CARBON SEQUESTRATION IN TREE PLANTATIONS AT KURUKSHETRA

SUMMARY

SUBMITTED TO

THE FACULTY OF LIFE SCIENCES

KURUKSHETRA UNIVERSITY KURUSHETRA

FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN

ENVIRONMENTAL SCIENCE

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AUGUST, 2014
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter-1</th>
<th>INTRODUCTION</th>
<th>1-16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter-2</td>
<td>REVIEW OF LITERATURE</td>
<td>17-42</td>
</tr>
<tr>
<td>Chapter-3</td>
<td>MATERIALS AND METHODS</td>
<td>43-62</td>
</tr>
<tr>
<td>Chapter-4</td>
<td>RESULTS AND DISCUSSION</td>
<td>63-201</td>
</tr>
<tr>
<td></td>
<td>4.1 Floristic diversity and herbaceous vegetation analysis of different plantations</td>
<td>63-74</td>
</tr>
<tr>
<td></td>
<td>4.2 Study of physico-chemical properties of soil of tree plantations</td>
<td>75-118</td>
</tr>
<tr>
<td></td>
<td>4.3 Quantification of soil organic carbon stocks in different plantations</td>
<td>119-137</td>
</tr>
<tr>
<td></td>
<td>4.4 Quantification of soil organic carbon stocks in soil aggregates</td>
<td>138-143</td>
</tr>
<tr>
<td></td>
<td>4.5 CO₂ evolution rates from the soil of different plantations</td>
<td>144-151</td>
</tr>
<tr>
<td></td>
<td>4.6 Quantification of plant biomass and productivity in different forestry plantations</td>
<td>152-175</td>
</tr>
<tr>
<td></td>
<td>4.7 Carbon dynamics and carbon flux in vegetation</td>
<td>176-188</td>
</tr>
<tr>
<td></td>
<td>4.8 Quantification and carbon estimation in litter fall</td>
<td>189-193</td>
</tr>
<tr>
<td></td>
<td>4.9 Total carbon pools in vegetation and soil of different plantations</td>
<td>194-200</td>
</tr>
<tr>
<td>Chapter-5</td>
<td>CONCLUSIONS</td>
<td>201-211</td>
</tr>
<tr>
<td>References</td>
<td></td>
<td>212-246</td>
</tr>
<tr>
<td>Appendix</td>
<td></td>
<td>I-XXVIII</td>
</tr>
</tbody>
</table>
1.1 INTRODUCTION

Terrestrial vegetation actively absorbs atmospheric CO$_2$ during growth. Also, different species respond in different ways for carbon utilization. In addition to the estimates of carbon in biomass, the rate of biomass accumulation in various forest types plays a significant role in the global carbon budget. Tree based systems have the potential to accumulate large amount of biomass and sequester substantial amount of carbon in perennial tree components and soil. These can also maintain the health of soil that can provide a wide range of ecosystem goods and service and hence play a crucial role in sustaining biological productivity of the land. Thus, quantification of carbon sequestration in soil and biomass is an essential requirement for predicting the future role of tree plantations in mitigating climate change.

In the present study, efforts were made to assess the carbon sequestration potential of five different tree plantations in the University Campus of Kurukshetra University. The tree plantations selected for study were (1) mixed plantation of *Acacia nilotica*+*Dalbergia sissoo*, (2) pure plantations of *Syzygium cumini* and (3) *Tectona grandis* (all native species) and pure plantations of (4) *Populus deltoides* and (5) *Eucalyptus tereticornis* (exotic species). The trees were planted under social forestry schemes of Forest Department of Haryana. All the plantations were of uniform i.e. 10 years. However, the tree density of theses plantations varied (*A. nilotica*+*D. sissoo*: 765trees/ha, *S. cumini*: 1125tree/ha, *T. grandis*: 400tree/ha, *E. tereticornis*: 1350tree/ha, and *P. deltoides*: 700trees/ha).

