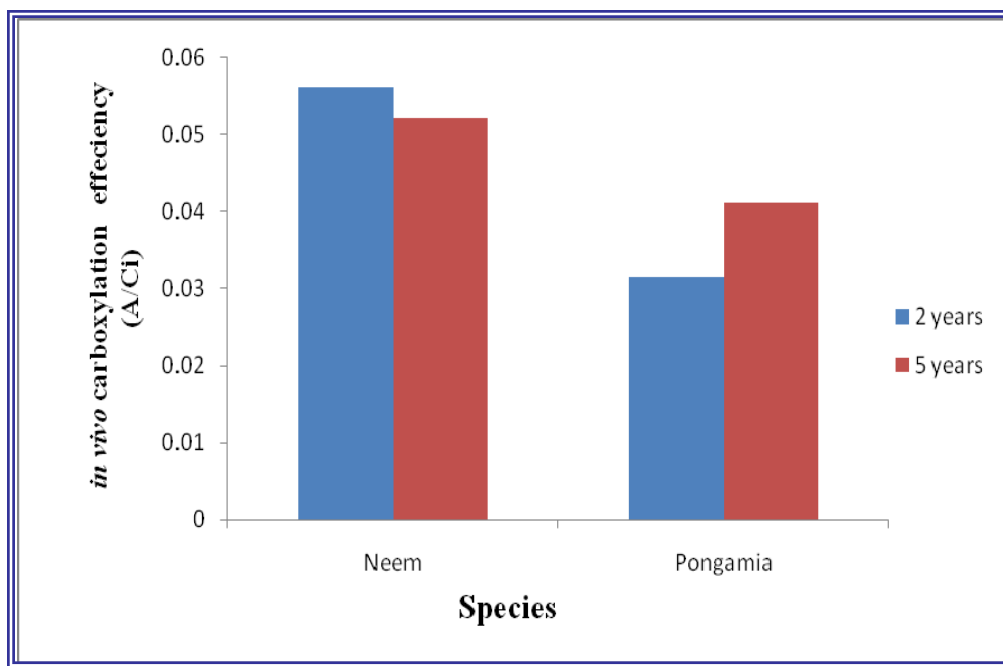


Fig 4.3 *In vivo* Carboxylation efficiency of neem and pongamia across 2 and 5 year age class

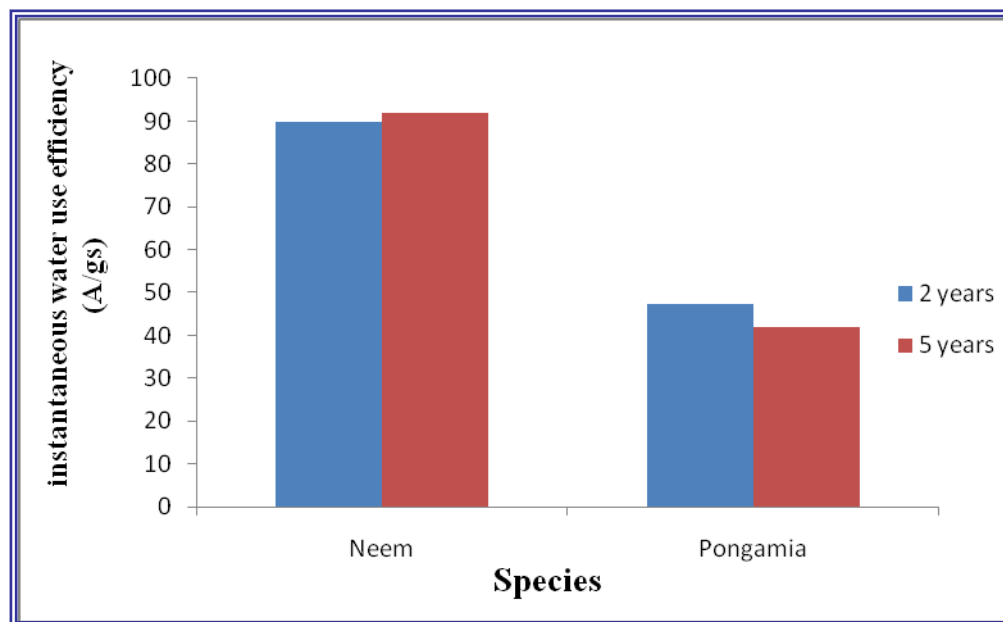


Fig 4.4 Instantaneous water use efficiency of neem and pongamia across 2 and 5 year age class.

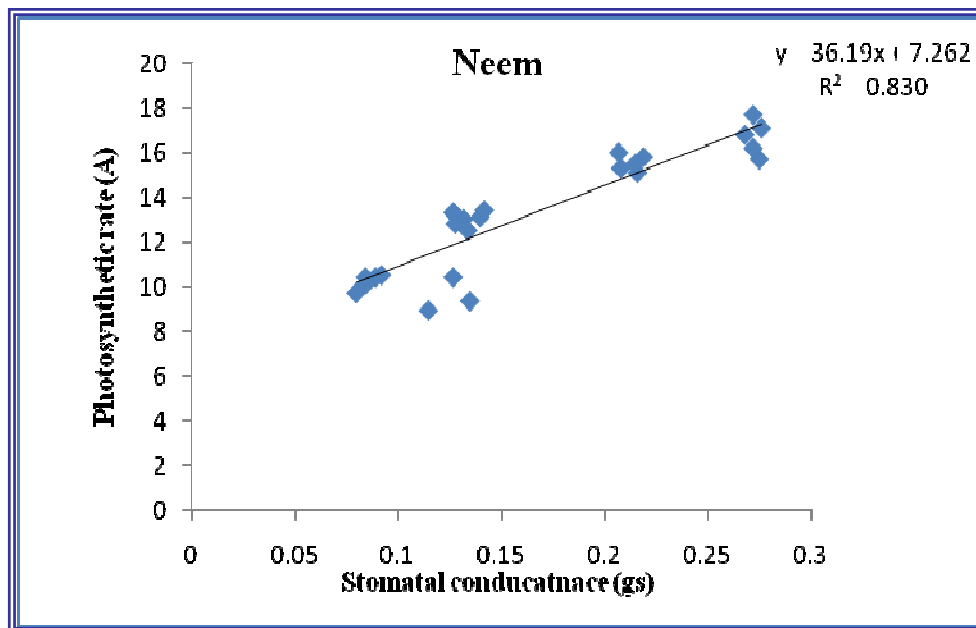


Fig 4.5 Relationship between the photosynthetic rate (A) and stomatal conductance (gs) in neem.

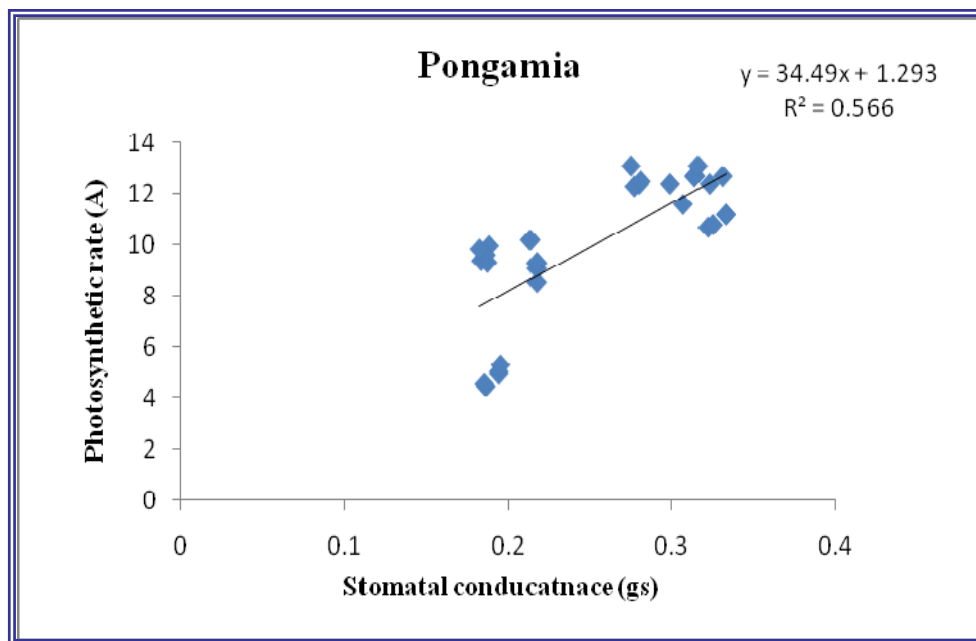


Fig 4.6 Relationship between the photosynthetic rate (A) and stomatal conductance (gs) in pongamia.

4.9 Correlation studies

Data on correlation co-efficient between Growth parameters- (Diameter, height, volume and biomass) for 2, 5 and 10 year age old *Azadiractha indica* (neem) and *Pongamia pinnata* (pongamia) were discussed as follows.

4.9.1 *Azadiractha indica* (neem)- 2 years

In 2 year age volume-diameter (0.748) is positively correlated and significant at 1% level. Biomass-height (0.637) is moderately positively correlated and they are statistically significant at 5% level. Whereas Diameter - height (0.028) are not at all correlated and they are non- significant (Table 4.9).

4.9.2 *Pongamia pinnata* (pongamia)- 2 years

Data on Correlation co-efficient between Growth parameters- (Diameter, Height, Volume and Biomass) for 2 year aged *Pongamia pinnata* (pongamia) were presented below.

In 2 year age plants volume-diameter (0.929) is positively correlated and significant at 1% level. Biomass-height (0.555) is moderately positively correlated and they are statistically significant at 5% level. Whereas diameter-height (0.249) are not at all correlated and they are non-significant (Table 4.10).

**Table 4.9 Correlation Co-efficient between the growth parameters
in *Azadiractha indica* - 2 years**

n=13

Growth Parameters	Correlation
Height v/s diameter	0.028
volume v/s diameter	0.748**
Biomass v/s Height	0.637*

**Significant at 0.01 level.

*Significant at 0.05 level

**Table 4.10 Correlation Co-efficient between the growth
parameters in *Pongamia pinnata*- 2 years**

n=13

Growth Parameters	Correlation
Height v/s diameter	0.249
volume v/s diameter	0.929**
Biomass v/s Height	0.555*

**Significant at 0.01 level.

*Significant at 0.05 level

4.9.3 *Azadiractha indica* (neem)-5 years

Data on correlation co-efficient between growth parameters- (Diameter, height, volume and biomass,) for 5 year aged *Azadiractha indica* (Neem) were observed as below.

In 5 year age, volume-diameter (0.968) is positively correlated and significant at 1% level. Biomass-height (0.845) is moderately positively correlated and they are statistically significant at 1% level. Whereas Diameter-height (0.734) are just correlated and they are significant at 1% level (Table 4.11).

4.9.4 *Pongamia pinnata* (pongamia)-5 years

Data on correlation co-efficient between growth parameters- (Diameter, height, volume and biomass,) for 5 year aged *Pongamia pinnata* (Pongamia) were presented below.

In 5 year age volume-diameter (0.934) are positively correlated and significant at 1% level. Biomass-height (0.781) is moderately positively correlated and they are statistically significant at 1% level. Whereas Diameter-height (0.574) are just correlated and they are significant at 1% level (Table 4.12)

Table 4. 11 Correlation Co-efficient between the growth parameters in *Azadiractha indica* (neem) - 5 years

n=20

Growth Parameters	Correlation
Height v/s diameter	0.734**
volume v/s diameter	0.968**
Biomass v/s Height	0.845**

**Significant at 0.01 level

Table 4.12 Correlation Co-efficient between the growth parameters in *Pongamia pinnata*-5 years

n=20

Growth Parameters	Correlation
Height v/s diameter	0.574**
volume v/s diameter	0.934**
Biomass v/s Height	0.781**

**Significant at 0.01 level

4.9.5 *Azadiractha indica* (neem)- 10 years

Data on correlation co-efficient between Growth parameters- (Diameter, height, volume, biomass, and carbon) for 10 year old *A. indica* were as follows.

In 10 year age volume-diameter (0.972) are positively correlated and significant at 1% level. Biomass-height (0.429) height-diameter (0.245) are not correlated and they are statistically found non significant (Table 4.13).

4.9.6 *Pongamia pinnata* (pongamia)-10 years

Data on correlation co-efficient between Growth parameters- (Diameter, height, volume, and biomass) for 10 year old *P. pinnata* (Neem) were presented below.

In 10 year age volume-diameter (0.910) are positively correlated and significant at 1% level. Biomass-height (0.242), height-diameter (0.150) is not correlated and they are statistically non significant (Table 4.14).

Table 4.13 Correlation Co-efficient between the growth parameters in *Azadiractha indica* (neem)- 10 years

n=20

Growth Parameters	Correlation
Height v/s diameter	0.245
volume v/s diameter	0.972**
Biomass v/s Height	0.429

**Significant at 0.01 level

Table 4.14 Correlation Co-efficient between the growth parameters in *Pongamia pinnata*-10 years

n=20

Growth Parameters	Correlation
Height v/s diameter	0.150
volume v/s diameter	0.910**
Biomass v/s Height	0.242

**Significant at 0.01 level

4.10 Experiment to develop Regression equation (RE) and a fixed co-efficient (FC) to calculate the leaf area (LA) of *Azadirachta indica* (neem) and *Pongamia pinnata* (pongamia)

Leaf area measurement can be a time consuming process and requires sophisticated electronic instruments. The objective of this study was to develop a simple, accurate, non-destructive and time saving predictive model for leaf area (LA) estimation in neem and pongamia. In this study a regression equation (RE) and a fixed coefficient (FC) was developed to calculate the Leaf area (LA) of neem and pongamia trees grown in natural conditions. The regression equation, Leaf area (LA) = $L \times W \times 0.6585 - 0.9828$ for pongamia and Leaf area (LA) = $L \times W \times 0.465x + 0.8781$ for neem was derived by taking actual leaf area as dependent variable and product of L and W as independent variable ($r = 0.97$ for Pongamia and $r = 0.86$ for neem.) The fixed co efficient calculated by taking the ratio of actual to product of L and W was found to be 0.634 for pongamia and 0.572 for neem. The equation and coefficient was validated and was found significant. The study indicates that either FC or RE can be used with precision to determine LA of neem and pongamia grown in natural condition, non-destructively. This type of short cut, rapid method is highly useful when a large number of provenances are to be tested or in places where instrumentation facility is not available (Fig 4.7-4.10).

4.10.1 Estimation of total leaf area in neem and pongamia

In present study non destructively regression equation was estimated for each species. The leaf area regression equation for neem Leaf area (LA) = $L \times W \times 0.465x + 0.878$ and regression equation Leaf area (LA) = $L \times W \times 0.6585 - 0.9828$ for pongamia was obtained and it was

found to slightly significant and there was a change in leaf area factor due to change in leaf shape. Using the factor total leaf area was estimated in trees belong to different age class. As expected there was higher leaf area in 5 year old plant compared to 2 year. The total leaf area in pongamia (0.367m^2) in 2 years, (0.626m^2) across 5 year was higher compared to the neem (0.072m^2) in 2 years and (0.122m^2) 5 years as shown in the figure.(Fig.4.11)

DISCUSSION

V. DISCUSSION

Tree borne oil seeds are the ray of hope for biodiesel production in India. Cultivation of pongamia and neem on farmland is not a new concept; it is a age old practice to grow one or two trees of pongamia and neem in dry land agricultural system. These two species are multipurpose trees and yield timber, oil as medicine and biofuel, cake and is used as organic manure. Amongst many species, which yield oil a source of energy in the form of bio-fuel, *Pongamia pinnata* and *Azadiractha indica* has been found to be one of the most suitable. In India pongamia is also known as N₂-fixing tree, not browsed by animals. These trees can be planted on degraded lands, farmer's field boundaries, wastelands / fallow lands. Neem an indigenous species known for its drought resistance. Normally it thrives in areas with sub-arid to sub-humid conditions with an annual rainfall between 400 and 1200 mm. Growth rate of neem is slow in initial stages and a height of 6-12 m may be expected in 20 years and has the ability to grow under varied agro climatic condition. *Pongamia pinnata* is a deciduous legume tree that grows to about 15-25 meters in height with a large canopy. The tree grows in wide range but well-adapted to arid zones and has many traditional uses.

Global warming is the most dreaded problem of the new millennium. Carbon emission is supposedly the strongest causal factor for global warming. So, increasing carbon emission is one of today's major concerns, which is well addressed in Kyoto Protocol. The Kyoto protocol is a 1997 international treaty that took effect in 2005 which currently bind ratifying nations to a similar system, with the UNFCCC setting caps for each nation. Kyoto protocol provides for this facet of its cap and trade program with the Clean Development Mechanism (CDM). The CDM, as well as joint implementation provide flexible

mechanisms to aid regulated entities in their compliance with their caps.

In October 2003, powerguda a village in Andhra pradesh became an environmental pioneer when it sold the equivalent of 147t of carbon dioxide in verified emission reduction to the World Bank. The emission reduction was calculated on the basis of 51t of Pongamia oil substituting for petroleum diesel over 10 years. Powerguda's action has inspired several other neighboring villages to plant Pongamia trees on a large scale.

India ranks 6th in terms of consumption of energy, which is 3.5% of the total world's commercial energy. The current consumption of diesel in India is about 40 mt (40% of the total petroleum product consumption), the demand is growing at a rate 5.6% per annum. Hence there will be a huge gap between demand and supply which needs to be met through increasing fuel imports or increasing production of biodiesel through developing biodiesel plantations without sacrificing the food security of the country. Biodiesel is renewable energy resource generated from rehabilitation of waste and degraded lands.

The present investigation entitled 'Evaluation of carbon sequestration ability of *Azadirachta indica* and *Pongamia pinnata*' is an attempt to throw some light on this aspect which is of global concern.

The results obtained in this study are discussed under the following headings.

1. Carbon stock present in the wood of *Azadirachta indica* and *Pongamia pinnata*.

2. Photosynthetic ability of *Azadirachta indica* and *Pongamia pinnata*.
3. Classify the species based on their growth behavior and carbon sequestration ability.

5.1 Carbon stock present in the wood of *Azadirachta indica* and *Pongamia pinnata*.

Climatic factors like moisture, rainfall, temperature, humidity affect the vegetation of which, the factor- rainfall plays a prominent role in each of the site conditions (Dwivedi, 1992). In the present study the analysis of variance showed significant effect of age on various parameters such as height, diameter, volume, biomass accumulation and carbon sequestration in *Azadirachta indica* and *Pongamia pinnata*. Where as gas exchange characteristics in *Azadirachta indica* and *Pongamia pinnata* were non significant. The age gradation has exhibited significant effect on all parameters. A comparison made with *Azadirachta indica* and *Pongamia pinnata* across different ages (2, 5 and 10 years) exhibited significant difference with respect to all of the parameters. The responses of *Azadirachta indica* and *Pongamia pinnata* at different age with respect to growth, biomass accumulation, carbon sequestration, and gas exchange characteristic to the broad variation in climatic factors within a narrow geographical area are found to be significant across parameters examined.

In case of *Pongamia pinnata* the height (0.80m), diameter (0.015m), volume (0.0003m³), biomass (0.09t/ha), and carbon sequestered in wood (0.045t/ha) across 2 years was more compared to height (0.51m), diameter (0.011m), volume (0.0001m³), biomass (0.03t/ha), and carbon sequestered in wood (0.015t/ha) of *Azadirachta indica* across 2 years. This is because in initial stages the growth rate

in neem is slow compared to pongamia (Jha., 1990) and it produces less leaves in the early ages. This might be the probable reason due to which growth rate of neem in 2 years is less compared to pongamia.

