Carbon sequestration potential in plantation forestry and agricultural land uses for mitigating climate change and increasing crop productivity on Gangetic-basin

Project Completion Report
(27-06-2011 to 26-12-2014)

Submitted to
Department of Science and Technology
New Delhi

by
Parveen Kumar

ICAR-Central Soil Salinity Research Institute
Karnal-132 001, Haryana

Annexure- VI

PROJECT COMPLETION REPORT

DST File No.: DST/IS-STAC/CO2-SR-58/09

1. Project Title: **Carbon sequestration potential in plantation forestry and agricultural land uses for mitigating climate change and increasing crop productivity on Gangetic basin**

2. Duration of Project: From 27-6-2011 To 26-12-2014

3. Principal Investigator:

   Name : **Dr. Parveen Kumar,** Principal Scientist (Agronomy)

   Institute : ICAR-Central Soil Salinity Research Institute, Karnal, Haryana

4. Co- Principal Investigators:

   Name : **Dr. S K Chaudhari,** ADG (Soil and Water Management)
   Institute : Division of Natural Resource Management
   KAB-II, Pusa Campus, New Delhi-12

   Name : **Dr. D K Sharma,** Director
   Institute :ICAR-Central Soil Salinity Research Institute, Karnal, Haryana

5. Collaborating Organizations : Nil

Organisation	Team members	Activities/Tasks Assigned
-	-	-
-	-	-
-	-	-

Part A- Summary Report

1. **Project Objectives**

Objectives as per the approved Project	Fully/Partially Achieved	Reason for partial Achievement
To find out crops, crop sequence and land use systems and their management strategies for utmost sequestration of atmospheric carbon in vegetation and soils, and conservation (protection) of carbon in the soils.	Fully achieved	-
To find out drivers that favour carbon sequestration in plants and soils, and disfavour soil respiration (loss of CO_2 from soils).	Fully achieved	-

1. Deliverables

As per the approved Project	Fully/Partially/Not Achieved	Reason for partial Non Achievement
Estimation of the atmospheric carbon fixation (photosynthesis) rate by the tree and agricultural crops, and its partitioning in different plant parts under the selected agro-ecosystems.	Fully achieved	-
Estimation of the carbon pool and rate of accumulation of carbon in aboveground and belowground plant parts in the selected agro-ecosystems.	Fully achieved	-
Measurement of carbon inputs (leaf, twig and root litters) in the soils in the selected agro-ecosystems.	Fully achieved	-
Estimation of sand and silt soil organic carbon (mineralizable carbon), and clay organic carbon (recalcitrant carbon) in the selected agro-ecosystems.	Fully achieved	-
Estimation of microbial biomass carbon (MB-C) in the soils of the selected agro-ecosystems.	Fully achieved	-
Estimation of soil respiration (CO_2 production) from the selected agro-ecosystems.	Fully achieved	-

Finding out drivers (fertilizer, mulching, and tillage) that promote carbon sequestration in plants and soils, and reduce soil respiration in the selected agro-ecosystems.	Fully achieved	-
Data compilation and report submission.	Fully achieved	-

2. Specific Benefits/Outcome

i). Patent, if any: Nil

ii). Product/Process developed

- Estimated carbon sequestration rate for *Populus deltoides* and *Eucalyptus tereticornis* block plantation.
- Determined aggregated carbon with soil particles for *Populus deltoides* and *Eucalyptus tereticornis* block plantation.
- Identified remunerative *Populus deltoides* and *Eucalyptus tereticornis* based agroforestry systems for improving soil carbon stock.
- Identified drivers (nutrient, tillage and residue management) in maize-wheat-greengram and rice-wheat cropping systems for increasing the soil organic carbon stock and mitigating the adverse effect of climate change.

iii). List of Publications arising from the project
(Indicate Impact Factors of the Journals: attach Copies of the Papers)