The plantations were assessed for their herbaceous diversity, seasonal variations in physico-chemical properties of soil up to one meter depth, soil carbon stocks, soil respiration rates and soil microbial biomass carbon. Also, the weight distribution in different soil aggregate size classes and carbon in soil aggregates was quantified. The tree biomass and net primary productivity, vegetation carbon stocks and carbon flux, CO$_2$ assimilation rates by tree biomass, monthly variations in litter fall were also determined for the selected plantations. The vegetation and soil carbon stocks were summed up for estimating the total carbon stocks of each plantation. The sum of carbon stocks of all the plantations was represented as the carbon stocks of the study area. The study was carried out over a period of three years from 2009 to 2012 and seasonal variations (winter, spring and rainy) were recorded for soil parameters. Soil parameters
were studied across one meter depth divided into five depths (0-15cm, 15-30cm, 30-45cm, 45-60cm and 60-100cm).

1.2: Floristic diversity and herbaceous vegetation analysis of different plantations

Out of the five plantations selected for the study, higher herbaceous diversity was found in *S. cumini* followed by *A. nilotica+D. sissoo* and *T. grandis*. The least number of herbs were observed in *P. deltoides* plantation (8). The value of Simpson Index and Shannon Weiner Index was highest in *S. cumini* plantation (0.40 and 2.64 respectively). The lowest value of Simpson Index for herbaceous community was in *T. grandis* (0.12) and *A. nilotica+D. sissoo* (0.12) while that of Shannon-Weiner Index was in *P. deltoides* (1.87). The herb communities of *A. nilotica+D. sissoo-S. cumini* and *S. cumini-T. grandis* were found to be most similar with each other on the basis of Index of Similarity (0.78). The least similar pair was *A. nilotica+D. sissoo-E. tereticornis* (0.4).

Generally, the plantations of exotic species such as *E. tereticornis* and *P. deltoides* have very sparse understorey vegetation that may be due to the allelopathic interference of these trees, besides the effect of competition.

1.3: Study of physico-chemical properties of soil of tree plantations

In terms of soil properties, generally highest soil moisture content was observed in the plantation of *A. nilotica+D. sissoo* in all seasons and across all depths (6.06-22.78%) whereas soil of *T. grandis* had least moisture content (1.87-15.26%). All the plantations accounted for higher moisture content in rainy season followed by winter and spring across all depths. Increasing trends in winter and spring and decreasing trends in rainy season down the depth were observed in the soil moisture. The soil of study sites was found to be moderately acidic (5.6-6.0) to moderately alkaline (7.9-8.5). The least or moderately acidic values of pH were observed in *A. nilotica+D. sissoo* plantation (5.75-8.04) and higher or moderately alkaline values were observed in *E. tereticornis* plantation (6.90-8.26). Soil pH, in general, increased down the depth in all the seasons and plantations. Also, the bulk density of soil increased down the depth in all plantations. The highest values of soil bulk density were generally observed in *T. grandis* plantation followed by *E. tereticornis* and *P. deltoides*. The plantation of *A. nilotica+D. sissoo* accounted for least soil bulk density.
• **Soil Carbon**

The highest percentage of total soil carbon was observed in *A. nilotica+D. sissoo* plantation (0.42-1.84%) followed by *S. cumini* (0.32-1.08%) and *P. deltoides* plantation (0.32-0.99%). *T. grandis* plantation accounted for lowest percentage of soil total carbon in upper soil profiles while *E. tereticornis* plantation accounted for lowest soil total carbon in deeper soil profiles. In general, the percent total soil carbon content decreased down the depth and increased from the initiation to the end of study.