Performance of *Azadiractha indica*, with respect to height (2.86m), diameter (0.055m), volume (0.007m³), biomass (1.93t/ha), and carbon sequestered in wood (0.969t/ha) across 5 years was more comparable to the height (1.73m), diameter (0.044m), volume (0.002m³), biomass (0.81t/ha), and carbon sequestration in the wood (0.408t/ha) of pongamia. Five year age neem overtook pongamia because rate of growth in neem is slow in initial stages but later growth enhances, as neem produces deep tap root and where as pongamia produces lateral roots. Tap root helps the neem to acquire more nutrients, water from the deeper layer of the soil.

Similarly the results of *Azadiractha indica* with respect to height (4.6m), diameter (0.065m), volume (0.017m³), biomass (4.33t/ha) , and carbon sequestered in wood (2.16t/ha) across 10 years was more compared to the height (4.07 m), diameter (0.06 m), volume (0.012 m³), biomass (3.50t/ha), and carbon sequestered in the wood (1.75t/ha). Pongamia tolerate the drier condition for shorter period. The results on studies carried out on six tree species clearly showed that the average consumption of water/g/of biomass was 0.51 for the *Eucalyptus terticonis*, compared to 1.30 for *Derris indica* (Chaturvedi. 1994.). But in case of neem it produces deep tap root, which helps it to over come drought condition and still enhance growth.

In the present study the growth rate in case of neem is slow compared to pongamia may be it's because of less total root volume in the initial stage, where in it may affect the uptake/absorption of nutrients and moisture. Since both neem and pongamia are grown

under unique spacing of 5m x 5m, plant density does not have any impact on the growth of the species.

5.1.1 Wood density and moisture content of the species

Wood density of the both the species were estimated and based on the results, it was found that density of *Pongamia pinnata* (696.58kg/m³) was more compared to density of *Azadiractha indica* (626.21kg/m³). According to Desch (1992), different timbers vary in density from about 160 kg/m³ to 1250 kg/m³. Hence density of pongamia is more compared to neem, it might be because certain factors like rate of growth, site conditions, and genetic composition of the species and within the provenance of same species.

Moisture content of the *Pongamia pinnata* (82.48%) in oven dry method was found to be more compared to neem (52.75%). Similarly in air dry method the moisture content of *Pongamia pinnata* (71%) was more compared to neem (42%) because in 5 year aged plants formation of heartwood will be less and most of the tissue is attributed to the components of cortex and parenchyma cells in the middle part of the stem that facilitates more moisture content in pongamia than neem.

Salient findings from the biomass estimation in present study indicate that various factors influence the growth performance of a species in a locality. Among them soil and climatic factors play a major role and in certain cases plants like pongamia and neem adapt themselves to any harsh condition.

Similar results in pongamia with respect to growth studies was noticed compared to the work done by Shivanna *et al.*, (2006) on *Pongamia pinnata* seedlings at different growth intervals of 8, 16, 24th

months observations. With respect to height, gbh, crown diameter during 16 and 24 month the mean crown height, girth and crown diameter was recorded as 3.1, 0.19, 1.5 m and 2.89, 0.24, 1.98m respectively and growth parameters like biomass yield, carbon sequestered during 8th 16th and 24th months were 4.23, 2.11, 8.06 and 4.03, 12.40, 6.20 tones of 'C'/ha respectively. There is a slight variation in the results obtained from the shivanna *et al.*, compared to present studies at the age of 2 years (24 month) interval because growth of pongamia vary with respect to climatic condition, site factors, soil condition and rainfall patterns in that region. Whereas pongamia grown in the present study across 2 years was found to be growing with other species like Jathropa, Simarouba, competition might have affected it growth rate at the intial stages.

The results with respect to height and dbh of 2, 5 and 10 years were similar with the findings of Banerjee (1973) at the age of 6 and 10 years and Sugur (1989) in *Acacia auriculiformis* at the age of 6 years. Similar results on the better performance of *Acacia auriculiformis* under a moderate rainfall of 1300 to 1400 mm per annum was observed by Webb *et al.* (1984) in *Acacia auriculiformis* in Australia. Tewari (1992) reported that, teak thrives well within an annual rainfall range of 1000-1500 mm. The report on *Acacia auriculiformis* showed that the species grows best in a humid climate, with rainfall of 1000 mm or up to 1800 mm and a dry period of 6 months (Kushalapa, 1988). The studies conducted on the growth performance of the teak at the age of 19 years suggests that the growth and yield attributes were superior, where the rainfall ranges from 1500-2000 mm compared to the two sites having the rainfall ranges of 1250-1500 mm and 2000-5000 mm (Aparanji, 2000).

The results obtained on biomass were similar compared to the findings on the biomass accumulation of *Eucalyptus tereticornis* of less than 3 year to 9 year old plantation in different agro-ecological regions of India. In dry tropical region biomass accumulation was more in cooler areas as compared to warmer areas water was not the limiting factor comparatively higher mean annual temperature of around 25°C seems to produce higher biomass. Vijay Rawat and Negi (2000), Siva Kumar *et al.* (2000) reported that rubber plantation accumulated a good proportion of biomass of age crossing their juvenile stage of growth and average proportion of biomass was relatively good in Northeastern India.

A similar result on the carbon sequestered was reported in the north eastern regions of India in rubber plantation accumulating 72.36 tons of carbon from one hectare by 27 year old plantation (Sivakumar *et al.* 2000). The results with respect to carbon sequestered were similar to the findings of Shivanna *et al.* (2006) at the growth intervals of 8, 16, 24th month observations in *Pongamia pinnata* seedlings. It is apparent from the present investigation that the performance of *Azadiractha indica* and *Pongamia pinnata* with respect to various parameters such as total height, diameter, volume, above ground biomass and carbon sequestered were more affected by moisture availability in the initial years (2 and 5 years) and by fertility build up (soil organic carbon) in later years (10 years).

Research findings from the overseas revealed that similar type of work on carbon sequestration in American chestnut at different sites consistently exhibited the largest mean growth in almost every category at every age on every site. This data demonstrates the significance within individual species of planting density and site quality on productivity and corresponding rates of carbon uptake.

These variable factors also make direct comparisons regarding carbon uptake among species planted under different densities difficult. Regardless of these limitations, the results from this study demonstrated that the American chestnut's ability to sequester carbon compares favorably with any other species in this region. (Diamant, 2005).

The results with respect to carbon sequestration were similar with the findings of (Loretta Gratani and Laura Varone., 2005). Their work revealed that total carbon sequestration is 84 ± 12 and 111 ± 9 Kg year⁻¹ of CO₂ for the small *Quercus ilex* and *Quercus pubescens* tree size, respectively, and 151 ± 10 and 185 ± 7 Kg year⁻¹ of CO₂ for the large *Quercus ilex* and *Quercus pubescens* tree size, respectively. *Quercus pubescens*, by its higher total photosynthetic leaf surface area (39% higher than *Quercus ilex*) and its higher mean yearly photosynthetic rates (48% higher than *Quercus ilex*) seems to have a greater role than *Quercus ilex*. However, taking into account the leaf longevity (i.e. 12 ± 3 months for *Q. ilex* and 4 ± 2 months for *Q. pubescens*), the evergreen species, by its continuous photosynthetic activity, contributes to reduce CO₂ throughout the year, and in particular during the winter months, when traffic volume has a pick, than *Q. pubescens*. On the whole, results of the present suggest that the evergreen and deciduous trees play a major role in sequestering CO₂ and reducing air temperature in the city of Rome, and there by delaying global warming. Nevertheless, there is a tradeoff between greater sequestration by *Q. ilex* versus *Q. pubescens* by the presence of leaves throughout the year, and also in winter, when the traffic has the highest picks (Loretta Gratani and Laura Varone, 2005).

Many studies on carbon sequestration ability of trees were done world wide in different species, age gradations, and different climatic

conditions. Research all over the world reveals that carbon sequestering ability of tree species vary from species to species and site conditions. (Table 5.1)

Table 5.1: Different research works on carbon stock per hectare.

Species	Age (Years)	Carbon stock (t/ha)	References
<i>Eucalyptus grandis</i>	2	9.15	Bradstock, 1981
<i>Eucalyptus fastigata</i>	4	30.9	Madgwick <i>et al.</i> , 1981
<i>Eucalyptus nitens</i>	4	40.9	Madgwick <i>et al.</i> , 1981
<i>Eucalyptus globules</i>	4	15.15	Cromer <i>et al.</i> , 1975
<i>Eucalyptus teriticornis</i>	4	17.8	Ahimana and Maghembe, 1987
<i>Eucalyptus diversicolor</i>	4	15.65	Grove and Malajczuk., 1985
<i>Eucalyptus grandis</i>	5	26.6	Bradstock, 1981
<i>Eucalyptus saligna</i>	5	50.68	Whitesell, <i>et al.</i> , 1988
<i>Shorea robusta</i>	6	5.22	<i>Jana et al.</i> , 2009
<i>Albizzia lebbek</i>	6	6.26	<i>Jana et al.</i> , 2009
<i>Tectona grandis</i>	6	7.97	<i>Jana et al.</i> , 2009
<i>Artocarpus integrifolia</i>	6	7.28	<i>Jana et al.</i> , 2009
<i>American chestnut</i>	8	2.07	Diamant, A., 2005
<i>Black walnut</i>	8	2.25	Diamant, A., 2005
<i>Red oak</i>	8	0.41	Diamant, A., 2005
<i>American chestnut</i>	12	6.28	Diamant, A., 2005
<i>Black walnut</i>	12	4.77	Diamant, A., 2005
<i>Red oak</i>	12	3.96	Diamant, A., 2005
<i>Azadiractha indica</i>	2	0.015	Present study
<i>Azadiractha indica</i>	5	0.96	Present study
<i>Azadiractha indica</i>	10	2.16	Present study
<i>Pongamia pinnata</i>	2	0.04	Present study
<i>Pongamia pinnata</i>	5	0.40	Present study
<i>Pongamia pinnata</i>	10	1.75	Present study

Earlier estimates by different scientists were higher than our estimate. The reasons for low carbon stock as estimated by my work may be due to: consideration of only above ground biomass, and worked in similar agro-climatic areas. Earlier works were estimated mostly based on aboveground and below ground carbon biomass, considered different age groups, different species and different agro-climatic areas, for which carbon stock per hectare may be in higher side. But still *Azadiractha indica* and *pongamia pinnta* over takes red oak with respect to carbon sequestration across 5 years. Similiarly *A.indica* across 10 years has more sequestering capacity compared to *American chestnut*. Pongamia and neem are very common trees found in dry land agriculture of our state. Despite the persistent drought the pongamia and neem trees will flourish well in dry regions. In addition to biofuel, these trees provide other resources vital for farming community like seed cake, used as bio pesticide etc. In general, it can be said that neem and pongamia are multipurpose trees. From the present study carbon sequestering capacity of neem and pongamia were estimated, keeping this information in future farmers can go for carbon trading as mentioned in the Kyoto protocol. With the progress of the forest stand ages, canopy cover and biomass of the trees will experience more rapid growth to a certain age (20 - 50 years) and the carbon held by these plants will also increase more biomass carbon stock to its optimum level (Marland and Marland, 1992).

Based on the results obtained from the correlation studies between growth parameters (Height, diameter, volume, and biomass) across 2, 5 and 10 years age in *Azadiractha indica* and *Pongamia pinnata* revealed that there was a positive correlation between the volume and diameter across different age gradation respectively and biomass- height are found to be moderately correlated in 2 and 5 year age gradation. Since carbon present in the wood stock is assumed to

be half of the biomass according to the IPCC. It is likely that there will be a positive correlation between the carbon-biomass.

5.2 Gas exchange characteristics

Analysis of growth and yield parameters in perennial plants requires experiments of long duration. To overcome the difficulties associated with long experimentation, a certain physiological process directly linked to growth can be analyzed. Photosynthesis is one of the major processes associated with growth and hence analysis of photosynthesis can give sufficient information on growth performance of tree crops. (Nataraja and Jacob, 1999). There are reports indicating the relation of photosynthetic measurements in growth analysis (Nataraja and Jacob, 1999). From this context in the present study attempts were made to analyze the photosynthesis performance of different age class (2 and 5 years) of *A. indica* and *P. pinnata*.

In the gas exchange studies in two species, it was found that photosynthetic rate ($11.84 \mu\text{moles m}^{-2}\text{sec}^{-1}$) across 2 year old plants in neem was high compared to pongamia ($9.455 \mu\text{moles m}^{-2}\text{sec}^{-1}$). Similarly in case of 5 year old trees the photosynthetic ability of pongamia ($12.63 \mu\text{moles m}^{-2}\text{sec}^{-1}$) was high compared to ($12.00 \mu\text{moles m}^{-2}\text{sec}^{-1}$) Neem. Stomatal conductance of pongamia across 2 year ($0.200 \text{ mol m}^{-2} \text{ sec}^{-1}$), 5 year ($0.301 \text{ mol m}^{-2} \text{ sec}^{-1}$), was more compared to the stomatal conductance of *A. indica* in 2 year ($0.132 \text{ mol m}^{-2} \text{ sec}^{-1}$), 5 year ($0.130 \text{ mol m}^{-2} \text{ sec}^{-1}$) respectively. Similarly the intercellular carbon dioxide rate in pongamia across 2 year (301ppm), 5 year (307.9 ppm) was more compared to *A. indica* at 2 years (209.55 ppm), 5 year (229.7 ppm) and transpiration rate in *P. pinnata* across 2 year ($4.11 \text{ mmol m}^{-2}\text{sec}^{-1}$), 5 year ($6 \text{ mmol m}^{-2}\text{sec}^{-1}$) was more compared to *A. indica* at 2 year ($2.84 \text{ mmol m}^{-2}\text{sec}^{-1}$), 5 year ($3.07 \text{ mmol m}^{-2}\text{sec}^{-1}$).

In the present study, instantaneous water use efficiency and *in vivo* carboxylation efficiency were assessed and it was observed that *in vivo* carboxylation efficiency in neem across different age class was high compared to pongamia as shown in the figure (Fig 4.3 and 4.4).

Higher carboxylation efficiency indicates better ability of plants to fix carbon and hence plants with high carboxylation efficiency are always preferred. Another parameter which is generally computed from gas studies is instantaneous water use efficiency estimated as A/g_s . From the present study indicates that neem has better ability to fix carbon per unit amount of water loss through transpiration and in the present study it is likely that high stomatal conductance (g_s) contributes for the high transpiration rate in the species.

From the present study it was noticed that stomatal conductance (g_s) seems to be the major factor responsible for determining photosynthesis in neem and pongamia. Photosynthesis is said to be a biochemical process and often regarded as diffusive process also. The rate of diffusion is controlled by two factors. One, the stomatal conductance and second the intercellular carbon dioxide rate. With increase in stomatal conductance rate there will be increase in photosynthetic rate. In case of 2 year old neem photosynthetic ability was more compared to *Pongamia pinnata*. Though the conductance rate in case of pongamia is high still higher photosynthetic rate was noticed in neem because in some plants there will be poorly developed mesophyll tissue and the lower correlation value between photosynthesis and stomatal frequency, so that despite a high density of stomata, the photosynthesis rate is not very high throughout the day.

Transpiration rate in case of pongamia was high compared to neem across age gradation. We can see that in case of 5 year old trees

of pongamia and neem transpiration rate was maximum compared to 2 year old plants. It is because in case of 5 year old trees root penetration will go very deep so that it accumulate more water and nutrients, due to this water use efficiency will be more in case of 5 year old trees compared to 2 year old plants. From the present study it was observed that transpiration rate is more in case of pongamia compared to neem.

Data on Photosynthetic ability of neem were found to be similar compared to the study on Variation in net photosynthesis, CO₂ exchange parameters, stomatal characteristics, leaf area and seedling dry weight investigated among 10 provenances of neem (*Azadirachta indica* A. Juss.). Significant provenance variation was established for net photosynthesis (8.14 to 15.13 $\mu\text{mol m}^{-2} \text{s}^{-1}$), Stomatal conductance (0.37 to 0.59 $\text{mol m}^{-2} \text{s}^{-1}$), Stomatal density (145 to 204 $\text{mol m}^{-2} \text{s}^{-1}$), and total guard cell length (2681 to 3873 μm). Net photosynthesis was positively correlated with whole-plant dry weight and leaf area. Stomatal density was positively correlated with net photosynthesis, whole-plant dry weight, and leaf area. Total guard cell length was positively correlated with all of these traits. Information on six traits was used in a cluster analysis to construct a dendrogram to assess phenetic relationships among the provenances. With a few exceptions, the dendrogram revealed three major clusters grouped according to rainfall distribution. The study indicated that whole-plant phytomass production of neem seedlings was associated with photosynthesis and stomatal characteristics during the early stages of growth (Kundu, et al., 1999).

McCree and Davies (1974) have shown that Stomatal sensitivity to decreasing leaf water potential may depend on availability of water to the plant during growth. It is therefore important in any controlled

environment work that realistic growth conditions should be selected. Stomatal conductance in pongamia across age gradation was more compared to neem because the plants are sensitive to water stress. Though both neem and pongamia were grown in dry area, leaf water potentials of the species decreases. Stomatal conductance and net photosynthesis were reduced at higher levels of plant water stress.

5.3 Estimation of leaf area as a parameter for growth analysis

Leaves are very important component of any tree and they are the sites for photosynthesis which intern helps in growth and development of whole tree. Total leaf area of a tree need to be known for growth and biomass studies. In the Present Study non-destructive method was used to develop the leaf area regression equation for neem (leaf area = $L \cdot W \cdot 0.465x + 0.8781$) and the leaf area regression equation for pongamia (Leaf area = $L \cdot W \cdot 0.6585 - 0.9828$). The relationship was found to be slightly significant ($P < 0.001$; $R^2 = 0.94$ for pongamia and $R^2 = 0.75$ for neem). As there was variation in the leaf factor between two species due to change in the leaf shape of the neem. Where as pongamia has compound pinnate leaves with the pointed end, which doesn't vary much in shape.

Using this factor total leaf area was estimated in trees belonging to different age class. As expected there was high leaf area in 5 year old plants compared to 2 year old. The total leaf area in pongamia was more compared to neem. Initial growth rate of trees depend on rate of development of leaf area or photosynthetic area. It is likely that the high proportion of biomass allocated to leaf can result in better growth due to overall increment in canopy photosynthesis. Therefore estimated leaf area is very critical while assessing the growth. Based on the present study it is possible to conclude that the leaf area factor can be estimated for individual species and used to arrive for total leaf

area in a non destructive way. In early stage of plant development 2 year old plants of pongamia had showed higher leaf area compared to neem which has resulted in increase in biomass however such relation was not noticed, it may be due to various other reasons .In addition to canopy photosynthesis, canopy respiration also contributes for biomass gain therefore total canopy alone be considered while correlating growth rate.

Results on the regression equation to measure leaf area developed for Neem and Pongamia were similar to the findings of (Nataraja *et al.*, 2003) in teak (*Tectona grandies*) grown in nursery. Where the regression equation, leaf area = $(L*W)*0.543+2.967$, was derived and was found significant in different provenances.

5.3.1 Practical implication of results:

1. From the present investigation it can be said that carbon sequestration potentials are high in *Azadiractha indica* compared to *Pongamia pinnata* at different age groups. So by planting these species farmers can reap additional benefits like trading carbon and one can sell the seeds in the market which are used to extract the oil and used as biofuel/insecticide.
2. In Kyoto protocol it is mentioned that there should be a system to reward farmers for planting and conserving native plant species. Hence it is important to quantify the carbon in native tree species.
3. Regression equation has been developed for *Azadiractha indica* and *Pongamia pinnata*. So that in future by using that regression equation leaf area of both the species can be measured without using any instrument.
4. By afforesting the trees with respect to climate change, we could reduce and mitigate the adverse effect on environment.