(A) **Papers published only in cited Journals (SCI)**

Research paper

1. Chaudhari SK, Gopali Bardhan, Parveen Kumar, Rakesh Singh, Ajay Kumar Mishra, Poornima Rai, Kailash Singh and DK Sharma. 2015. Short-Term Tillage and Residue Management Impact on Physical Properties of a Reclaimed Sodic Soil. *Journal of Indian Society of Soil Science,* **36(1)**: (NAAS: 4.95; in press).
2. Chaudhari SK, Parveen Kumar, Ajay Kumar Mishra, Kailash Singh, Poornima Rai, Rakesh Singh and DK Sharma. 2015. Labile carbon fractions build-up and dynamics under vertical stratification of *Populus deltoides* and *Eucalyptus tereticornis* based agroforestry systems in Trans-Gangetic Plains of India. *Annals of Agricultural Research New Series,* **36(1):** (NAAS: 3.02; in press).
3. Chaudhari SK, Parveen Kumar, Kailash Singh, Ajay Kumar Mishra, Poornima Rai, Rakesh Singh, and D.K. Sharma. 2014. Aggregate Fractions and Organic Carbon dynamics in Partially Reclaimed Sodic Soils growing *Eucalyptus tereticornis*. *Journal of Soil Salinity and Water Quality,* **6(1):** (in press).
4. Kumar Parveen, AK Mishra, SK Chaudhari, DK Sharma, K Singh, P Rai and R Singh. 2014. Growth, estimated carbon sequestration potential and soil carbon build up under

different age of *eucalyptus tereticornis* plantation in Trans-Gangetic plains of India. *Applied Ecology and Environmental Research* (NAAS: 6.59; under review).

5. Kumar Parveen, AK Mishra, SK Chaudhari, R Singh, K Singh, P Rai, G Bardhan, CB Pandey and DK Sharma. 2014. Biomass estimation and carbon sequestration in *Populus deltoides* plantations in India. *Plant Soil and Environment* (NAAS: 7.11; under review)
6. Kumar Parveen, Kailash Singh, Ajay Kumar Mishra, Ashwani Kumar, Rakesh Singh, Poornima Rai, SK Chaudhari and DK Sharma. 2014. Effect of temporal changes and plantation age on gas exchange characteristics of *Populus deltoides* plantation in the Indo-Gangetic plains of India. *Range Management and Agroforestry* (NAAS: 6.17; under review).
7. Kumar Parveen, Kailash Singh, Ashwani Kumar, Rakesh Singh, Ajay Kumar Mishra, Poornima Rai, SK Chaudhari and DK Sharma. 2014. Residual effect of nitrogen management options on physiological and agronomical traits of green gram in maize-wheat-green gram system in reclaimed sodic soil of India. *Vegetos* (NAAS: 6.02; under review)
8. Kumar Parveen, SK Chaudhari, Ajay Kumar Mishra, Kailash Singh, Poornima Rai, Rakesh Singh, and D.K. Sharma. 2014. Labile Carbon Dynamics and Soil Amelioration in six-year old *Eucalyptus tereticornis* Plantation in Sodic Soils. *Journal of Soil Salinity and Water Quality* **6(1):** (in press).

(B) **Papers published in Conference Proceedings, Popular Journals etc.**

1. Chaudhari S.K., Mishra A.K., Kumar P., Singh Kailash, Rai Poornima. 2013. Different soil carbon forms and water stable aggregate under vertical stratification of 4-year block plantation *Populus* and *Eucalyptus*. In Abstracts of Papers presented in 'National Seminar on Developments in Soil Science: 2013' held at CAZRI, Jodhpur during 23-26 October, 2013 p. 3. (Oral presentation)
2. Chaudhari S.K., Singh Kailash, Kumar P., Singh Rakesh, Mishra A.K. 2013. Soil oxidizable carbon and nutrient dynamics under different of *Populus* based agroforestry system. In Abstracts of Papers presented in 'National Seminar on Developments in Soil Science: 2013' held at CAZRI, Jodhpur during 23-26 October, 2013 p. 4. (Oral presentation)
3. Chaudhari, S.K., Kumar, Parveen, Mishra, A.K., Singh, Rakesh, Bardhan, G. and Sharma, D.K. 2013. Eco-physical and soil responses of *Prosopis juliflora* in Indo-Gangetic plains of India. In Dialogue Papers presented in 'National Workshop on *Prosopis juliflora*: Retrospect and Prospects' held at Bhuj, Gujarat during 26-28 February, 2013 p. 7.
4. Chaudhari, S.K., Kumar, Parveen, Mishra, A.K., Singh, Rakesh, Bardhan, G. and Sharma, D.K. 2013. Carbon sequestration under different realm of block plantation in Trans-Gangetic Plains of India. In Dialogue Papers presented in 'National Workshop on *Prosopis juliflora*: Retrospect and Prospects' held at Bhuj, Gujarat during 26-28 February, 2013 p. 51.
5. Chaudhari, S.K., Mishra, A.K., Kumar, Parveen, Singh, Rakesh, Bardhan, G. and Sharma, D.K. 2012. Biomass and carbon allocation in 4-year old Populus and Eucalyptus agro-forestry systems in Trans-Gangetic Plains of India. In Abstracts of Papers presented