The general trend of soil organic carbon was same as that of total soil carbon with a decline down the depths and an increase over the study period. The percentage of soil organic carbon was higher in soil of mixed plantation of *A. nilotica+D. sissoo* (0.24-1.8%) followed by *S. cumini* (0.24-1.04%) and *P. deltoides* (0.21-0.99%). *T. grandis* plantation accounted for lowest percentage of soil organic carbon in surface soil while in deeper layers the lowest soil organic carbon content was observed in *E. tereticornis* plantation. Inorganic carbon content of soil generally increased with increasing depth in all the plantations. Significant differences were generally observed in the total carbon and organic carbon content of soil between different depths, between different seasons and between different species.

1.4: **Quantification of soil organic carbon stocks in different plantations**

The soil total and organic carbon stocks based on percentage of total and organic carbon content in the soil, soil bulk density and soil depths were highest in *A. nilotica+D. sissoo* plantation (111.71Mg/ha and 95.98Mg/ha respectively) followed by *S. cumini* (93.78Mg/ha and 73.36Mg/ha respectively) and *P. deltoides* (76.97Mg/ha and 65.07Mg/ha respectively). The incremental changes in total carbon stocks of soil over the entire study period were highest in *S. cumini* plantation (31.05Mg/ha) followed by *A. nilotica+D. sissoo* (23.94Mg/ha) and *T. grandis* (17.09Mg/ha). However, the incremental changes in the soil organic carbon during the study period were observed to be highest in *A. nilotica+D. sissoo* plantation (23.43Mg/ha) followed by plantations of *S. cumini* (22.26 Mg/ha), and *T. grandis* (17.29Mg/ha). The *E. tereticornis* plantation accounted for least incremental changes in both total carbon stocks (14.15Mg/ha) and organic carbon stocks (13.51Mg/ha) of soil. The inorganic carbon stocks were higher in *S. cumini* (20.42Mg/ha) followed by *T. grandis* (16.66) and *A. nilotica+D. sissoo* (15.73Mg/ha). Plantation of *P. deltoides* accounted for least stocks of soil inorganic
carbon (11.89Mg/ha). The stocks of inorganic soil carbon showed an increase over the study period in *A. nilotica*+*D. sisoo* (0.51Mg/ha), *E. tereticornis* (0.64Mg/ha), *S. cumini* (8.79Mg/ha) and *P. deltoides* plantation (1.37Mg/ha). However, the plantations of *T. grandis* accounted for a decrease in inorganic soil carbon stocks (-0.20Mg/ha).

1.5 Quantification of soil organic carbon stocks in soil aggregates

Fractionation of whole soil into aggregates of different size classes depicted that major portion of whole soil was occupied by the micro-aggregates of size 250-53µm (50.7-72.95%) followed by silt and clay associated fraction of size <53µm (11.34-24.88%). The least contribution to the whole soil was from macro-aggregates bearing size 2mm-250µm (5.46-21.48%). These trends were found to be similar across all depths and all plantation species. Although the percentage of organic carbon was observed to be highest in macro-aggregates, the carbon storage (mg/g) based on weight fraction and bulk density values was highest in micro-aggregates among all plantations and soil depths.

1.6 CO₂ evolution rates from the soil of different plantations

The soil respiration in terms of CO₂ efflux was highest in rainy season in all plantations. Among different plantations, the higher respiration rates were observed in *P. deltoides* plantation (13.02MgC/ha) followed by *T. grandis* (12.88MgC/ha), *S. cumini* (12.47MgC/ha) and *E. tereticornis* (10.16MgC/ha). The least values of soil respiration were observed in *A. nilotica*+*D. sisoo* (9.99MgC/ha) coinciding with its highest soil carbon content. The rates of CO₂ evolutions from the soil surface in the present study were found to be positively correlated with soil moisture, soil temperature, rainfall and atmospheric temperature. The soil respiration rates were significantly correlated with soil moisture and rainfall in all the plantations (r= 0.68-0.87). However, significant correlation between soil respiration rate and soil temperature were observed only in *A. nilotica*+*D. sisoo* (r= 0.65) and *E. tereticornis* (r=0.57). The correlations were also significant between soil respiration rates and rainfall for *S. cumini* (r= 0.75), *T. grandis* (r= 0.82), *P. deltoides* (r= 0.66) and *E. tereticornis* plantations (r= 0.76). The significant correlation between soil respiration rates and mean monthly atmospheric temperature were observed for the plantations of *A. nilotica*+*D. sisoo* and *P. deltoides*. 
• Soil Microbial Biomass Carbon