5.3.2 Future line of work

1. From the literature it is found that no study has been made to assess the carbon sequestering capacity of *Pongamia pinnata* and *Azadiractha indica* plantations in India. Elsewhere in the world there are only few studies reported.
2. *Azadiractha indica* and *pongamia pinnata* are relatively fast growing species of short rotation period, the biomass and carbon sequestration studies in diverse conditions with reference to zone and age are required to be studied on a large scale.
3. Since carbon sequestration is a major tool for reducing global warming in various sectors, hence emphasis on research should be given in the multi disciplines of Forestry, Agro forestry Agriculture etc.
4. Carbon sequestration studies could be strengthened by application of remote sensing in natural forests and plantations.
5. The soil analysis should be done to know the soil organic carbon Storage (t/ha) at various localities.
6. The modern method of litter and soil analysis for carbon should be followed for natural forest and plantation species.

SUMMARY

VI. SUMMARY

In the present study *Azadirachta indica* and *Pongamia pinnata* each under three different age gradations (2, 5 and 10 years) were evaluated for various parameters such as growth, volume, above ground biomass and carbon sequestered in trees.

1. To assess the carbon stock present in the wood of *Azadirachta indica* and *Pongamia pinnata*.
2. To assess photosynthetic ability of *Azadirachta indica* and *Pongamia pinnata*.
3. To classify the species based on their growth behavior & carbon sequestration ability.

In the present investigation, the analysis of variance showed significant effect on various parameters such as total height, diameter, form factor, volume, above ground biomass and carbon sequestration in *Azadirachta indica* and *Pongamia pinnata*.

1. Assessment of Carbon stock present in the wood of *Azadirachta indica* and *Pongamia pinnata*.

➤ The growth parameters of pongamia of 2 years age are higher than neem but in 5th and 10th year the growth parameter are higher in neem compared to Pongamia.

➤ Wood density and moisture content were assessed and from the present study the wood density of pongamia was higher compared to neem. Similarly, moisture content of pongamia was higher compared to neem.

2. **Assessment of photosynthetic ability of *Azadirachta indica* and *Pongamia pinnata*.**

➤ The gas exchange characteristics of *Azadirachta indica* in 2 years and 5 years revealed that mean photosynthetic rate of *Azadirachta indica* was high in case of 2 years compared to *Pongamia pinnata*. In case of 5 years *Pongamia* has more photosynthetic rate compared to neem and it was found to differ significantly in case of *Pongamia* across different age class.

➤ Stomatal conductance for both the species were assessed at 2 and 5 year age class, results revealed that stomatal conductance of *Pongamia pinnata* across 2 and 5 year age gradation was high compared to the stomatal conductance of *Azadirachta indica* and statistically stomatal conductance in *Pongamia pinnata* was found to be significantly different ($P < 0.005$) and it was non significant in *Azadirachta indica*.

➤ Intercellular carbon dioxide rate (C_i) across 2 and 5 years was high in *Pongamia pinnata* compared to *Azadirachta indica* and statistically the result was found non significant. Transpiration rate (E) was more in *Pongamia pinnata* at 2 and 5 years compared to *Azadirachta indica* and the result were found to be statistically significant, ($P < 0.005$) in *Pongamia pinnata* and non significant in *Azadirachta indica* across different age class.

➤ It was found that in 2 and 5 year plantation the *in vivo* carboxylation efficiency was found to be maximum in neem compared to *Pongamia*.

➤ The instantaneous water use efficiency was found to be maximum in neem across 2 and 5 years compared to *Pongamia*.

3. **Classification of the species based on their growth behavior & carbon sequestration ability.**

➤ Among two species *Azadirachta indica* and *Pongamia pinnata*, the growth parameters of *Pongamia pinnata* of 2 year age more compared to neem. But in 5th and 10th year growth of neem has over took pongamia.

➤ Based on the gas exchange studies, it was found that in 2 year age plants photosynthetic rate is more in neem compared to pongamia and in 5 years pongamia has over took neem with respect to photosynthetic ability. Similarly the stomatal conductance, intercellular carbon dioxide rate, transpiration rate was higher in pongamia across ages compared to neem. Water use efficiency and in vivo carboxylation efficiency across 2 and 5 years were more in *Azadirachta indica* compared to and *Pongamia pinnata*. Similarly it was found that stomatal conductance, intercellular carbon dioxide rate across 2 and 5 years were more in *Pongamia pinnata* compared to *Azadirachta indica*.

➤ Correlation studies between growth parameters (height, diameter, volume, and biomass) across 2, 5 and 10 years age in *Azadirachta indica* and *Pongamia pinnata* revealed that there was a positive correlation between the volume and diameter across ages and biomass and height are found to moderately positively correlated across 2 and 5 age gradation and found non significant in 10 year age gradation.

➤ The regression equation, Leaf area (LA) = $L \cdot W \cdot 0.6585 - 0.9828$ for pongamia and Leaf area (LA) = $L \cdot W \cdot 0.465x + 0.8781$ for neem was derived by taking actual leaf area as dependent variable and product of L and W as independent variable ($r = 0.97$ for pongamia and

$r = 0.86$ for neem.) The fixed coefficient calculated by taking the ratio of actual to product of L and W was found to be 0.634 for pongamia and 0.572 for neem. The equation and coefficient was validated and was found significant. The study indicates that either FC (fixed co-efficient) or RE (regression equation) can be used with precision to determine LA (leaf area) of neem and pongamia grown in natural condition, non-destructively.

➤ The total leaf area in pongamia across age class was high compared to the neem.

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INTRODUCTION

I.INTRODUCTION

It is generally accepted that forests can play a critical role in capturing and storing large amounts of carbon from the atmosphere and can thus contribute to reducing the buildup of atmospheric carbon dioxide. Despite their relatively fast growth, it has been suggested that tropical plantations are a small sink of atmospheric carbon because they occupy a relatively small area in relation to other vegetation types and land uses worldwide (Brown *et al.*, 1986). The area of plantations annually planted in the tropics is currently, 10% of the simultaneously deforested area, and tree planting currently compensates for 0.3% (at most) of the carbon released by deforestation (Bruenig 1996). To have a significant impact as a global Carbon sink, plantations would need to be established on an unprecedented scale (Sedjo 1989, Myers and Goreau 1991, Houghton 1996). However, rates of reforestation and afforestation worldwide are likely to grow over the next decades as many countries seek to compensate for the loss of natural forests, and thus the role of plantations in sequestering may also increase (Gladstone and Ledig 1990, Rotmans and Swart 1991, Houghton 1996). Several exotic and indigenous tree species growing in a variety of tropical environments should be tested with respect to their rates of growth and biomass accumulation, especially those that produce good quality timber, which results in longer-term storage of the fixed carbon.

Global warming is amongst the most dreaded problems of the new millennium. Carbon emission is supposedly the strongest causal factor for global warming. So, increasing carbon emission is one of today's major concerns, which is well addressed in Kyoto Protocol. Trees are amongst the most significant elements of any landscape, both due to biomass and diversity. Their Key role in ecosystem dynamics is well known. However, it is paradoxical that the vegetation has undergone destruction and degradation in the modern times due

to industrial and technological advancement achieved by human society. This advancement has resulted in emission of carbon in the ecosystem. Therefore, there is need to address environmental issues related to them. Trees are important sinks for atmospheric carbon i.e. carbon dioxide, since 50% of their standing biomass is carbon itself (Ravindranath *et al.*, 1997).

Afforestation and other forest management options to sequester Carbon in tropical latitudes may fail unless they address local economic, social, environmental, and political needs of people in the developing world (Cairns and Meganck 1994, Houghton 1996). Tree plantations are a source of cash, savings, and insurance for the individual farmers (Chambers and Leach, 1990).

On the other hand; fast growing tropical tree plantations incorporate considerable amounts of nutrients in their biomass over a relatively short period of time. Site fertility declines can limit sustained plantation forestry in tropical regions: soil fertility can be decreased through excessive removal of living biomass, particularly if nutrients in tree crowns are lost through harvest or site preparation (Jorgensen and Wells 1986, Perry and Maghembe 1989). This can be particularly serious when plantations are established on soils that are inherently poor. Therefore, examination of the role of tropical plantations as Carbon sinks necessitates integrative approaches to evaluate not only the rates of Carbon sequestration by different tree species, but also their design and management to minimize potential deleterious effects on ecosystem nutrients and to make plantations economically, socially, and environmentally sound land use Options.

Neem and Pongamia trees are grown commercially in plantations to extract chemicals or alkaloids from the seeds and leaves. Azadirachtin has been promoted as a new insecticide that is

considered more 'Environment friendly' than synthetic insecticides. Plantations have been established in tropical to subtropical regions of the world, including semi-arid and wet tropical regions, from sea level to about 700 m elevation (NRC 1992). Those advocating the planting of Neem as a commercial crop cite a wide range of potential benefits. Some go as far as saying Neem is 'a tree for solving global problems' (NRC 1992).

Amongst the many species, which can yield oil as a source of energy in the form of bio-fuel, *Pongamia pinnata* has been found to be one of the most suitable species in India being widely grown, it is N₂-fixing tree, not browsed by animals and oil is non-edible. The fast growing nature, capacity to adapt and thrive well in different agro climatic conditions had led to the use of pongamia for afforestation programme in India.

With the above information in background, the present study was conducted with the following objectives;

- 3.** To assess the carbon stock present in the wood of *Azadirachta indica* and *Pongamia pinnata*.
- 4.** To assess photosynthetic ability of *Azadirachta indica* and *Pongamia pinnata*.
- 3.** To compare the species based on their growth behavior and carbon sequestration ability.

REVIEW OF LITERATURE

II. REVIEW OF LITERATURE

2.1 Global Climate Change

Although we are currently concerned about global warming caused by anthropogenic activities, the Earth's climate has fluctuated many times in the past in response to natural mechanisms of climate change. Such changes in global climate have also occurred over much longer time scales, from hundreds to millions of years. In fact the current global warming trend which began at the end of the 19th century spans only a tiny fraction of the Earth's climatic history. Taking a longer perspective on climate variability can help us gain a better understanding of the global climate and of the evolution of the climate today and in the future.

The overall state of the global climate is largely determined by balance between energy the Earth receives from the Sun and the heat which the Earth releases back to space, called the global energy balance. Many causes of climate change involve processes that alter the global energy balance. The enhanced greenhouse effect is a potential cause of climate change because the extra quantities of greenhouse gases put into the air by mankind trap more heat in the atmosphere. This upsets the global energy balance and causes a rise in global surface temperature. Although most scientists agree that global warming is the result of the enhanced greenhouse effect, natural processes can also upset the global energy balance in this way, causing similar rises in global temperature. A change in the amount of energy received by the sun for example has often been proposed as the cause of global warming. The challenge facing scientists is to establish beyond doubt a link between global warming and man-made greenhouse gas pollution.

Unlimited human demand has resulted in over exploitation of natural resources. There are many evidences to show the increasing consumption of fossil fuels, population growth, industrialization and forest clearance, which is strongly correlated with the increasing global CO₂ concentration (Rotty and Maryland, 1986; Bazzaz, 1990, Bowes, 1993). There will always be uncertainty in understanding a systems complex as the world's climate. However there is now strong evidence that significant global warming is occurring. The evidence comes from direct measurements of rising surface air temperatures and subsurface ocean temperatures and from phenomena such as increases in average global sea levels, retreating glaciers, and changes to many physical and biological systems. It is likely that most of the warming in recent decades can be attributed to human activities (IPCC, 2001). This warming has already led to changes in the Earth's climate.

The existence of greenhouse gases in the atmosphere is vital to life on Earth. In their absence average temperatures would be about 30 centigrade degrees lower than they are today. But human activities are now causing atmospheric concentrations of greenhouse gases including carbon dioxide, methane, troposphere ozone, and nitrous oxide to rise well above pre-industrial levels. Carbon dioxide levels have increased from 280 ppm in 1750 to over 375 ppm today higher than any previous levels that can be reliably measured (i.e. in the last 420,000 years). Increasing greenhouse gases are causing temperatures to rise; the Earth's surface warmed by approximately 0.6° C over the twentieth century. The Intergovernmental Panel on Climate Change (IPCC) projected that the average global surface temperatures will continue to increase to between 1.4° C and 5.8° C above 1990 levels, by 2100.

2.2 Climate change negotiation

During the last quarter of the 20th century there was a buzz of research activities. This was largely to understand the influence of increased carbon dioxide concentration on plant response. The consensus that clearly emerged from these studies is that, there is an unprecedented increase in carbon dioxide concentration in the atmosphere and will bring about changes in the biosphere. In the light of these studies consolidation of views at global level was felt very urgent in reaction and the following developments started taking place.

2.3 Genesis of UNFCC

Increasing scientific evidence of human interference with the climate system, coupled with growing public concern over global environmental issues, began to push climate change onto the political agenda in the mid-1980s. Recognizing the needs of policymakers for authoritative and up-to-date scientific information, the World Meteorological Organization (WMO) and the UN Environment Programme (UNEP) established the Intergovernmental Panel on Climate Change (IPCC) in 1988. In 1990, the IPCC issued its First Assessment Report, confirming that human-induced climate change was indeed a threat and calling for a global treaty to address the problem.

In May 1992 international climate change negotiators agreed to the United Nation Framework Convention on Climate Change (UNFCC) which was signed at earth summit held at Rio de Janeiro (Anon., 1992). The main objective of the convention was stabilization of Green house gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with climate

system. The convention has given targets, to industrialized countries and economies in transition, to reduce their respective green house gas emissions to their 1990 level by 2000, but it was not very effective.

2.4 Genesis of Kyoto protocol

When they adopted the Convention, governments knew that its commitments would not be sufficient to seriously tackle climate change. At COP 1 (Berlin, March/April 1995), in a decision known as the Berlin Mandate, Parties therefore launched a new round of talks to decide on stronger and more detailed commitments for industrialized countries. After two and a half years of intense negotiations, the Kyoto Protocol was adopted at COP 3 in Kyoto, Japan; on 11 December 1997. This has been a landmark achievement in the international climate change negotiations, well known as Kyoto protocol. Under this protocol, developed countries are required to reduce their collective, carbon dioxide to at least 5.2 percent below their 1990 emission levels by 2012. Recognizing the need of the developing and least developed countries to have more industries for their development, the protocol does not bind these countries by any emission reduction targets during the first commitment period i.e. 2008-2012 (Anon., 1996).

2.5 Carbon sequestration

Plants absorb carbon from the atmosphere in the process of photosynthesis, some part of absorbed carbon is released back into the atmosphere and the remaining portion is stored in the form of biomass. In this natural process the sequestered carbon dioxide will be converted into biomass. But trees, in general, are considered as major

sink of carbon because they retain carbon for longer duration, and also believed to be a closed system with little leakage. Therefore carbon sequestration is basically withholding carbon in some safe form other than the gaseous form in the atmosphere and as long possible. The carbon absorbing capacity is high in the initial stages of plant when growth rate is high and it declines towards maturity.

A massive tree- planting program will have to be accompanied by a parallel effort to stop further deforestation. Globally large areas of already deforested lands remain available for reforestation (i.e. they have not been taken up for permanent settlement by human communities); there could be 5-7.6 million km² deforested lands available for productive use (Myers and Goreau, 1991)

If we consider that a fast growing tree plantation produces 20 ton biomass per ha per year, then it can sequester 10 ton of atmospheric carbon per ha per year (because roughly half the plant growth is made of carbon). Therefore, to fix 1Gt (Giga ton) of carbon from the atmosphere we need to plant trees on 100 million ha (1millionkm²) per year. In addition to reforestation of natural forested areas, we should concentrate on afforestation of marginal lands; water shed area, and urban areas. With a little care the trees grown under these areas can be made to sequester a huge amount of carbon as they continue grow.

For a successful evergreen revolution we need to involve all sections of the society including the farmers. In Costa Rica money grows trees says one of the recent issues of New Scientist (Pearce., 1998). The American and Norwegian businesses are about to pay farmers there to plant trees on their land. The farmer's job is to let the trees grow! The companies will pay the farmers \$10 for every tone of carbon that tree absorb from the atmosphere during photosynthesis.

In turn, the companies will get certificates (carbon credits) declaring that they have paid for CO₂ to be removed from the atmosphere. This kind of strategies must be developed in all developing countries where pollutants from industries are reaching the atmosphere at an alarming rate.

Enhancing carbon sequestration through different land use options to mitigate global warming is being undertaken in a big way in many countries. Optimal use of land and other natural resources for sustainable Management to create carbon sinks are major aims of this exercise by the governments and many other agencies working towards this goal.

2.6 Carbon sequestration and Indian scenario

Bhadwal and Singh (2002) have attempted to predict the carbon sequestration scenario in India from the year 2000, as base year, to a Situation during the year 2050 through a model developed by World Resources Institute. The authors have looked at carbon Sequestration potential in three scenarios, namely the economically feasible, the business as usual (BAU) and the potential scenario. The results depict a rosy picture of the country, indicating there would be a two-fold increase in the rate of annual carbon sequestration from 5.273 billion tons (bt) during the Year 2000 to over 10.5 bt/year in BAU, 11.92 bt/year and 12.21 bt/year in potential Scenario.

Ravindranath *et al.* (1997) estimated flows from the foresters are projected the same for the year 2011 (Table 2.1). They projected the future carbon flows in two separate conditions i) business as usual ii) favorable scenario. In the former condition, they assumed that the existing carbon absorption and release by forests remain same, where as in latter case they assumed that the condition are modified to help

the carbon absorption from the atmosphere like, increased short term and long term forestry projects, increased productivity of forest, more and more use of nonconventional energy sources instead of biomass plants, advanced stoves for household etc.

In the same study, they also estimated the net emission of carbon from the forest sector of India. For the year 1986 the gross emission from deforestation in that year, plus committed emission from deforestation in the preceding years, was estimated to be 64×10^6 t of carbon. The carbon sequestration (or net woody biomass accumulation in trees for long term storage) from the area brought under tree plantations and the existing forest area under forest succession was estimated to offset the gross carbon emission in India, leading to no net emission of carbon from the forest sector. Medium term projections for India (for the year 2011) show that under a business as usual scenario at current rates of afforestation, projected carbon emission would continue to be balanced by sequestration.

**Table 2.1: Carbon flows-current and future scenarios in India
(10⁶t)**

Carbon flux	1986	2011 Business as usual	2011 Favorable scenario
Carbon storage			
-Forest			
Vegetation	4179	4179	4186
Soil	5399	5399	5399
-Plantation	-	850	1181
-Perennials	-	75	3000
-Natural regeneration	-	-	1096
Total	9528	10503	14856
Carbon uptake			
-Forest	68.7	68.87	68.87
-Natural regeneration	-	00.23	09.38
-Afforestation	-	27.00	37.50
-Reforestation	-	-	75.00
Total	68.7	96.10	190.75

(Source: Ravindranath *et al.*, 1997)

2.7 Biomass accumulation & carbon sequestration in trees

Mahendranath Subedi (2004) conducted above ground biomass studies of *Quercus semecarpifolia* in temperate forests of Nepal. Above ground tree layer biomass was found to be 479.17, 357.53, 462.60,

358.02, 272.15 and 304.21 t/ha from east to west directions in temperate forest respectively.

Deva Kumar *et al.* (2007) conducted a study on the comparative assessment of biomass production in three different landscapes. Biomass production was highest in coffee plantations (468 t/ha) and least in the natural forests (94.5 t/ha).

Vijay Rawat and Negi (2004) revealed that *Eucalyptus tereticornis* biomass varied from 11.9 t/ha in three year old plantation to 146 t/ha in 9 year old plantation in moist regions. In dry tropical region it varied 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 cooler areas as compared to warmer areas. Where water is not the limiting factor comparatively higher mean annual temperature of around 25°C seems to produce higher biomass.

Roy *et al.* (2006) reported that eight year old trees of *Melia azedarach* planted in single line (2m apart) at Indian Grass land and Fodder Research Institute (IGFRI), Jhansi. The trees contributed a total biomass production of 21.11 t/ha of which 66, 24 and 10 per cent were contributed by minor timber, firewood and fodder respectively.

Jana *et al.* (2009) conducted research in 6 year old trees of *shorea robusta*, *Albizzia lebbek*, *Tectona grandis*, and *Artocarpus integrifolia*. Study revealed that the annual carbon sequestration rate from ambient air were estimated at 8.97 t C ha⁻¹ by *Shorea robusta*, 11.97 t C ha⁻¹ by *Albizzia lebbek*, 2.07 t C ha⁻¹ by *Tectona grandis* and 3.33 t C ha⁻¹ by *Artocarpus integrifolia*. The percentage of carbon content (except root) in the aboveground biomass of *Shorea robusta*, *Albizzia lebbek*, *Tectona grandis* and *Artocarpus integrifolia* were 47.45,

47.12, 45.45 and 43.33, respectively. The total aboveground biomass carbon stock per hectare as estimated for *Shorea robusta*, *Albizia lebbek*, *Tectona grandis* and *Artocarpus integrifolia* were 5.22, 6.26, 7.97 and 7.28 t C ha⁻¹, respectively in these forest stands.

Verma *et al.* (2006) conducted a study in nine year old energy plantation consisting of *Eucalyptus tereticornis*, *Melia azedarch* and *Leucaena leucocephala* at four planting densities viz. 5000, 10000, 15000 and 20000 plants/ha. Above ground biomass computed on mean tree and per ha basis differed significantly with the species and density. The contribution of leaf, branch and stem to mean tree biomass irrespective of the species and plant densities varied from 4.11 to 5.21, 16.19 to 25.84 and 69.89 to 79.72 respectively.

To estimate the dry matter from the standing biomass of trees, generally the volume of the wood is multiplied by the density of the specific species of the wood. However density of all the species across the globe may not be available. In order to accumulate such issue IPCC has recommended to use 50 per cent of the fresh weight of that biomass (Anon, 1996, Ajay Kumar. and Singh., 2003).

After converting the volume of wood into biomass, the next step would be to find out the carbon content in the biomass. The carbon content of the different part of the plant has been found to vary to a certain extent. But in general 50% of the biomass is taken as carbon content for all the carbon estimation (Anon, 1996 and Mac Dicken, 1997).

Siva Kumar *et al.* (2000) focused on the potentials of rubber plantations in carbon sequestration and presented some economic models, which could form the basis for the smart partnership between land owners downstream manufactures and global multinationals for

the purpose of sustainable rubber cultivation. Carbon sequestration from one hectare 27 year old stand of rubber tree was 72.36 tones. The major portion was sequestered in the trunk and primary branch comprising of 21.6 and 18.9 tons respectively. The result showed that sequestration capacity among different organs, highest carbon sequestration of 88 per cent was found in the latex vessels, leaves and twigs have carbon content of 53.8 per cent other woody tissue is trunk and branches.

Udaya Morabad *et al.* (2006) quantified the carbon sequestration in harvested wood of Kodagu District in Karnataka for a period of 13 years (1992 to 2004). He found that totally $373.88 \times 10^9 \text{ m}^3$ (114.9 Gg 'C') of wood was removed from the district, out of which was 58.74 Gg 'C' was fixed in the form of wood products.

Significant difference was recorded in *Pongamia pinnata* seedlings at different growth intervals of 8, 16, 24th months observations. With respect to height, gbh, crown diameter during 16 and 24 month the mean crown height, girth and crown diameter was recorded as 3.1, 0.19, 1.5 m and 2.89, 0.24, 1.98m respectively and growth parameters like biomass yield, carbon sequestered during 8th 16th and 24th months were 4.23, 2.11, 8.06 and 4.03, 12.40, 6.20 tonnes of 'C'/ha respectively (Shivanna *et al.*, 2006).

2.8 Carbon stock present in Wood

Trees are the major sinks of CO₂ and many scientists have measured carbon content using different method. Elias and Polvin (2003) measured the carbon content in woods of 32 tropical broad leaved trees and found carbon content ranging from 44.4% to 49.4%. Lamloom and Savidge (2006) analyzed the heartwood of 19 conifers and 22 broadleaved trees and they reported that conifers (47.21%-55.20%)

had somewhat higher carbon content than broadleaved species (46.27%-49.97%). These reports suggest that variations in Carbon content between species should be taken into account for accurate evaluation of carbon sequestration in trees and forests.

Variations in carbon content in wood among 102 clones, selected from almost the entire natural distribution area, were investigated in *Larix kaempferi*. The average carbon content was 50.50%, 50.94%, and 50.80% in sapwood, heartwood, and whole wood, respectively. (Eitaro Fukatsu *et al.*, 2006). Negi, *et al.*, (2003) reported that wood, which constitutes maximum portion of total biomass, stored maximum amount of carbon. While comparing the different life forms, it was observed that the maximum carbon is stored in the order of conifers > deciduous > evergreen > bamboos. Thus it can be said that the conifers are more efficient in carbon sequestration.

Carbon content showed statistically significant variation among species, ranging from 48.4% to 51.0%. The volatile Carbon fraction was non-negligible, averaging 2.2%, and showed high variation among species. Studies found that wood Carbon content was appreciably higher in conifer than hardwood (angiosperm) species ($50.8 \pm 0.1\%$ vs. $49.5 \pm 0.2\%$, respectively). Wood carbon density (gC/cm^3) showed very high inter-specific variation, due to differences in wood specific gravity (Thomas *et al.*, 2007).

Fuel wood harvest and consumption in a sustainable manner and decay of wood will not make any net CO_2 contribution assuming that the system remains in equilibrium (Singh *et al.*, 1997).

2.9 Photosynthetic ability of trees

Wood production declines as forest age. Decrease in production has been attributed to higher respiration associated with increasing biomass but direct measurement fails to support this assumption. An alternate hypothesis is that growth decline is caused by reduced net photosynthesis. To test this hypothesis, (Yoder *et al.*, 1994) compared the net photosynthetic rate of foliage from trees that had seized height growth with foliage from actively growing mature trees. Results showed that net photosynthesis per unit area of one year old foliage from old *Pinus contorta* and *Pinus ponderosa* averaged 14-30% lower than the same aged foliage from younger trees. Computer simulation from previous study indicated that differences of this magnitude are sufficient to explain the lower wood production in old trees. In order to predict carbon sequestration of vegetation with the future rise in atmospheric CO₂ concentration and temperature, long-term effect of high CO₂ and high temperature on responses of both photosynthesis and transpiration of plants as a whole community to environmental parameters need to be elucidated (Tako *et al.*, 2001).

Voronin *et al.* (2001) reported that the positive correlation between CO₂ exchange in the leafy parts of branch and light intensity was observed in the afternoons. This signifies that, apart from light, no environmental factor limited photosynthesis.

As plants acclimate to growth in elevated $p\text{CO}_2$ (partial pressure of CO₂) they often fail to sustain the initial, maximal stimulation of net CO₂ uptake rate under optimal microclimate conditions (Gunderson and Wullschleger, 1994; Sage, 1994; Curtis, 1996; Drake, Gonzalez-Meler and Long, 1997). Rogers and Humphries (2000) demonstrated that this phenomenon could be attributed almost entirely to a decrease in the carboxylation capacity of Rubisco. Knowledge of

photosynthetic sensitivity and potential long-term photosynthetic acclimation responses to elevated CO₂ may be used to predict annual global carbon influx into terrestrial ecosystems (Luo *et al.* 1996) and improve models of forest ecosystem response to global climate change.

In fact, a doubling of atmospheric CO₂ partial pressure results in a 50 per cent reduction in the ratio of photorespiration to photosynthesis (Sharkey, 1988), thereby increasing net photosynthesis.

Reduction in photosynthetic capacity, often termed down regulation or photosynthetic adjustment, after long-term exposure to elevated CO₂ has been observed in trees (Lewis *et al.* 1996, Atkinson *et al.* 1997, Rey and Jarvis, 1998) and is often attributed to an imbalance in the source-sink relationship due to the accumulation of leaf carbohydrates (Webber *et al.* 1994, Van Oosten and Besford 1994, Jones *et al.* 1996, Cheng *et al.* 1998). Substantial production of carbohydrates induced by higher photosynthetic rates at elevated CO₂ partial pressure initiates a feedback mechanism that ultimately reduces photosynthetic capacity.

In two deciduous trees, *Castanea sativa* (El Kohen and Mousseau, 1994) and *Betula pendzda* (Rey and Jarvis, 1998), Photosynthetic adjustment to elevated CO₂ increased as the growing season progressed.

The large reduction in Photosynthetic capacity and associated Photosynthetic components observed in *Ponderosa pine* in late summer may be greater than the Photosynthetic adjustment expected earlier in the growing season. Nonetheless, photosynthetic adjustment was observed in *Betula pendula*, an indeterminate growth species, in mid-season (Rey and Jarvis 1998), further suggesting that at least

some degree of photosynthetic adjustment in *Ponderosa pine* probably occurred earlier in the growing season. (Hellmers and Strain, 1972) work on loblolly pine trees shows that the relationship between photosynthetic capacity and sink demand in loblolly pine trees is complex because this species produces from one to seven distinct flushes of needle cohorts in each growth season. Kramer and Kozlowski (1979) described the growth of pine trees as a system of sinks in competition for Photosynthate from a shifting source as ontology proceeds.

The effect of leaf age on photosynthesis capacity, a critical parameter in the theory of optimal leaf longevity, was studied for two tropical pioneer tree species, *Cecropia longipes* and *Urera caracasna*, in a seasonally dry forest in panama. These species continuously produce short lived leaves (74 and 93d, respectively) during the rainy season (may-december) on orthotropic branches. However, they differ in leaf production rate, maximum no of leaves branch, light environment experienced by the leaves, leaf mass per unit area, and nitrogen content. Light saturated photosynthetic rates for marked leaves of known ages (± 1 wk) were measured with two contrasting schemes (repeated measurements vs. chronosequence within branch), which overall produced similar results. In both the species, photosynthetic rates and nitrogen use efficiency were negatively correlated with leaf age and positively correlated with light availability. Photosynthetic rates declined faster with leaf age in *Cecropia* than *Urera* as predicted by the theory.

2.10 Carbon dioxide and photosynthetic rate in trees

Plant tissue (including wood) is composed of about half carbon, all of which comes from carbon dioxide in the atmosphere. Photosynthesis rates tend to increase as carbon dioxide levels rise,

leading to an increase in dry weight, or biomass, of plants grown under elevated carbon dioxide levels. Compared to plants grown at existing carbon dioxide levels, plants “fertilized” by elevated levels of atmospheric carbon dioxide increase their photosynthesis rates (Norby *et al.*, 1999, Kimball *et al.*, 2002, Nowak *et al.*, 2004). Plants are always CO₂ limited for photosynthesis. CO₂ can enhance photosynthetic rate of C₃ plants over a wide range of concentration when all other environmental factors are optimum. Photosynthetic quantum efficiency of C₃ plants at all irradiation levels increases markedly with CO₂ (Ehleringer and Bjorkman, 1977). This indicates that growth responses may be enhanced at low light intensity and elevated concentrations of CO₂ as observed in wheat (Mac dowell, 1972). In species with C₄ metabolism there was little or no response of photosynthesis on quantum efficiency to an increase in CO₂ (Pearcy and Bjorkman, 1983).

2.11 Wood density

It is commonly accepted to speak of the weight of wood in terms of standard volume. Wood density is therefore defined as the mass per unit volume (kg/m³). It is an important factor that influences the strength of timber (Akpan, 1998). According to Desch (1992), different timbers vary in density from about 160 kg/m³ to 1250 kg/m³. Factors such as rate of growth, site conditions, and genetic composition are responsible for this variation. Due to this variation, knowledge about the density of wood species is required to enhance their optimum utilization.

2.12 Quantification of carbon in trees

Quantification of biomass in trees, in general, is not an easy task. Though there are some studies specific to certain species,

generally in natural forest it is still difficult. Never the less dynamic growth analysis approach has been quite useful in such cases and various models developed are in use. With the global initiative of UNFCCC generation of this information has become very important especially for the carbon trading purpose. Therefore, IPCC has come out with guidelines to employ protocols for such estimations. Employing such general guidelines not only help in maintaining uniformity across the globe but also easy to assess and these protocols are based on a large data base and scientifically developed. There are continuous efforts to further improve these methodologies.

2.13 Conversion factor for estimation of carbon content from biomass value

To estimate the carbon from the standing biomass of trees, a method generally followed. In this method, 50 percent of the fresh weight of the standing biomass is considered as the dry weight of that biomass (Anon., 1996). Therefore, 0.5 is used as factor and is multiplied with the standing biomass while estimating the carbon of the standing biomass. This is used by many workers (Ajay kumar and Singh, 2003).

2.14 Leaf area and its essential importance in growth analysis

Leaf area (LA) is an essential component to estimate plant growth through its incidence on crop physiology mechanisms (Ramesch and Singh, 1989; Portela, 1999; Bhatt and Chanda, 2003). It is used as a variable into Canopy photosynthesis models, training systems evaluation and pruning Practices (Gutirez and Lavín, 2000). In sweet cherry (*Prunus avium* L.), like in other crops, the measurement of LA, both expressed per tree or as Leaf Area Index (LAI), can be a time consuming process (Portela, 1999) and requires

sophisticated electronic instruments, which are expensive especially for developing countries (Bhatt and Chanda, 2003). Moreover, destructive methods may cause inconvenient for some investigations (Chirinos *et al.*, 1997).

Therefore, alternatives to estimate Leaf area on the field may be provided by practical and non-destructive methods (Gutirez and Lavín, 2000). For example, a rapid and non-destructive method to estimate LA is the use of equations that needs leaf dimensions (length and width) as inputs. These have been used for grapevine (Gutirez and Lavín, 2000; Williams and Martinson, 2003), Taro (Hsiu-Ying *et al.*, 2004), common bean (Bhatt and Chanda, 2003), Hyacinth bean (Singh, 1990), Banana (Potdar and Pawar, 1991) and Melon (Chirinos *et al.*, 1997). Such equations allow growers and researchers to estimate LA in relation to other factors like crop load, Drought stress and insect damage (Williams and Martinson, 2003).

It is known that the initial growth rate of seedlings mainly depends on the rapidity with which photosynthesizing area (leaf area) is expanding to generate sufficient photosynthates. Therefore giving emphasis on screening provenances/clones and exploiting existing generic variability for leaf area at nursery stage, and incorporating them in tree improvement programme could be a good approach. Leaf area estimations are also required for growth analysis such as leaf area ratio (LAR) to determine the seedling growth performance and for studying ecophysiology of tree seedlings under nursery situations (Kitajima, 1997). However the issue of estimating total leaf area plant is a practical problem, especially when a large no of provenances/clones are to be examined. To overcome such a difficulty, several methods have been devised for in situ determination of leaf area using regression equation is one of the methods used

(Schneirtr,1978) while some workers calculate leaf area by measuring the length and width of a leaf and multiplying by the product of fixed coefficient (Nanja reddy *et al.*,1995). Nataraja *et al.*, (2003) estimated leaf area of teak by using a constant factor 0.660. However in their study necessary validation was not incorporated as shape and size of teak leaves vary considerably according to the age of the plant.

MATERIAL AND METHODS

III. MATERIAL AND METHODS

India is the land of farmers and villages scattered all over and most often contiguous chain of villages has uniformity spread of green cover with selected trees with multipurpose use. Pongamia and neem are very common trees found in dry land agriculture of our state. Despite the persistent drought the pongamia and neem trees will flourish well in dry regions. In addition to biofuel, these trees provide other resources vital to farming community. Farmers should earn carbon credits for the trees and bushes maintained by them or new native species planted by farming community.

The present investigation was undertaken to estimate the quantity of carbon sequestered by *Azadirachta indica* and *Pongamia pinnata* in plantations. The photosynthetic ability in case of neem and pongamia were looked into by studying the various gas exchange characteristics using IRGA (Infrared Gas Analyzer). In addition to this regression equation or fixed co efficient was developed to estimate the variation of total leaf area across different age gradation. The materials used and method adopted in this study are presented in this chapter.

3.1 Study area

The present investigation was carried out at University of Agricultural Sciences- Bengaluru campus, which is situated at a longitude of 12°58¹ north, longitude of 17° 35¹ east and at an altitude of 930 m above MSL. The average annual rainfall of the experimental area was about 890.9 mm.

Soil of the experiment site:

The topography of the experimental site was fairly uniform with a gentle gradient towards western side. The soil of the experimental site was red sandy loam in texture.

The red sandy loam soil of the experimental site was acidic (pH 5.12-6.21) and normal with respect to salt content (electrical conductivity at 26°C was 0.11-0.16 dSm⁻¹). The organic content was 0.39 percent. The soil was slow in available nitrogen (192.91-254.56kg ha⁻¹), high in available P₂O₅ (117.24 -161.39 kg ha⁻¹) and medium in k₂O content (153.87-200.66 kg ha⁻¹).

Cultivation practices:

Silvicultural practices for neem and pongamia has not been developed in India, but package and practice prescribed by state forest department are followed with a spacing of 5m x 5m.

3.2 Studies carried out and observations recorded

- A. Above ground biomass estimation
- B. Gas exchange studies
- C. Wood density and moisture content
- D. Leaf area measurement

D. Above ground biomass estimation: Following parameters were recorded:

1. Tree height
2. Diameter
3. Canopy size
4. Biomass of branches

E. Gas exchange studies:

1. Photosynthetic rate
2. Stomatal conductance
3. Intercellular carbon dioxide concentration
4. Transpiration rate

F. Wood density and Moisture content:

D. Leaf area measurement:

1. Actual leaf area
2. Measured leaf area

3.3 Above ground biomass

To predict the above ground biomass, amount of carbon stored and the amount of CO₂ removed from atmosphere by *Azadirachta indica* and *Pongamia pinnata* species, twenty trees were randomly selected in each age gradations (2, 5 and 10 years) to estimate the above ground biomass and total carbon sequestered in *Pongamia pinnata* and *Azadirachta indica*. Collar diameter, height of individual trees and canopy size were recorded for 2 and 5 year age species. But for 10 year age species height and diameter at breast height were recorded (Chaturvedi. 1975).

In order to know the proportion of biomass added by different tree component like (primary branch, secondary, tertiary etc and leaves) to the tree, length and diameter of the each branch of individual species were recorded in 5 year age in both species. In each individual species number of leaves was counted and leaf area was calculated. Volume of these species was estimated by recording height and diameter using the formula $V = \pi d^2 / 4 * h$ (Chaturvedi. 1975).

Destructive sampling was done in 5 year age of both the species to estimate the biomass; both fresh weight and oven dry weight were recorded. Wood densities of both the species were estimated according to the Indian standards (IS). Based on the obtained value of wood density of each species, biomass was estimated by using the formula.

$$\text{i.e. Biomass} = V \times W.D$$

Where,

V= Volume

WD= Wood density

5. Tree height: Height of the twenty randomly selected trees of neem and pongamia in each age gradation (2, 5 and 10 years) was measured using measuring tape (20 m).

6. Stem Diameter: Collar diameter was measured for 2 and 5 year old plants using Calliper and for 10 years age class tree species, diameter was measured at the breast height (DBH).

7. Canopy size: In order to measure the canopy size, Length and width of the crown of twenty randomly selected trees of neem and pongamia were measured by using measuring tape (20 m).