The plantation of *T. grandis* accounted for higher SMBC (0.38mg/g) followed by *A nilotica+D. sisoo* (0.37mg/g) and *S. cumini* (0.34mg/g) whereas lowest SMBC was in *E. tereticornis* (0.24 mg/g). The total soil microbial biomass carbon up to 30cm of soil depth as assessed for the tree plantations at the end of study period was higher in *S.cumini* (1.49mg/g) followed by *T. grandis* (0.95mg/g) and *E. tereticornis* (0.77mg/g) whereas, the mixed plantation of *A.nilotica+D. sisoo* accounted for least soil microbial biomass carbon (0.72mg/g). In general, the SMBC decreased with increasing depth in all the plantations. The SMBC was higher in rainy season as compared to winter and summer, coinciding with the higher soil respiration rates. The lower soil respiration rates in case of *A. nilotica+D. sisoo* can also be attributed to the lower soil microbial biomass carbon. The differences in the soil microbial biomass carbon were found to be significant between species and between different depths.

1.7: Quantification of plant biomass and productivity in different forestry plantations

Biomass and volume equations were applied to estimate the biomass of different components of all tree plantations. The highest total biomass (AGB+BGB) was of *T. grandis* plantation (232.31Mg/ha) followed by *P. deltoides* (186.21Mg/ha), *E. tereticornis* (98.50Mg/ha) and *A. nilotica+D. sisoo* (88.04Mg/ha). The lowest biomass was of *S. cumini* (53.84Mg/ha). However, the highest Net Primary Productivity was observed in *E. tereticornis* (11.83Mg/ha/yr) plantation indicating its fast growing characteristics followed by *P. deltoides* (9.74Mg/ha/yr) and *S. cumini* (7.20Mg/ha/yr). The mixed plantation of *A. nilotica+D. sisoo* accounted for least Net Primary Productivity (0.49Mg/ha/yr) over a period of one year. The biomass accumulation ratio was highest in *T. grandis* and lowest in *S. cumini* plantation. The biomass of the different tree components was significantly correlated with the basal area of the trees of all the studied tree plantations.

1.8: Carbon dynamics and carbon flux in vegetation

The carbon pools on the basis of biomass were also found to be highest in *T. grandis* (110.35Mg/ha/yr) and lowest in *S. cumini* (25.58Mg/ha/yr) plantation. The carbon fluxes as corresponding to NPP were higher in case of *E. tereticornis* (5.62Mg/ha/yr) and lowest in *A. nilotica+D. sisoo* (2.32Mg/ha/yr) plantation. However, the mean
carbon pools per tree were found to be highest in *T. grandis* plantation (2.63Mg/ha/yr) followed by *P. deltoides* plantation (1.05Mg/ha/yr) representing their higher carbon sequestration potential over other species. These were followed by mixed plantation of *A. nilotica*+*D. sissoo* (1.03Mg/ha/yr) and pure plantations of *E. tereticornis* (0.29Mg/ha/yr) and *S. cumini* (0.19Mg/ha/yr). Based on amount of vegetation carbon pools, the *T. grandis* plantation also accounted for highest CO₂ assimilation in its biomass (404.61Mg/ha) followed by *P. deltoides* (324.32Mg/ha) and *E. tereticornis* (171.55Mg/ha). Among all plantation sites, the least amount of CO₂ was assimilated by *S. cumini* (93.78Mg/ha).

1.9: Quantification and carbon estimation in litter fall

A large proportion of the above ground net primary productivity of the trees is added to the soil surface in the form of litter fall. Litter-fall in present field study and carbon content in the litter as a fraction of its biomass was observed to be highest in *T. grandis* plantation (13.94Mg/ha/yr) followed by *E. tereticornis* (10.84Mg/ha/yr) and *S. cumini* (8.10Mg/ha/yr). The mixed plantation of *A. nilotica*+*D. sissoo* accounted for lowest litter-fall during the period of one year (4.02Mg/ha). In general, most of the litter-fall was concentrated in the dry winter and summer season in all the plantations. Leaf litter accounted for a major part of the total litter fall while minor contribution was observed to be from twig litter. The differences in the amount of litter fall were significant between different species and different months.

1.10: Total carbon pools in vegetation and soil of different plantations

Total carbon stocks of the plantation as a sum of vegetation and soil carbon stocks were found to be highest in the *T. grandis* plantation (171.49Mg/ha). This was followed by *P. deltoides* (153.52Mg/ha) and *A. nilotica*+*D. sissoo* (139.2Mg/ha). The least stocks were of *S. cumini* plantation (98.94Mg/ha). The soil carbon stocks contributed 41-79% to the total carbon stocks of respective plantation being maximum in *S. cumini* and minimum in *T. grandis* plantation. The contribution from vegetation carbon stocks to the total carbon stocks of plantations varied from 21-59% being highest in *T. grandis* and lowest in *S. cumini*. Out of the total carbon stocks summed up for all studied plantations in the University Campus, the highest carbon was sequestered by *T. grandis* plantation (25%). This was followed by *P. deltoides* (22%), *A. nilotica*+*D. sissoo* (20%) and *E. tereticornis* (17%). The least values were observed for *S. cumini*
plantation (16%). The highest contribution to the total soil organic carbon stocks over these five plantations was from *A. nilotica*+*D. sissoo* (26%) and to the vegetation carbon stocks were from *T. grandis* (34%). The low soil carbon pools of *T. grandis, P. deltoides* irrespective of their higher vegetation carbon pools can be attributed to the high soil respiration rates as compared to other species resulting in the loss of soil carbon. Also, large scale human interference such as fires, throwing of construction material on the soil surface, tillage of the field etc may have negative impact on the soil carbon pool. These activities may hinder with the natural decomposition process of the fallen litter as well as the recovery of soil carbon. The low soil carbon pools of fast growing exotic species like *E. tereticornis* may also be due to its negative impacts on physico-chemical properties of soil, water usage, understorey ground cover along with its allelopathic effects.

Although, the plantations of *T. grandis* and *P. deltoides*, in the present study were observed to be much more efficient in storing carbon in their biomass, their efficiency of sequestering carbon in the soil was comparatively lower than that of mixed plantation of *A. nilotica*+*D. sissoo* due to higher soil respiration rates. The mixed plantation, along with its highest soil carbon pool also had a considerable amount of vegetation carbon stocks. From these results, it can be inferred that the mixed plantation should be preferred over the monocultures. The results of the present study also explained the benefits of native species over exotic species (viz *E. tereticornis* and *P. deltoides*) in terms of conserving more herbaceous diversity, higher vegetation and soil carbon pools as in case of *T. grandis*, and in terms of higher herbaceous vegetation and soil carbon pools as in *A. nilotica*+*D. sissoo* and *S. cumini*.

The study demonstrates that tree plantations with such large storage houses of carbon in their vegetation and soil can play a significant role in mitigating the dire consequences of climate change by decreasing or stabilizing the concentrations of atmospheric carbon dioxide. Social forestry schemes in this regard can play a crucial role for the betterment of existing forest, creating new areas with tree cover with significant ecological and environmental benefits. In this way, along with the natural forests, the tree plantations through afforestation and reforestation programmes comprising social forestry schemes can prove to be a successful pathway in carbon sequestration and climate change mitigation.