8. Biomass of branches: In order to estimate the biomass added to whole tree by the individual branches, each branch (primary, secondary and tertiary) of individual tree species of neem and pongamia were measured by taking its length and diameter using calliper and tape.

3.4 Gas exchange characteristics

All the gas exchange parameters were measured using portable (IRGA) (Li- COR 6400, Nebraska, USA)

3.4.1 Description of portable photosynthesis system

A portable photosynthesis system (IRGA) (Li-COR 6400, Nebraska, USA) was used for recording gas parameters. Since the instrument operates in an open system, it is possible to maintain steady state CO₂ Concentration and relative humidity in the leaf chamber.

3.4.2 Recording gas exchange parameters: The top fully expanded leaf was clamped to leaf chamber and held perpendicular to the incident light. Relative humidity was maintained at a steady state level equal to the ambient RH to stimulate a condition very similar to that of an ambient air. By altering the flow rates of dry air, it is possible to maintain desirable RH in the leaf chamber. Recording of data was done at saturated light intensities. Keeping in mind the possible diurnal variations of A and gs all observations were made between 9 am and noon on a bright sunny day.

The instrument gives the following gas exchange parameters.

1. Photosynthetic rate (A) μ moles m⁻² sec⁻¹
2. Stomatal conductances (gs) mol m⁻² sec⁻¹
3. Transpiration (E) m moles m⁻² sec⁻¹
4. Intercellular CO₂ concentration (c_i) ppm
5. Vapour pressure deficit (VPD) milli bars.

All gas exchange traits were measured under growth conditions by maintaining VPD between 20-30 milli bars. Leaf was clamped in the leaf chamber and once A and gs value were stabilized the data were recorded. IRGA was used to measure the gas exchange parameters like photosynthetic rate, stomatal conductance, intercellular carbon dioxide rate and transpiration. By using the formula ' A/c_i ' *in vivo* carboxylation efficiency was estimated and similarly instantaneous water use efficiency was also calculated using formula ' A/g_s '.

3.5 Estimation of wood density and moisture content

It is commonly accepted to speak of the weight of wood in terms of standard volume. Wood density is therefore defined as the mass per unit volume (Kg/m^3). It is an important factor that influences the strength of the timber. In this research estimation of wood density of neem and pongamia species was carried out to know the biomass added by the each species at different age class.

Plantation of neem and pongamia of five year age was chosen for this experiment. The population consists of 20 trees each, Out of this number, one tree each in both the species were selected and felled. Trees were separated into different components after felling (i.e., branches, trunk, leaves etc.) initial weight of all those components were taken in the field and later they were brought to lab for further work. Therefore due to variation of density along tree trunk, felled tree was divided into three sections and totally six samples were taken from the tree trunk of neem and pongamia. Each wood specimen were cut to sizeable dimension of 2.5 cm x 2 cm x 2 cm for the test in accordance with IS: 1708 (part-1). Prior to density determination, the moisture contents of the test pieces were determined. This was done by recording wet weight of the samples and thereafter oven drying the wood samples at a temperature of $103^\circ\text{C} \pm 2^\circ\text{C}$ for 24 hours. After the

wood samples have dried, weight of the samples were recorded at the regular interval, using the electronic weighing balance until a constant mass was obtained for each of the wood samples. The moisture content of the wood samples was then determined based on their oven dry weights, using the equation:

$$MC = \frac{W_1 - W_o}{W_o} \times 100$$

Where: MC=Moisture content of the wood samples (%)

W_1 = Weight of the wood sample at test in gms before drying,
and

W_o = Oven dry weight of the wood sample in gms.

There after specimens were cut to standard sizes of 6 cm x 2 cm x 2 cm (IS: 1708). Based on these standard sizes their masses were recorded using the electronic weighing balance. In the same vein, the volume of wood specimen in terms of their length, width and height were also measured using a pair of callipers. Densities of the wood samples were then calculated with the equation:

$$\text{Specific gravity at test} = \frac{W_1}{V_1}$$

Where,

W_1 = Weight in gms of test specimen.

V_1 = Volume in cm³ of test specimen

3.6 Leaf area measurement

Leaf area measurement of tree is a time consuming process and requires sophisticated electronic instruments. The objective of this study was to develop a simple, accurate, non-destructive and time

saving predictive model for leaf area (LA) estimation in neem and pongamia. In this study, tree of five year age class of neem and pongamia were selected for recording this parameter. In each population of neem and pongamia, 100 leaves (n=100) were selected randomly and detached from the tree. Leaf length (L) was measured as a straight line from the apex to the base of the leaf blade and leaf width (W) was measured across the widest portion of the blade at right angle to the length. The total leaf area was recorded using graphical method and expressed as m². The measured leaf area and product of length and width of leaf was used to develop regression equation (Snedecor and Cochran, 1987) to calculate leaf area. Fixed coefficient (FC) was calculated by using the following formula:

$$FC = (LA / P)$$

Where,

LA= Measured leaf area, and

P = Product of leaf length and width.

3.7 Carbon content

The volume of wood of each species was multiplied with the density of that particular species to obtain the biomass of the tree. In the present study density of the tree was estimated based on the Indian standard (IS: 1708 (part 2)-1986. Standing biomass of the tree species was calculated by using volume and wood density of the species. Carbon content of wood was taken as 50 percent of the dry weight of the wood (Anon., 1996).

3.8 Analysis of data

The data on growth, volume, biomass and carbon sequestered was analyzed by one Factor Complete randomized Design (One way

ANOVA). The data were analyzed using programme on Agreis software and along with that correlation studies were done to know the relationship between the growth parameters in both the species using SPSS Software.

EXPERIMENTAL RESULTS

IV. EXPERIMENTAL RESULTS

Global warming is amongst the most dreaded problems of the new millennium. Carbon emission is supposedly the strongest causal factor for global warming. So, increasing carbon emission is one of today's major concerns, which is well addressed in Kyoto Protocol. Worldwide there are many works done regarding the sequestering ability of different tree species under different climatic condition. Sequestering ability of tree species reported by researchers from all over the world reveals that carbon sequestering ability of tree species varies from species to species, climatic condition and with different age class.

The results of the study conducted to evaluate the carbon sequestration ability of *Azadirachta indica* and *Pongamia pinnata* at different age classes (2, 5 and 10 years) in GKVK, Bengaluru is presented here. The study was carried out,

1. To assess the carbon stock present in the wood of *Azadirachta indica* and *Pongamia pinnata*.
2. To assess photosynthetic ability of *Azadirachta indica* and *Pongamia pinnata*.
3. To classify the species based on their growth behavior & carbon sequestration ability.

In addition, support studies were conducted to develop Regression equation (RE) and a fixed coefficient (FC) to calculate the Leaf Area (LA) of *A. indica* (neem) and *P. pinnata* (pongamia) trees grown in natural conditions.

4.1 Assessing the carbon stock present in the wood of *Azadirachta indica* and *Pongamia pinnata*.

The carbon sequestration assessed based on the data of growth performance of *A. indica* and *P. pinnata* viz., total height (m), diameter(m), volume (m³), above ground biomass (t/ha),etc are presented in this chapter.

4.1.1 Total height (m)

Between the two species, *A. indica* (neem) and *P. pinnata* (pongamia), the total height across 2 year age plants was found maximum in pongamia (0.80m) followed by neem (0.51m). The total height across 5 year age trees was found maximum in neem (2.86 m) followed by pongamia (1.73m). The total height of 10 year age trees was found to be maximum in neem (4.67m) followed by pongamia (4.07m). The growth of tree with respect to height in two species *A. indica* (neem) and *P. pinnata* (pongamia) was found significant. The effect of age on height growth was significant among all age groups (Table 4.1 and 4.2).

Significantly higher total height was recorded in *A. indica* at 5 and 10 year age and *P. pinnata* at 2 year age.

4.1.2 Stem Diameter (m)

The diameter across 2 year age plants was found maximum in *P. pinnata* (0.015m) followed by *A. indica* (neem) (0.011m). The diameter across 5 year age trees was found maximum in neem (0.055m) followed by pongamia (0.044m). The diameter across 10 year age trees was found maximum in neem (0.065m) followed by pongamia (0.060m). The diameter of both the species were found significant. The

effect of age on diameter was significant among all age class (Table 4.1- 4.2).

Significantly maximum stem diameter was observed in *A. indica* at 5 and 10 year age and *P. pinnata* at 2 year age.

4.1.3 Volume (m³)

The volume across 2 year age trees of both the species was found maximum in *P. pinnata* (0.0003m³) followed by neem (0.0001m³). The volume across 5 year age trees was found maximum in neem (0.007m³) followed by pongamia (0.002m³). The volume across 10 year age trees was found maximum in neem (0.017m³) followed by pongamia (0.012m³). The volume of both the species was found significant and the effect of age on volume was significant among in all ages (Table 4.1- 4.2).

Significantly maximum volume was reported in *A. indica* at 5 and 10 year age and *P. pinnata* at 2 year age

4.1.4 Wood density and moisture content of the species

Wood density of the both the species were estimated and based on the results, it was found that density of *P. pinnata* (696.58kg/m³) was more compared to density of *A. indica* (626.21kg/m³). According to Desch (1992), different timbers vary in density from about 160 kg/m³ to 1250 kg/m³. Hence density of pongamia is more compared to neem, it might be because certain factors like rate of growth, site conditions, and genetic composition of the species and within the provenance of same species.

Moisture content of the *P. pinnata* (82.48%) in oven dry method was found to be more compared to neem (52.75%). Similarly in air dry

method the moisture content of *P. pinnata* (71%) was more compared to neem (42%) because in 5 year aged plants formation of heartwood will be less and most of the tissue is attributed to the components of cortex and parenchyma cells in the middle part of the stem that facilitates more moisture content in pongamia than neem. (Table 4.3)

4.1.5 Above ground biomass (t/ha)

The results of the above ground biomass across 2 year age trees was found maximum in *P. pinnata* (0.09 t/ha) followed by neem (0.03 t/ha). The above ground biomass across 5 year age trees was found maximum in neem (1.93 t/ha) followed by pongamia (0.81t/ha). The above ground biomass across 10 year age trees was found maximum in neem (4.33 t/ha) followed by pongamia (3.50 t/ha). (Fig 4.1)

4.1.6 Carbon sequestration (t/ha)

Pongamia of 2 year age trees was found to have higher capacity of sequestering carbon (0.04t/ha) compared to neem (0.01t/ha). The carbon sequestration across 5 year age trees was found maximum in neem (0.96t/ha) followed by pongamia (0.40t/ha). The carbon sequestration across 10 year age trees was found maximum in neem (2.16t/ha) followed by pongamia (1.75t/ha). (Fig 4.2).

Table 4.1 Height, diameter, and volume, of *Pongamia pinnata* in relation to age class.

	Pongamia				
Age (yr)	Height (m)	Diameter (m)	Volume (m³)	Biomass (t/ha)	Carbon (t/ha)
2	0.804	0.015	0.000	0.090	0.045
5	1.739	0.044	0.002	0.816	0.408
10	4.070	0.060	0.012	3.500	1.750
Mean	2.204	0.039	0.005	1.469	0.734
F- value	*	*	*	*	*
S.Em±	0.164	0.003	0.001	0.339	0.169
CD (5%)	0.328	0.007	0.002	0.678	0.339

*Significant at 5% level

Table 4.2 Height, diameter, and volume, of *Azadiractha indica* in relation to age class.

	Neem				
Age (yr)	Height (m)	Diameter (m)	Volume (m³)	Biomass (t/ha)	Carbon (t/ha)
2	0.510	0.011	0.0001	0.031	0.015
5	2.863	0.055	0.0077	1.938	0.969
10	4.601	0.065	0.0173	4.335	2.167
Mean	2.658	0.044	0.0084	2.101	1.050
F-value	*	*	*	*	*
S.Em ±	0.197	0.005	0.0022	0.539	0.269
CD (5%)	0.394	0.010	0.0043	1.079	0.540

* Significant at 5%level

Table 4.3 Wood density and moisture content of *Azadiractha indica* and *Pongamia pinnata*.

Species	Density of wood (kg/m³)	Moisture content (%)
Neem	626.21	52.75
Pongamia	696.58	82.48

4.2 Gas exchange characteristics of *Azadiractha indica* (Neem) and *Pongamia pinnata* at different age class.

The gas exchange characteristics Viz., A, gs, Ci, and Tr of *A. indica* (neem) were studied at different age class. Based on the results obtained it was found that in 2 year age neem plants mean photosynthetic rate was ($11.84 \mu\text{mol m}^{-2}\text{s}^{-1}$) and at 5 year the photosynthetic rate was ($12.00 \mu\text{mol m}^{-2}\text{s}^{-1}$) Among two age group photosynthetic rate was found non significant.

Similarly mean stomatal conductance ($0.132 \text{ mol m}^{-2} \text{ s}^{-1}$) at 2 year old was more compared to stomatal conductance ($0.130 \text{ mol m}^{-2} \text{ s}^{-1}$) at 5 year, Mean intercellular carbon dioxide concentration rate (229.7 ppm) at 5 year was more compared to intercellular carbon dioxide concentration (209.55 ppm) at 2 year, Mean transpiration rate ($3.07 \text{ m moles m}^{-2}\text{s}^{-1}$) at 5 year age was more compared to the transpiration rate ($2.84 \text{ m moles m}^{-2}\text{s}^{-1}$) at 2 year and all these parameters were found non significant. (Table 4.4)

Photosynthetic rate (A), stomatal conductance (gs), Intercellular carbon dioxide rate (Ci) and transpiration rate (E) of *P. pinnata* was studied at 2 and 5 year age class. Based on the results obtained, it was found that in 5 year aged trees, the mean photosynthetic rate ($12.63 \mu\text{mol m}^{-2}\text{s}^{-1}$) of pongamia was more compared to photosynthetic rate ($9.45 \mu\text{mol m}^{-2}\text{s}^{-1}$) at 2 year age and photosynthetic rate was found to differ significantly.

Similarly mean Stomatal conductance ($0.301 \text{ mol m}^{-2} \text{ s}^{-1}$) at 5 year age trees was more compared to Stomatal conductance ($0.200 \text{ mol m}^{-2}\text{s}^{-1}$) at 2 year old, and they are found to be significantly different ($P < 0.005$). Mean intercellular carbon dioxide concentration rate (307.9 ppm) at 5 year aged trees was more compared to

intercellular carbon dioxide concentration (301 ppm) at 2 year, and they were found non significant. Mean transpiration rate ($6.00 \text{ m moles m}^{-2} \text{ s}^{-1}$) at 5 year age trees was more compared to the transpiration rate ($4.11 \text{ m moles m}^{-2} \text{ s}^{-1}$) at 2 year and all those parameters are found to be significantly different ($P < 0.005$). (Table 4.5)

4.3 To classify the species based on their growth behavior & carbon sequestration ability

Among two species *A. indica* and *P. pinnata*, the total height across 2 year old plants was found maximum in pongamia (0.80m) followed by neem (0.51m). The total height across 5 year age trees was found maximum in neem (2.86m) followed by pongamia (1.73m). The total height of 10 year age trees was found to be maximum in Neem (4.67m) followed by pongamia (4.07m). The height growth with respect to two species was found significant statistically. The effect of age on height growth was significant among all age groups.

Significantly maximum total height was reported in *Azadirachta indica* at 5 and 10 year age and *P. pinnata* at 2 year age class.

Diameter in *A. indica* and *P. pinnata*, across 2 year old plants was found maximum in *P. pinnata* (0.015m) followed by neem (0.011m). The diameter across 5 year age was found maximum in neem (0.055m) followed by pongamia (0.044m). The diameter across 10 year age was found maximum in neem (0.065m) followed by pongamia (0.060m). The diameter with respect to two species *A. indica* and *P. pinnata* was found significant. The effect of age on diameter was significant among all age class.

Table 4.4 Gas exchange parameter readings of *Azadiractha indica* (neem) at different age class.

Neem				
Age (yrs)	A	gs	Ci	E
2	11.84	0.132	209.5	2.848
5	12.00	0.130	229.7	3.078
F value	NS	NS	NS	NS
SEm±	4.116	0.051	71.38	1.038
CD at 5% level	11.42	0.143	198.20	2.88

NS-Non significant

Note:

Photosynthetic rate (A) $\mu\text{mol m}^{-2}\text{s}^{-1}$

Stomatal conductance (gs) $\text{mol m}^{-2}\text{s}^{-1}$

Intercellular carbon dioxide rate (Ci) ppm

Transpiration rate (E) $\text{m moles m}^{-2}\text{s}^{-1}$

Table 4.5 Gas exchange parameter readings of *Pongamia pinnata* at different age class.

Pongamia				
Age(yrs)	A	gs	Ci	E
2	9.455	0.200	301	4.11
5	12.63	0.301	307.9	6.00
F value	*	*	NS	*
SEm±	0.111	0.014	3.953	0.396
CD at 5% level	0.309	0.038	10.976	1.099

* Significant

NS : Non significant

Note:

A: Photosynthetic rate ($\mu\text{mol m}^{-2}\text{s}^{-1}$)

gs: Stomatal conductance ($\text{mol m}^{-2}\text{s}^{-1}$)

Ci : Intercellular carbon dioxide rate (ppm)

E: Transpiration rate ($\text{m moles m}^{-2}\text{s}^{-1}$)

Significantly maximum diameter was reported in *A. indica* at 5 and 10 year age and *P. pinnata* at 2 year age class.

Similarly in *A. indica* and *P. pinnata*, the Volume across 2 year old plants was found maximum in *P. pinnata* (0.0003m³) followed by neem (0.0001m³). The volume across 5 year age trees was found maximum in neem (0.007m³) followed by pongamia (0.002m³). The volume across 10 year age trees was found maximum in neem (0.017m³) followed by Pongamia (0.012m³). The volume with respect to two species *A. indica* and *P. pinnata* was found significant. The effect of age on volume was significant among all age class.

Significantly maximum Volume was reported in *A. indica* at 5 and 10 year age and *P. pinnata* at 2 year age class.

The results of above ground biomass across 2 year old plants was found maximum in *P. pinnata* (0.09t/ha) followed by neem (0.03t/ha). The above ground biomass across 5 year age trees was found maximum in neem (1.93t/ha) followed by pongamia (0.81t/ha). Above ground biomass across 10 year age trees was found maximum in neem (4.33t/ha) followed by pongamia (3.50t/ha). Similarly Carbon sequestration capacity in *A. indica* and *P. pinnata*, across 2 year age plants was found maximum in *P. pinnata* (0.04t/ha) followed by neem (0.01t/ha). The carbon sequestration across 5 year age trees was found maximum in neem (0.96t/ha) followed by pongamia (0.40t/ha). The carbon sequestration across 10 year age trees was found maximum in neem (2.16t/ha) followed by pongamia (1.75t/ha. (Table 4.6)

Table 4. 6 Classifying *Azadiractha indica* (neem) and *Pongamia pinnata* (pongamia) based on different growth parameters at different age class.

	Height(m)		Diameter(m)		volume(m ³)		Biomass(t/ha)		Carbon(t/ha)	
Age (yr)	Neem	Pongamia	Neem	Pongamia	Neem	Pongamia	Neem	Pongamia	Neem	Pongamia
2	0.51	0.80	0.01	0.015	0.0001	0.0003	0.03	0.09	0.01	0.04
5	2.86	1.73	0.05	0.044	0.0077	0.0029	1.93	0.81	0.96	0.40
10	4.60	4.07	0.06	0.060	0.0173	0.0126	4.33	3.50	2.16	1.75
Mean	2.65	2.20	0.04	0.039	0.0084	0.0053	2.10	1.46	1.05	0.73
F-value	*	*	*	*	*	*	*	*	*	*
S.Em±	0.19	0.16	0.005	0.003	0.0022	0.0012	0.5393	0.339	0.269	0.169
CD(5%)	0.39	0.32	0.010	0.007	0.0043	0.0024	1.0799	0.678	0.54	0.339

*Significant at 0.05 level

4.4 Contribution of trunk and branches to the total above ground biomass of *Azadiractha indica* and *Pongamia pinnata*

It was observed that in *A. indica* the contribution of trunk (29.94%) towards above ground biomass was more compared to the branches like primary (26.33%), secondary (16.25%), tertiary (8.02%), Quaternary (11.06%), pentanary (11.03%), and hexanary (0.36%). But in *P. pinnata* it was found that contribution of primary branch (29.79%) towards total above ground biomass was more compared to the trunk (15.44%) and rest of the branches like secondary (27.34%), tertiary (16.43%), quaternary (10.75%), and pentanary (0.25%) (Table 4.7).

4.5 Comparison of the *Azadiractha indica* (neem) and *Pongamia pinnata* (pongamia) based on their gas exchange characteristics

The results of gas exchange characteristics of *A. indica* and *P. pinnata* shows that mean photosynthetic rate of *A. indica* ($11.84 \mu\text{mol m}^{-2}\text{s}^{-1}$) at 2 year old plants, was more compared to the pongamia ($9.45 \mu\text{mol m}^{-2}\text{s}^{-1}$). Where as in 5 year old trees the photosynthetic rate of pongamia ($12.63 \mu\text{mol m}^{-2}\text{s}^{-1}$) was superior compared to the photosynthetic rate of neem ($12.00 \mu\text{mol m}^{-2}\text{s}^{-1}$) and it was found to differ significantly in pongamia across age class.

Stomatal conductance for both the species was assessed at 2 and 5 year old trees. Based on the result it was found that stomatal conductance of *P. pinnata* ($0.200 \text{ mol m}^{-2}\text{s}^{-1}$) at 2 year, 5 year ($0.301 \text{ mol m}^{-2}\text{s}^{-1}$) was more compared to the stomatal conductance of *A. indica* ($0.132 \text{ mol m}^{-2}\text{s}^{-1}$) at 2 year, 5 year ($0.130 \text{ mol m}^{-2}\text{s}^{-1}$) and statistically stomatal conductance in *P. pinnata* across ages was found

to be significantly different ($P < 0.005$) and in case of neem across ages, it was found non significant.

Similarly inter cellular carbon dioxide rate (C_i) was more in *P. pinnata* at 2 year old (301 ppm), 5 year old (307.9 ppm) compared to *A. indica* at 2 years (209.5 ppm), 5 years (229.7 ppm) and statistically the result was found to be differ significantly in case of pongamia across age class but in case of neem it was found non significant. Transpiration rate (E) was more in *P. pinnata* at 2 years ($4.11 \text{ mmol m}^{-2} \text{ s}^{-1}$), 5 years ($6.00 \text{ mmol m}^{-2} \text{ s}^{-1}$) compared to *A. indica* at 2 years ($2.84 \text{ mmol m}^{-2} \text{ s}^{-1}$), 5 years ($3.07 \text{ mmol m}^{-2} \text{ s}^{-1}$) and statistically the result was found to be significantly different ($P < 0.005$) in *P. pinnata* across age class and differ significantly. But in case of neem, it was found non significant (Table 4.8).

4.6 Comparison of water use efficiency, in vivo carboxylation efficiency, instantaneous water use efficiency in *Azadiractha indica* (neem) and *Pongamia pinnata* (pongamia) at different age class

It was observed that in 2 year old plants, in vivo carboxylation efficiency was maximum in neem ($0.056 \mu \text{ moles m}^{-2} \text{ s}^{-1}$) compared to pongamia ($0.031 \mu \text{ moles m}^{-2} \text{ s}^{-1}$). In 5 year old trees in vivo carboxylation efficiency was found to be maximum in neem ($0.052 \mu \text{ moles m}^{-2} \text{ s}^{-1}$) compared to pongamia ($0.041 \mu \text{ moles m}^{-2} \text{ s}^{-1}$). (Fig 4.3)

Instantaneous water use efficiency in 2 year old plants was found to be maximum in neem (89.69) compared to pongamia (47.2) and in 5 years instantaneous water use efficiency was found to be maximum in neem (91.85) compared to pongamia (41.96). (Fig 4.4)

4.7 Relationship between photosynthetic rate and stomatal conductance

The leaf photosynthetic characteristics are said to be a very good initial approach to study the response of plants to environmental conditions. In most plants there is strong positive relationship between photosynthesis and stomatal conductance.

In the present study relationship between photosynthetic rate and stomatal conductance rate were assessed in neem and pongamia. There was a positive relationship between the photosynthetic rate and stomatal conductance in case neem with an r value of ($r=0.91$) (Fig.4.5) and similarly in case of pongamia also there is a positive relationship between the photosynthetic rate and stomatal conductance as shown in the (Fig.4.6) ($r=0.75$).

4.8 Instantaneous water use efficiency and carboxylation efficiency in *Azadiractha indica* and *Pongamia pinnata*.

Based on the Photosynthetic rate, stomatal conductance and intercellular carbon dioxide concentration in two species, a few related physiological parameters were assessed. As estimated in neem A/c_i was ($0.056 \mu \text{ moles. m}^{-2}.\text{s}^{-1}$) in 2 year old plants as compared to ($0.052 \mu \text{ mols. m}^{-2}.\text{s}^{-1}$) in 5 year old trees. Similarly in pongamia the A/c_i was ($0.031 \mu \text{ mols. m}^{-2}.\text{s}^{-1}$) in 2 year old plants as compared to ($0.041 \mu \text{ mols. m}^{-2}.\text{s}^{-1}$) in 5 year old trees. (Fig.4.3)

The instantaneous water use efficiency calculated by A/g_s ratio was (89.69) in two year old plants of neem and it was (91.85) in 5 year old trees. Similarly in pongamia the A/g_s ratio in 2 year old plants was (47.27) and (41.96) in case of 5 year old trees as shown in the figure. (Fig. 4.4)

Table 4.7 Percentage contribution of trunk and branches to the total above ground biomass in *Azadiractha indica* (neem) and *Pongamia pinnata* (pongamia).

Neem		Pongamia	
Branches	Percentage (%)	Branches	Percentage (%)
Primary	26.33	Primary	29.79
Secondary	16.25	Secondary	27.34
Tertiary	8.02	Tertiary	16.43
Quaternary	11.06	Quaternary	10.75
Pentanary	11.03	Pentanary	0.25
Hexanary	0.36	Trunk	15.44
Trunk	26.94		

Table 4.8 Comparison of *Azadiractha indica* (neem) and *Pongamia pinnata* (pongamia) based on Gas exchange characteristics at different age class.

	Neem	Pongamia	Neem	Pongamia	Neem	Pongamia	Neem	Pongamia
Age (yrs)	A		gs		Ci		E	
2	11.84	9.455	0.132	0.200	209.5	301	2.848	4.11
5	12.00	12.63	0.130	0.301	229.7	307.9	3.078	6.00
F value	NS	*	NS	*	NS	NS	NS	*
S.Em±	4.116	0.111	0.051	0.014	71.38	3.953	1.038	0.396
CD @ 5%level	11.428	0.309	0.143	0.038	198.20	10.976	2.88	1.099

NS-non significant *Significant at 5% level

Note: Photosynthetic rate (A), Stomatal conductance (gs), Intercellular carbon dioxide rate (Ci),
Transpiration rate (E)

4.9 Correlation studies

Data on correlation co-efficient between Growth parameters- (Diameter, height, volume and biomass) for 2, 5 and 10 year age old *Azadiractha indica* (neem) and *Pongamia pinnata* (pongamia) were discussed as follows.

4.9.1 *Azadiractha indica* (neem)- 2 years

In 2 year age volume-diameter (0.748) is positively correlated and significant at 1% level. Biomass-height (0.637) is moderately positively correlated and they are statistically significant at 5% level. Whereas Diameter - height (0.028) are not at all correlated and they are non-significant (Table 4.9).

4.9.2 *Pongamia pinnata* (pongamia)- 2 years

Data on Correlation co-efficient between Growth parameters- (Diameter, Height, Volume and Biomass) for 2 year aged *Pongamia pinnata* (pongamia) were presented below.

In 2 year age plants volume-diameter (0.929) is positively correlated and significant at 1% level. Biomass-height (0.555) is moderately positively correlated and they are statistically significant at 5% level. Whereas diameter-height (0.249) are not at all correlated and they are non-significant (Table 4.10).

**Table 4.9 Correlation Co-efficient between the growth parameters in
Azadiractha indica - 2 years**

n=13

Growth Parameters	Correlation
Height v/s diameter	0.028
volume v/s diameter	0.748**
Biomass v/s Height	0.637*

**Significant at 0.01 level.

*Significant at 0.05 level

**Table 4.10 Correlation Co-efficient between the growth parameters
in *Pongamia pinnata*- 2 years**

n=13

Growth Parameters	Correlation
Height v/s diameter	0.249
volume v/s diameter	0.929**
Biomass v/s Height	0.555*

**Significant at 0.01 level.

*Significant at 0.05 level

4.9.3 *Azadiractha indica* (neem)-5 years

Data on correlation co-efficient between growth parameters- (Diameter, height, volume and biomass,) for 5 year aged *Azadiractha indica* (Neem) were observed as below.

In 5 year age, volume-diameter (0.968) is positively correlated and significant at 1% level. Biomass-height (0.845) is moderately positively correlated and they are statistically significant at 1% level. Whereas Diameter-height (0.734) are just correlated and they are significant at 1% level (Table 4.11).

4.9.4 *Pongamia pinnata* (pongamia)-5 years

Data on correlation co-efficient between growth parameters- (Diameter, height, volume and biomass,) for 5 year aged *Pongamia pinnata* (Pongamia) were presented below.

In 5 year age volume-diameter (0.934) are positively correlated and significant at 1% level. Biomass-height (0.781) is moderately positively correlated and they are statistically significant at 1% level. Whereas Diameter-height (0.574) are just correlated and they are significant at 1% level (Table 4.12)

Table 4. 11 Correlation Co-efficient between the growth parameters in *Azadiractha indica* (neem) - 5 years

n=20

Growth Parameters	Correlation
Height v/s diameter	0.734**
volume v/s diameter	0.968**
Biomass v/s Height	0.845**

**Significant at 0.01 level

Table 4.12 Correlation Co-efficient between the growth parameters in *Pongamia pinnata*-5 years

n=20

Growth Parameters	Correlation
Height v/s diameter	0.574**
volume v/s diameter	0.934**
Biomass v/s Height	0.781**

**Significant at 0.01 level

4.9.5 *Azadiractha indica* (neem)- 10 years

Data on correlation co-efficient between Growth parameters- (Diameter, height, volume, biomass, and carbon) for 10 year old *A. indica* were as follows.

In 10 year age volume-diameter (0.972) are positively correlated and significant at 1% level. Biomass-height (0.429) height-diameter (0.245) are not correlated and they are statistically found non significant (Table 4.13).

4.9.6 *Pongamia pinnata* (pongamia)-10 years

Data on correlation co-efficient between Growth parameters- (Diameter, height, volume, and biomass) for 10 year old *P. pinnata* (Neem) were presented below.

In 10 year age volume-diameter (0.910) are positively correlated and significant at 1% level. Biomass-height (0.242), height-diameter (0.150) is not correlated and they are statistically non significant (Table 4.14).

**Table 4.13 Correlation Co-efficient between the growth parameters
in *Azadiractha indica* (neem)- 10 years**

n=20

Growth Parameters	Correlation
Height v/s diameter	0.245
volume v/s diameter	0.972**
Biomass v/s Height	0.429

**Significant at 0.01 level

**Table 4.14 Correlation Co-efficient between the growth parameters
in *Pongamia pinnata*-10 years**

n=20

Growth Parameters	Correlation
Height v/s diameter	0.150
volume v/s diameter	0.910**
Biomass v/s Height	0.242

**Significant at 0.01 level

4.10 Experiment to develop Regression equation (RE) and a fixed co-efficient (FC) to calculate the leaf area (LA) of *Azadirachta indica* (neem) and *Pongamia pinnata* (pongamia)

Leaf area measurement can be a time consuming process and requires sophisticated electronic instruments. The objective of this study was to develop a simple, accurate, non-destructive and time saving predictive model for leaf area (LA) estimation in neem and pongamia. In this study a regression equation (RE) and a fixed coefficient (FC) was developed to calculate the Leaf area (LA) of neem and pongamia trees grown in natural conditions. The regression equation, Leaf area (LA) = $L*W*0.6585 - 0.9828$ for pongamia and Leaf area (LA) = $L*W*0.465x + 0.8781$ for neem was derived by taking actual leaf area as dependent variable and product of L and W as independent variable ($r = 0.97$ for Pongamia and $r = 0.86$ for neem.) The fixed co efficient calculated by taking the ratio of actual to product of L and W was found to be 0.634 for pongamia and 0.572 for neem. The equation and coefficient was validated and was found significant. The study indicates that either FC or RE can be used with precision to determine LA of neem and pongamia grown in natural condition, non-destructively. This type of short cut, rapid method is highly useful when a large number of provenances are to be tested or in places where instrumentation facility is not available (Fig 4.7-4.10).

4.10.1 Estimation of total leaf area in neem and pongamia

In present study non destructively regression equation was estimated for each species. The leaf area regression equation for neem Leaf area (LA) = $L*W*0.465x + 0.8781$ and regression equation Leaf area (LA) = $L*W*0.6585 - 0.9828$ for pongamia was obtained and it was found to slightly significant and there was a change in leaf area factor due to

Pongamia pinnata

n=100

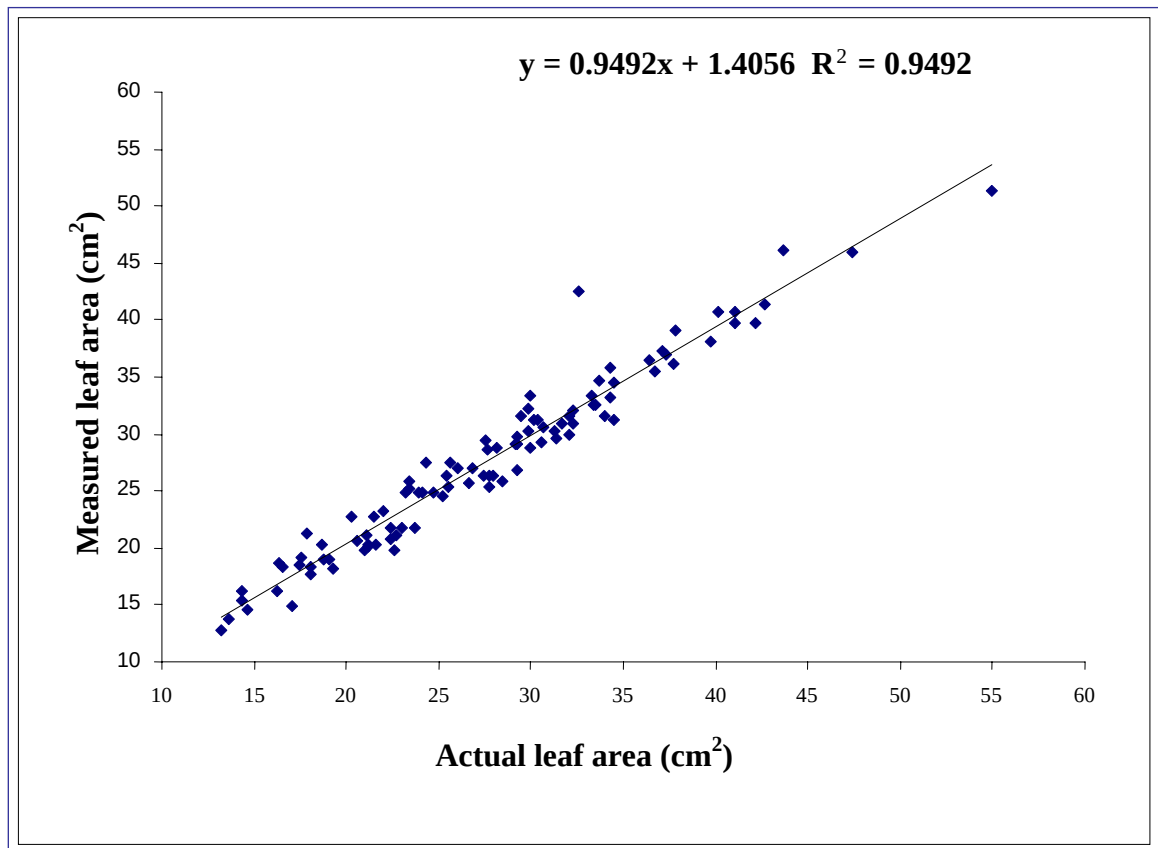


Fig 4.7 Relationship between the Actual leaf area and Area estimated using regression Equation $Y = (L*W)*0.6585 - 0.9828$.

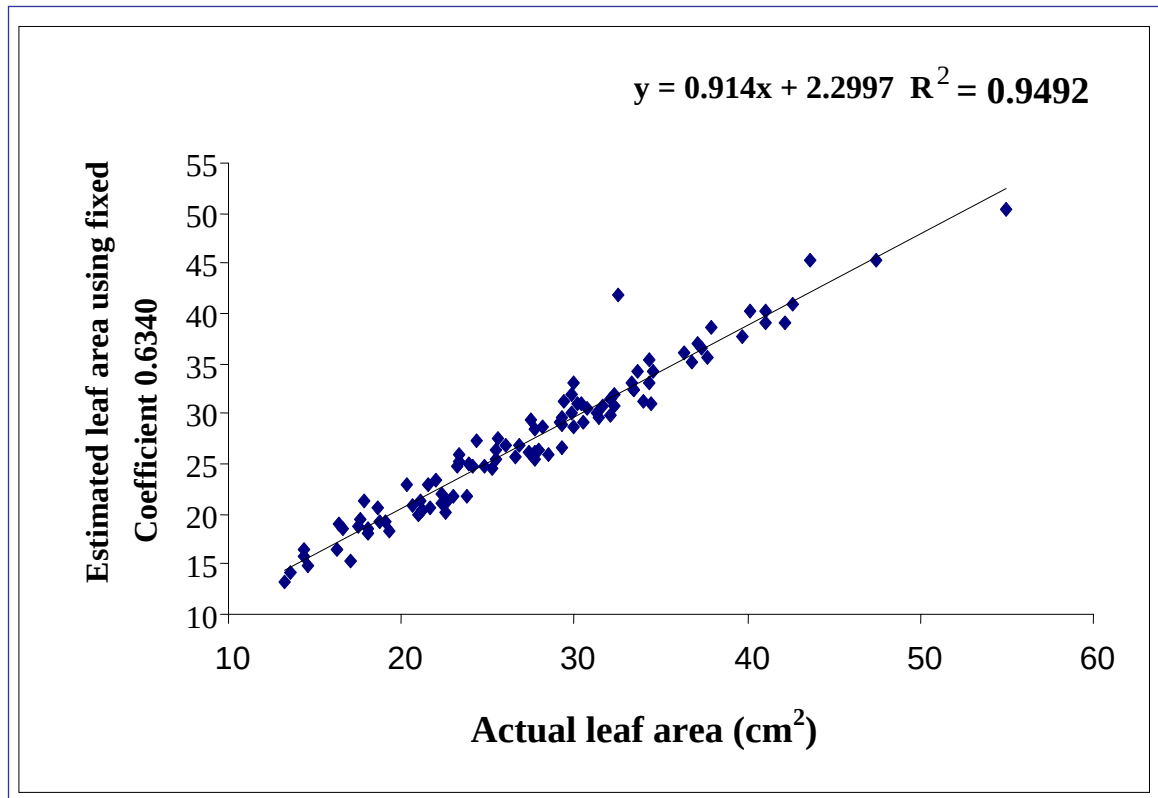


Fig 4.8 Relationship between the actual leaf area and area estimated using fixed coefficient 0.6340.

Azadiractha indica

n=100

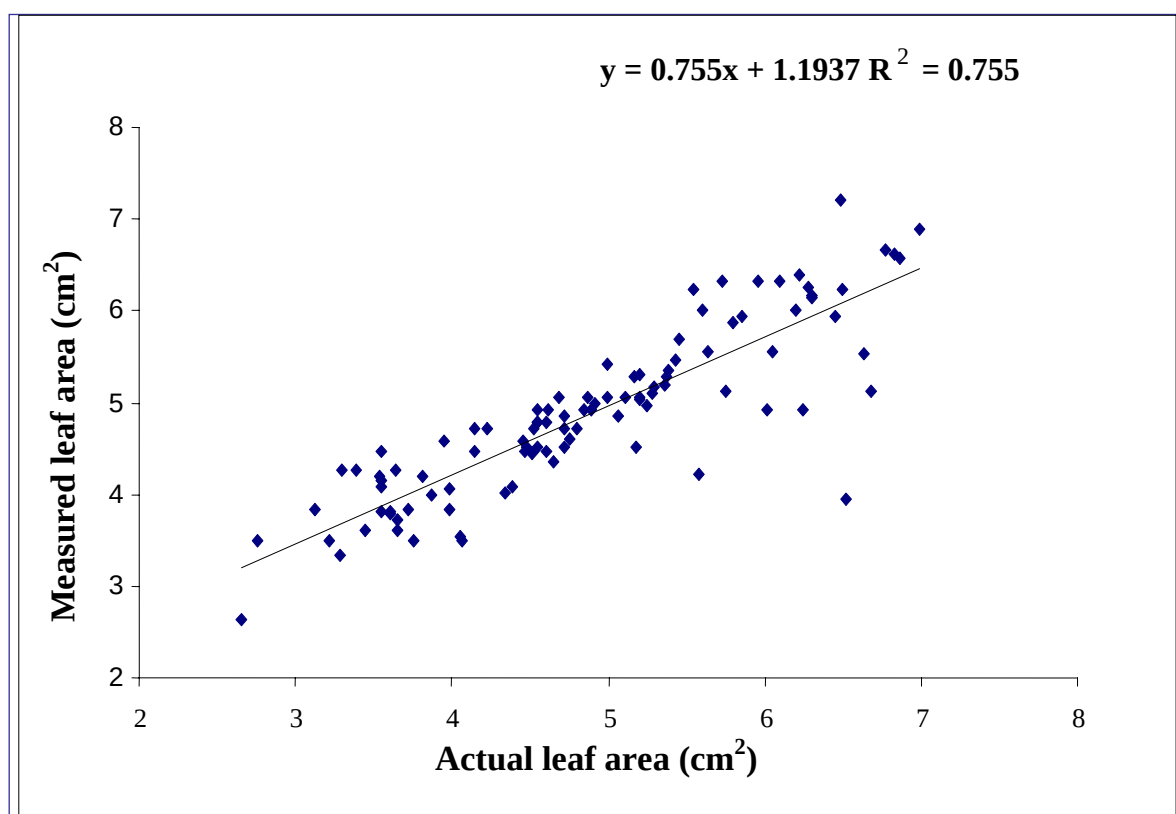


Fig 4.9 Relationship between the actual leaf area and area estimated using regression Equation $y = (L*W)*0.465 + 0.8781$.

Azadiractha indica (Neem)

n=100

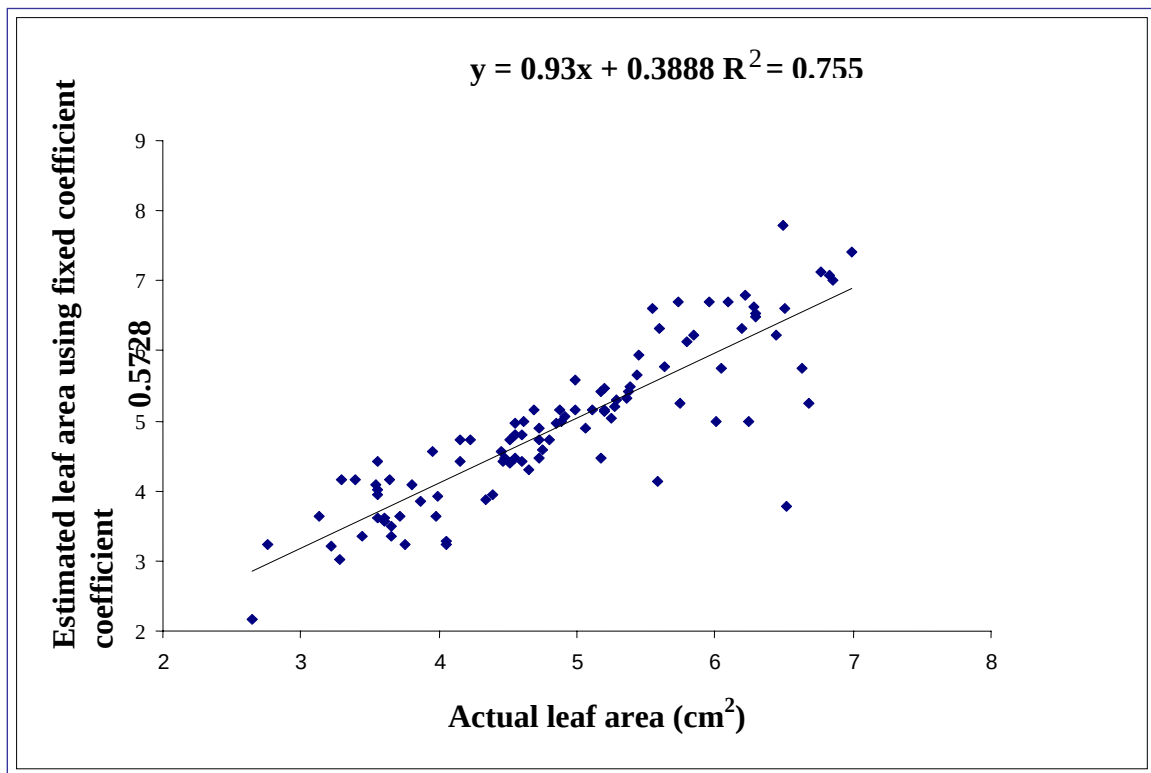


Fig 4.10 Relationship between the actual leaf area and area estimated using fixed Coefficient 0.5728.

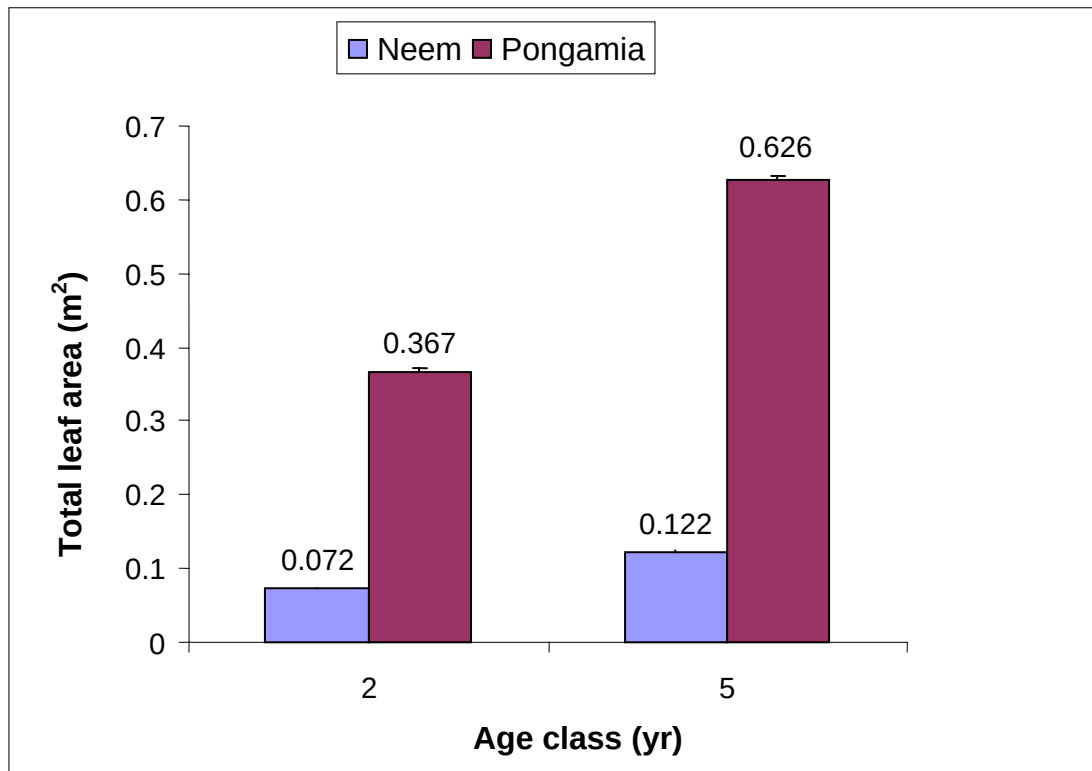


Fig 4.11 Variation in total leaf area across the age class.

change in leaf shape. Using the factor total leaf area was estimated in trees belong to different age class. As expected there was higher leaf area in 5 year old plant compared to 2 year. The total leaf area in pongamia (0.367m^2) in 2 years, (0.626m^2) across 5 year was higher compared to the neem (0.072m^2) in 2 years and (0.122m^2) 5 years as shown in the figure.(Fig.4.11)

DISCUSSION

V. DISCUSSION

Tree borne oil seeds are the ray of hope for biodiesel production in India. Cultivation of pongamia and neem on farmland is not a new concept; it is a age old practice to grow one or two trees of pongamia and neem in dry land agricultural system. These two species are multipurpose trees and yield timber, oil as medicine and biofuel, cake and is used as organic manure. Amongst many species, which yield oil a source of energy in the form of bio-fuel, *Pongamia pinnata* and *Azadiractha indica* has been found to be one of the most suitable. In India pongamia is also known as N₂-fixing tree, not browsed by animals. These trees can be planted on degraded lands, farmer's field boundaries, wastelands / fallow lands. Neem an indigenous species known for its drought resistance. Normally it thrives in areas with sub-arid to sub-humid conditions with an annual rainfall between 400 and 1200 mm. Growth rate of neem is slow in initial stages and a height of 6-12 m may be expected in 20 years and has the ability to grow under varied agro climatic condition. *Pongamia pinnata* is a deciduous legume tree that grows to about 15-25 meters in height with a large canopy. The tree grows in wide range but well-adapted to arid zones and has many traditional uses.

Global warming is the most dreaded problem of the new millennium. Carbon emission is supposedly the strongest causal factor for global warming. So, increasing carbon emission is one of today's major concerns, which is well addressed in Kyoto Protocol. The Kyoto protocol is a 1997 international treaty that took effect in 2005 which currently bind ratifying nations to a similar system, with the UNFCCC setting caps for each nation. Kyoto protocol provides for this facet of its cap and trade program with the Clean Development Mechanism (CDM).

The CDM, as well as joint implementation provide flexible mechanisms to aid regulated entities in their compliance with their caps.

In October 2003, powerguda a village in Andhra pradesh became an environmental pioneer when it sold the equivalent of 147t of carbon dioxide in verified emission reduction to the World Bank. The emission reduction was calculated on the basis of 51t of Pongamia oil substituting for petroleum diesel over 10 years. Powerguda's action has inspired several other neighboring villages to plant Pongamia trees on a large scale.

India ranks 6th in terms of consumption of energy, which is 3.5% of the total world's commercial energy. The current consumption of diesel in India is about 40 mt (40% of the total petroleum product consumption), the demand is growing at a rate 5.6% per annum. Hence there will be a huge gap between demand and supply which needs to be met through increasing fuel imports or increasing production of biodiesel through developing biodiesel plantations without sacrificing the food security of the country. Biodiesel is renewable energy resource generated from rehabilitation of waste and degraded lands.

The present investigation entitled 'Evaluation of carbon sequestration ability of *Azadirachta indica* and *Pongamia pinnata*' is an attempt to throw some light on this aspect which is of global concern.

The results obtained in this study are discussed under the following headings.

1. Carbon stock present in the wood of *Azadirachta indica* and *Pongamia pinnata*.
2. Photosynthetic ability of *Azadirachta indica* and *Pongamia pinnata*.

3. Classify the species based on their growth behavior and carbon sequestration ability.

5.1 Carbon stock present in the wood of *Azadiractha indica* and *Pongamia pinnata*.

Climatic factors like moisture, rainfall, temperature, humidity affect the vegetation of which, the factor- rainfall plays a prominent role in each of the site conditions (Dwivedi, 1992). In the present study the analysis of variance showed significant effect of age on various parameters such as height, diameter, volume, biomass accumulation and carbon sequestration in *Azadiractha indica* and *Pongamia pinnata*. Where as gas exchange characteristics in *Azadiractha indica* and *Pongamia pinnata* were non significant. The age gradation has exhibited significant effect on all parameters. A comparison made with *Azadiractha indica* and *Pongamia pinnata* across different ages (2, 5 and 10 years) exhibited significant difference with respect to all of the parameters. The responses of *Azadiractha indica* and *Pongamia pinnata* at different age with respect to growth, biomass accumulation, carbon sequestration, and gas exchange characteristic to the broad variation in climatic factors within a narrow geographical area are found to be significant across parameters examined.

In case of *Pongamia pinnata* the height (0.80m), diameter (0.015m), volume (0.0003m³), biomass (0.09t/ha), and carbon sequestered in wood (0.045t/ha) across 2 years was more compared to height (0.51m), diameter (0.011m), volume (0.0001m³), biomass (0.03t/ha), and carbon sequestered in wood (0.015t/ha) of *Azadiractha indica* across 2 years. This is because in initial stages the growth rate in neem is slow compared to pongamia (Jha., 1990) and it produces less leaves in the early ages. This might be the probable reason due to which growth rate of neem in 2 years is less compared to pongamia.

Performance of *Azadiractha indica*, with respect to height (2.86m), diameter (0.055m), volume (0.007m³), biomass (1.93t/ha), and carbon sequestered in wood (0.969t/ha) across 5 years was more comparable to the height (1.73m), diameter (0.044m), volume (0.002m³), biomass (0.81t/ha), and carbon sequestration in the wood (0.408t/ha) of pongamia. Five year age neem overtook pongamia because rate of growth in neem is slow in initial stages but later growth enhances, as neem produces deep tap root and where as pongamia produces lateral roots. Tap root helps the neem to acquire more nutrients, water from the deeper layer of the soil.

Similarly the results of *Azadiractha indica* with respect to height (4.6m), diameter (0.065m), volume (0.017m³), biomass (4.33t/ha) , and carbon sequestered in wood (2.16t/ha) across 10 years was more compared to the height (4.07 m), diameter (0.06 m), volume (0.012 m³), biomass (3.50t/ha), and carbon sequestered in the wood (1.75t/ha). Pongamia tolerate the drier condition for shorter period. The results on studies carried out on six tree species clearly showed that the average consumption of water/g/of biomass was 0.51 for the *Eucalyptus terticonis*, compared to 1.30 for *Derris indica* (Chaturvedi. 1994.). But in case of neem it produces deep tap root, which helps it to over come drought condition and still enhance growth.

In the present study the growth rate in case of neem is slow compared to pongamia may be it's because of less total root volume in the initial stage, where in it may affect the uptake/absorption of nutrients and moisture. Since both neem and pongamia are grown under unique spacing of 5m x 5m, plant density does not have any impact on the growth of the species.

5.1.1 Wood density and moisture content of the species

Wood density of the both the species were estimated and based on the results, it was found that density of *Pongamia pinnata* (696.58kg/m³) was more compared to density of *Azadiractha indica* (626.21kg/m³). According to Desch (1992), different timbers vary in density from about 160 kg/m³ to 1250 kg/m³. Hence density of pongamia is more compared to neem, it might be because certain factors like rate of growth, site conditions, and genetic composition of the species and within the provenance of same species.

Moisture content of the *Pongamia pinnata* (82.48%) in oven dry method was found to be more compared to neem (52.75%). Similarly in air dry method the moisture content of *Pongamia pinnata* (71%) was more compared to neem (42%) because in 5 year aged plants formation of heartwood will be less and most of the tissue is attributed to the components of cortex and parenchyma cells in the middle part of the stem that facilitates more moisture content in pongamia than neem.

Salient findings from the biomass estimation in present study indicate that various factors influence the growth performance of a species in a locality. Among them soil and climatic factors play a major role and in certain cases plants like pongamia and neem adapt themselves to any harsh condition.

Similar results in pongamia with respect to growth studies was noticed compared to the work done by Shivanna *et al.*, (2006) on *Pongamia pinnata* seedlings at different growth intervals of 8, 16, 24th months observations. With respect to height, gbh, crown diameter during 16 and 24 month the mean crown height, girth and crown diameter was recorded as 3.1, 0.19, 1.5 m and 2.89, 0.24, 1.98m respectively and growth parameters like biomass yield, carbon sequestered during 8th 16

th and 24th months were 4.23, 2.11, 8.06 and 4.03, 12.40, 6.20 tones of 'C'/ha respectively. There is a slight variation in the results obtained from the shivanna *et al.*, compared to present studies at the age of 2 years (24 month) interval because growth of pongamia vary with respect to climatic condition, site factors, soil condition and rainfall patterns in that region. Whereas pongamia grown in the present study across 2 years was found to be growing with other species like Jathropa, Simarouba, competition might have affected its growth rate at the initial stages.

The results with respect to height and dbh of 2, 5 and 10 years were similar with the findings of Banerjee (1973) at the age of 6 and 10 years and Sugur (1989) in *Acacia auriculiformis* at the age of 6 years. Similar results on the better performance of *Acacia auriculiformis* under a moderate rainfall of 1300 to 1400 mm per annum was observed by Webb *et al.* (1984) in *Acacia auriculiformis* in Australia. Tewari (1992) reported that, teak thrives well within an annual rainfall range of 1000-1500 mm. The report on *Acacia auriculiformis* showed that the species grows best in a humid climate, with rainfall of 1000 mm or up to 1800 mm and a dry period of 6 months (Kushalapa, 1988). The studies conducted on the growth performance of the teak at the age of 19 years suggests that the growth and yield attributes were superior, where the rainfall ranges from 1500-2000 mm compared to the two sites having the rainfall ranges of 1250-1500 mm and 2000-5000 mm (Aparanji, 2000).

The results obtained on biomass were similar compared to the findings on the biomass accumulation of *Eucalyptus tereticornis* of less than 3 year to 9 year old plantation in different agro-ecological regions of India. In dry tropical region biomass accumulation was more in cooler areas as compared to warmer areas water was not the limiting factor comparatively higher mean annual temperature of around 25°C seems to

produce higher biomass. Vijay Rawat and Negi (2000), Siva Kumar *et al.* (2000) reported that rubber plantation accumulated a good proportion of biomass of age crossing their juvenile stage of growth and average proportion of biomass was relatively good in Northeastern India.

A similar result on the carbon sequestered was reported in the north eastern regions of India in rubber plantation accumulating 72.36 tons of carbon from one hectare by 27 year old plantation (Sivakumar *et al.* 2000). The results with respect to carbon sequestered were similar to the findings of Shivanna *et al.* (2006) at the growth intervals of 8, 16, 24th month observations in *Pongamia pinnata* seedlings. It is apparent from the present investigation that the performance of *Azadirachta indica* and *Pongamia pinnata* with respect to various parameters such as total height, diameter, volume, above ground biomass and carbon sequestered were more affected by moisture availability in the initial years (2 and 5 years) and by fertility build up (soil organic carbon) in later years (10 years).

Research findings from the overseas revealed that similar type of work on carbon sequestration in American chestnut at different sites consistently exhibited the largest mean growth in almost every category at every age on every site. This data demonstrates the significance within individual species of planting density and site quality on productivity and corresponding rates of carbon uptake. These variable factors also make direct comparisons regarding carbon uptake among species planted under different densities difficult. Regardless of these limitations, the results from this study demonstrated that the American chestnut's ability to sequester carbon compares favorably with any other species in this region. (Diamant, 2005).

The results with respect to carbon sequestration were similar with the findings of (Loretta Gratani and Laura Varone., 2005). Their work

revealed that total carbon sequestration is 84 ± 12 and 111 ± 9 Kg year⁻¹ of CO₂ for the small *Quercus ilex* and *Quercus pubescens* tree size, respectively, and 151 ± 10 and 185 ± 7 Kg year⁻¹ of CO₂ for the large *Quercus ilex* and *Quercus pubescens* tree size, respectively. *Quercus pubescens*, by its higher total photosynthetic leaf surface area (39% higher than *Quercus ilex*) and its higher mean yearly photosynthetic rates (48% higher than *Quercus ilex*) seems to have a greater role than *Quercus ilex*. However, taking into account the leaf longevity (i.e. 12 ± 3 months for *Q. ilex* and 4 ± 2 months for *Q. pubescens*), the evergreen species, by its continuous photosynthetic activity, contributes to reduce CO₂ throughout the year, and in particular during the winter months, when traffic volume has a pick, than *Q. pubescens*. On the whole, results of the present suggest that the evergreen and deciduous trees play a major role in sequestering CO₂ and reducing air temperature in the city of Rome, and there by delaying global warming. Nevertheless, there is a tradeoff between greater sequestration by *Q. ilex* versus *Q. pubescens* by the presence of leaves throughout the year, and also in winter, when the traffic has the highest picks (Loretta Gratani and Laura Varone, 2005).

Many studies on carbon sequestration ability of trees were done world wide in different species, age gradations, and different climatic conditions. Research all over the world reveals that carbon sequestering ability of tree species vary from species to species and site conditions. (Table 5.1)

Table 5.1: Different research works on carbon stock per hectare.

Species	Age (Years)	Carbon stock (t/ha)	References
<i>Eucalyptus grandis</i>	2	9.15	Bradstock, 1981
<i>Eucalyptus fastigata</i>	4	30.9	Madgwick <i>et al.</i> , 1981
<i>Eucalyptus nitens</i>	4	40.9	Madgwick <i>et al.</i> , 1981
<i>Eucalyptus globules</i>	4	15.15	Cromer <i>et al.</i> , 1975
<i>Eucalyptus teriticornis</i>	4	17.8	Ahimana and Maghembe, 1987
<i>Eucalyptus diversicolor</i>	4	15.65	Grove and Malajczuk., 1985
<i>Eucalyptus grandis</i>	5	26.6	Bradstock, 1981
<i>Eucalyptus saligna</i>	5	50.68	Whitesell, <i>et al.</i> , 1988
<i>Shorea robusta</i>	6	5.22	<i>Jana et al.</i> , 2009
<i>Albizzia lebbek</i>	6	6.26	<i>Jana et al.</i> , 2009
<i>Tectona grandis</i>	6	7.97	<i>Jana et al.</i> , 2009
<i>Artocarpus integrifolia</i>	6	7.28	<i>Jana et al.</i> , 2009
<i>American chestnut</i>	8	2.07	Diamant, A., 2005
<i>Black walnut</i>	8	2.25	Diamant, A., 2005
<i>Red oak</i>	8	0.41	Diamant, A., 2005
<i>American chestnut</i>	12	6.28	Diamant, A., 2005
<i>Black walnut</i>	12	4.77	Diamant, A., 2005
<i>Red oak</i>	12	3.96	Diamant, A., 2005
<i>Azadiractha indica</i>	2	0.015	Present study
<i>Azadiractha indica</i>	5	0.96	Present study
<i>Azadiractha indica</i>	10	2.16	Present study
<i>Pongamia pinnata</i>	2	0.04	Present study
<i>Pongamia pinnata</i>	5	0.40	Present study
<i>Pongamia pinnata</i>	10	1.75	Present study

Earlier estimates by different scientists were higher than our estimate. The reasons for low carbon stock as estimated by my work may be due to: consideration of only above ground biomass, and worked in similar agro-climatic areas. Earlier works were estimated mostly based on aboveground and below ground carbon biomass, considered different age groups, different species and different agro-climatic areas, for which carbon stock per hectare may be in higher side. But still *Azadiractha indica* and *pongamia pinnta* over takes red oak with respect to carbon sequestration across 5 years. Similiarly *A.indica* across 10 years has more sequestering capacity compared to *American chestnut*. Pongamia and neem are very common trees found in dry land agriculture of our state. Despite the persistent drought the pongamia and neem trees will flourish well in dry regions. In addition to biofuel, these trees provide other resources vital for farming community like seed cake, used as bio pesticide etc. In general, it can be said that neem and pongamia are multipurpose trees. From the present study carbon sequestering capacity of neem and pongamia were estimated, keeping this information in future farmers can go for carbon trading as mentioned in the Kyoto protocol. With the progress of the forest stand ages, canopy cover and biomass of the trees will experience more rapid growth to a certain age (20 - 50 years) and the carbon held by these plants will also increase more biomass carbon stock to its optimum level (Marland and Marland, 1992).

Based on the results obtained from the correlation studies between growth parameters (Height, diameter, volume, and biomass) across 2, 5 and 10 years age in *Azadiractha indica* and *Pongamia pinnata* revealed that there was a positive correlation between the volume and diameter across different age gradation respectively and biomass- height are found to be moderately correlated in 2 and 5 year age gradation. Since carbon present in the wood stock is assumed to be half of the biomass according

to the IPCC. It is likely that there will be a positive correlation between the carbon-biomass.

5.2 Gas exchange characteristics

Analysis of growth and yield parameters in perennial plants requires experiments of long duration. To overcome the difficulties associated with long experimentation, a certain physiological process directly linked to growth can be analyzed. Photosynthesis is one of the major processes associated with growth and hence analysis of photosynthesis can give sufficient information on growth performance of tree crops. (Nataraja and Jacob, 1999). There are reports indicating the relation of photosynthetic measurements in growth analysis (Nataraja and Jacob, 1999). From this context in the present study attempts were made to analyze the photosynthesis performance of different age class (2 and 5 years) of *A. indica* and *P. pinnata*.

In the gas exchange studies in two species, it was found that photosynthetic rate ($11.84 \mu\text{moles m}^{-2}\text{sec}^{-1}$) across 2 year old plants in neem was high compared to pongamia ($9.455 \mu\text{moles m}^{-2}\text{sec}^{-1}$). Similarly in case of 5 year old trees the photosynthetic ability of pongamia ($12.63 \mu\text{moles m}^{-2}\text{sec}^{-1}$) was high compared to ($12.00 \mu\text{moles m}^{-2}\text{sec}^{-1}$) Neem. Stomatal conductance of pongamia across 2 year ($0.200 \text{ mol m}^{-2} \text{ sec}^{-1}$), 5 year ($0.301 \text{ mol m}^{-2} \text{ sec}^{-1}$), was more compared to the stomatal conductance of *A. indica* in 2 year ($0.132 \text{ mol m}^{-2} \text{ sec}^{-1}$), 5 year ($0.130 \text{ mol m}^{-2} \text{ sec}^{-1}$) respectively. Similarly the intercellular carbon dioxide rate in pongamia across 2 year (301 ppm), 5 year (307.9 ppm) was more compared to *A. indica* at 2 years (209.55 ppm), 5 year (229.7 ppm) and transpiration rate in *P. pinnata* across 2 year ($4.11 \text{ mmol m}^{-2}\text{sec}^{-1}$), 5 year ($6 \text{ mmol m}^{-2}\text{sec}^{-1}$) was more compared to *A. indica* at 2 year ($2.84 \text{ mmol m}^{-2}\text{sec}^{-1}$), 5 year ($3.07 \text{ mmol m}^{-2}\text{sec}^{-1}$).

In the present study, instantaneous water use efficiency and *invivo* carboxylation efficiency were assessed and it was observed that *invivo* carboxylation efficiency in neem across different age class was high compared to pongamia as shown in the figure (Fig 4.3 and 4.4).

Higher carboxylation efficiency indicates better ability of plants to fix carbon and hence plants with high carboxylation efficiency are always preferred. Another parameter which is generally computed from gas studies is instantaneous water use efficiency estimated as A/g_s . From the present study indicates that neem has better ability to fix carbon per unit amount of water loss through transpiration and in the present study it is likely that high stomatal conductance (g_s) contributes for the high transpiration rate in the species.

From the present study it was noticed that stomatal conductance (g_s) seems to be the major factor responsible for determining photosynthesis in neem and pongamia. Photosynthesis is said to be a biochemical process and often regarded as diffusive process also. The rate of diffusion is controlled by two factors. One, the stomatal conductance and second the intercellular carbon dioxide rate. With increase in stomatal conductance rate there will be increase in photosynthetic rate. In case of 2 year old neem photosynthetic ability was more compared to *Pongamia pinnata*. Though the conductance rate in case of pongamia is high still higher photosynthetic rate was noticed in neem because in some plants there will be poorly developed mesophyll tissue and the lower correlation value between photosynthesis and stomatal frequency, so that despite a high density of stomata, the photosynthesis rate is not very high throughout the day.

Transpiration rate in case of pongamia was high compared to neem across age gradation. We can see that in case of 5 year old trees of pongamia and neem transpiration rate was maximum compared to 2

year old plants. It is because in case of 5 year old trees root penetration will go very deep so that it accumulate more water and nutrients, due to this water use efficiency will be more in case of 5 year old trees compared to 2 year old plants. From the present study it was observed that transpiration rate is more in case of pongamia compared to neem.

Data on Photosynthetic ability of neem were found to be similar compared to the study on Variation in net photosynthesis, CO₂ exchange parameters, stomatal characteristics, leaf area and seedling dry weight investigated among 10 provenances of neem (*Azadirachta indica* A. Juss.). Significant provenance variation was established for net photosynthesis (8.14 to 15.13 $\mu\text{mol m}^{-2} \text{s}^{-1}$), Stomatal conductance (0.37 to 0.59 $\text{mol m}^{-2} \text{s}^{-1}$), Stomatal density (145 to 204 $\text{mol m}^{-2} \text{s}^{-1}$), and total guard cell length (2681 to 3873 μm). Net photosynthesis was positively correlated with whole-plant dry weight and leaf area. Stomatal density was positively correlated with net photosynthesis, whole-plant dry weight, and leaf area. Total guard cell length was positively correlated with all of these traits. Information on six traits was used in a cluster analysis to construct a dendrogram to assess phenetic relationships among the provenances. With a few exceptions, the dendrogram revealed three major clusters grouped according to rainfall distribution. The study indicated that whole-plant phytomass production of neem seedlings was associated with photosynthesis and stomatal characteristics during the early stages of growth (Kundu, et al., 1999).

McCree and Davies (1974) have shown that Stomatal sensitivity to decreasing leaf water potential may depend on availability of water to the plant during growth. It is therefore important in any controlled environment work that realistic growth conditions should be selected. Stomatal conductance in pongamia across age gradation was more compared to neem because the plants are sensitive to water stress.

Though both neem and pongamia were grown in dry area, leaf water potentials of the species decreases. Stomatal conductance and net photosynthesis were reduced at higher levels of plant water stress.

5.3 Estimation of leaf area as a parameter for growth analysis

Leaves are very important component of any tree and they are the sites for photosynthesis which intern helps in growth and development of whole tree. Total leaf area of a tree need to be known for growth and biomass studies. In the Present Study non-destructive method was used to develop the leaf area regression equation for neem (leaf area = $L \cdot W \cdot 0.465x + 0.8781$) and the leaf area regression equation for pongamia (Leaf area = $L \cdot W \cdot 0.6585 - 0.9828$). The relationship was found to be slightly significant ($P < 0.001$; $R^2 = 0.94$ for pongamia and $R^2 = 0.75$ for neem). As there was variation in the leaf factor between two species due to change in the leaf shape of the neem. Where as pongamia has compound pinnate leaves with the pointed end, which doesn't vary much in shape.

Using this factor total leaf area was estimated in trees belonging to different age class. As expected there was high leaf area in 5 year old plants compared to 2 year old. The total leaf area in pongamia was more compared to neem. Initial growth rate of trees depend on rate of development of leaf area or photosynthetic area. It is likely that the high proportion of biomass allocated to leaf can result in better growth due to overall increment in canopy photosynthesis. Therefore estimated leaf area is very critical while assessing the growth. Based on the present study it is possible to conclude that the leaf area factor can be estimated for individual species and used to arrive for total leaf area in a non destructive way. In early stage of plant development 2 year old plants of pongamia had showed higher leaf area compared to neem which has resulted in increase in biomass however such relation was not noticed, it

may be due to various other reasons .In addition to canopy photosynthesis, canopy respiration also contributes for biomass gain therefore total canopy alone be considered while correlating growth rate.

Results on the regression equation to measure leaf area developed for Neem and Pongamia were similar to the findings of (Nataraja *et al.*, 2003) in teak (*Tectona grandies*) grown in nursery. Where the regression equation, leaf area = $(L*W)*0.543+2.967$, was derived and was found significant in different provenances.

5.3.1 Practical implication of results:

1. From the present investigation it can be said that carbon sequestration potentials are high in *Azadiractha indica* compared to *Pongamia pinnata* at different age groups. So by planting these species farmers can reap additional benefits like trading carbon and one can sell the seeds in the market which are used to extract the oil and used as biofuel/insecticide.
2. In Kyoto protocol it is mentioned that there should be a system to reward farmers for planting and conserving native plant species. Hence it is important to quantify the carbon in native tree species.
3. Regression equation has been developed for *Azadiractha indica* and *Pongamia pinnata*. So that in future by using that regression equation leaf area of both the species can be measured without using any instrument.
4. By afforesting the trees with respect to climate change, we could reduce and mitigate the adverse effect on environment.

5.3.2 Future line of work

1. From the literature it is found that no study has been made to assess the carbon sequestering capacity of *Pongamia pinnata* and *Azadiractha indica* plantations in India. Elsewhere in the world there are only few studies reported.
2. *Azadiractha indica* and *pongamia pinnata* are relatively fast growing species of short rotation period, the biomass and carbon sequestration studies in diverse conditions with reference to zone and age are required to be studied on a large scale.
3. Since carbon sequestration is a major tool for reducing global warming in various sectors, hence emphasis on research should be given in the multi disciplines of Forestry, Agro forestry Agriculture etc.
4. Carbon sequestration studies could be strengthened by application of remote sensing in natural forests and plantations.
5. The soil analysis should be done to know the soil organic carbon Storage (t/ha) at various localities.
6. The modern method of litter and soil analysis for carbon should be followed for natural forest and plantation species.

SUMMARY

VI. SUMMARY

In the present study *Azadirachta indica* and *Pongamia pinnata* each under three different age gradations (2, 5 and 10 years) were evaluated for various parameters such as growth, volume, above ground biomass and carbon sequestered in trees.

4. To assess the carbon stock present in the wood of *Azadirachta indica* and *Pongamia pinnata*.
5. To assess photosynthetic ability of *Azadirachta indica* and *Pongamia pinnata*.
6. To classify the species based on their growth behavior & carbon sequestration ability.

In the present investigation, the analysis of variance showed significant effect on various parameters such as total height, diameter, form factor, volume, above ground biomass and carbon sequestration in *Azadirachta indica* and *Pongamia pinnata*.

4. **Assessment of Carbon stock present in the wood of *Azadirachta indica* and *Pongamia pinnata*.**

➤ The growth parameters of pongamia of 2 years age are higher than neem but in 5th and 10th year the growth parameter are higher in neem compared to Pongamia.

➤ Wood density and moisture content were assessed and from the present study the wood density of pongamia was higher compared to neem. Similarly, moisture content of pongamia was higher compared to neem.

5. **Assessment of photosynthetic ability of *Azadirachta indica* and *Pongamia pinnata*.**

➤ The gas exchange characteristics of *Azadirachta indica* in 2 years and 5 years revealed that mean photosynthetic rate of *Azadirachta indica* was high in case of 2 years compared to *Pongamia pinnata*. In case of 5 years *Pongamia* has more photosynthetic rate compared to neem and it was found to differ significantly in case of *Pongamia* across different age class.

➤ Stomatal conductance for both the species were assessed at 2 and 5 year age class, results revealed that stomatal conductance of *Pongamia pinnata* across 2 and 5 year age gradation was high compared to the stomatal conductance of *Azadirachta indica* and statistically stomatal conductance in *Pongamia pinnata* was found to be significantly different ($P < 0.005$) and it was non significant in *Azadirachta indica*.

➤ Intercellular carbon dioxide rate (C_i) across 2 and 5 years was high in *Pongamia pinnata* compared to *Azadirachta indica* and statistically the result was found non significant. Transpiration rate (E) was more in *Pongamia pinnata* at 2 and 5 years compared to *Azadirachta indica* and the result were found to be statistically significant, ($P < 0.005$) in *Pongamia pinnata* and non significant in *Azadirachta indica* across different age class.

➤ It was found that in 2 and 5 year plantation the *in vivo* carboxylation efficiency was found to be maximum in neem compared to *Pongamia*.

➤ The instantaneous water use efficiency was found to be maximum in neem across 2 and 5 years compared to *Pongamia*.

6. **Classification of the species based on their growth behavior & carbon sequestration ability.**

➤ Among two species *Azadirachta indica* and *Pongamia pinnata*, the growth parameters of *Pongamia pinnata* of 2 year age more compared to neem. But in 5th and 10th year growth of neem has over took pongamia.

➤ Based on the gas exchange studies, it was found that in 2 year age plants photosynthetic rate is more in neem compared to pongamia and in 5 years pongamia has over took neem with respect to photosynthetic ability. Similarly the stomatal conductance, intercellular carbon dioxide rate, transpiration rate was higher in pongamia across ages compared to neem. Water use efficiency and in vivo carboxylation efficiency across 2 and 5 years were more in *Azadirachta indica* compared to and *Pongamia pinnata*. Similarly it was found that stomatal conductance, intercellular carbon dioxide rate across 2 and 5 years were more in *Pongamia pinnata* compared to *Azadirachta indica*.

➤ Correlation studies between growth parameters (height, diameter, volume, and biomass) across 2, 5 and 10 years age in *Azadirachta indica* and *Pongamia pinnata* revealed that there was a positive correlation between the volume and diameter across ages and biomass and height are found to moderately positively correlated across 2 and 5 age gradation and found non significant in 10 year age gradation.

➤ The regression equation, Leaf area (LA) = $L \cdot W \cdot 0.6585 - 0.9828$ for pongamia and Leaf area (LA) = $L \cdot W \cdot 0.465x + 0.8781$ for neem was derived by taking actual leaf area as dependent variable and product of L and W as independent variable ($r = 0.97$ for pongamia and $r = 0.86$ for neem.) The fixed coefficient calculated by taking the ratio of actual to

product of L and W was found to be 0.634 for pongamia and 0.572 for neem .The equation and coefficient was validated and was found significant. The study indicates that either FC (fixed co-efficient) or RE (regression equation) can be used with precision to determine LA (leaf area) of neem and pongamia grown in natural condition, non-destructively.

➤ The total leaf area in pongamia across age class was high compared to the neem.

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