in 'National Seminar on Developments in Soil Science: 2012' held at Ludhiana, Punjab during 3-6 December, 2012 p. 21.

6. Kumar Parveen, Singh, Rakesh, Chaudhari, S.K., Sharma, D.K., Mishra, A.K. and Bardhan, G. 2012. Growth, yield and carbon sequestration by wheat crop under different nitrogen management options in Trans-Gangetic plains of India. *In Extended summaries Vol. 2: 3rd International Agronomy Congress, Nov. 26-30, 2012, New Delhi, India* pp 180-181.
7. Kumar, Parveen, Chaudhari, S.K., Mishra, A.K., Singh, K., Rai, P and Sharma, D.K. 2014. Terrestrial carbon sequestration in Poplar based agroforestry systems in North-Western states of India. Paper presented in 'World Congress on Agroforestry: Trees for life-Accelerating the impact of agroforestry' during 10-14 February, 2014.
8. Kumar, Parveen, AK Mishra, Kailash Singh, Poornima Rai, Rakesh Singh, SK Chaudhari and DK Sharma. 2015. Carbon dynamics under residue and tillage management practices under rice-wheat system in Trans-Gangetic plains of India. In Compedium of Paper presented in '12th Agricultural Science Congress on Sustainable Livelihood Security for Smallholder farmers' during 3-6 February, 2015 at Karnal, p. 89.
9. Mishra, A.K., Chaudhari, S.K., Singh, Kailash, Kumar, Parveen, Rai, P., Singh, Rakesh and Sharma, D.K. 2014. Vertical allocation of soil carbon forms and water stable aggregate under block plantation of *Eucalyptus tereticornis*. In Abstracts of Paper presented in '4th National Seminar on Innovative saline agriculture in changing environment' during 12-14 December, 2014 at Gwalior, p. 24 (Oral presentation).
10. Mishra, A.K., Kumar, Parveen, Rai, P., Singh, Kailash, Singh, Rakesh, Chaudhari, S.K. and Sharma, D.K. 2014. Labile carbon dynamics and sensitivity analysis under 6-year old *Eucalyptus tereticornis* plantation in sodic soils of Trans-Gangetic plains of India. In Abstracts of Paper presented in '4th National Seminar on Innovative saline agriculture in changing environment' during 12-14 December, 2014 at Gwalior, p. 9.

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(C) **Technical/popular articles**

1. Chaudhari, S.K., Kumar, P., Mishra, A.K., Singh, R., Bardhan, G. and Sharma, D.K. 2012. Comparative study of carbon dynamics based on physiological responses and soil carbon fluxes in agroforestry systems. *Salinity News*, CSSRI, Karnal 18(2): 4p.
2. Chaudhari, S.K., Kumar, Parveen, Sharma, D.K., Singh, Rakesh, Mishra, A.K. and Bardhan, G. 2012. Carbon sequestration potential in plantation forest and agricultural land uses. *Salinity News*, CSSRI, Karnal 18(1): p. 2.
3. Kumar, Parveen, SK Chaudhari, Ajay K Mishra, Kailash Singh, Poornima Rai, Rakesh Singh and DK Sharma. 2014. Ecosystem carbon sequestration under different aged *Populus deltoides* plantation in Trans-Gangetic plains of India. *Salinity News*, CSSRI, Karnal 20(1): 2p.
4. Mishra, AK, SK Chaudhari, Parveen Kumar, Kailash Singh, Poornima Rai and DK Sharma. 2014. Consequences of straw burning on different carbon fractions and nutrient dynamics. *Indian Farming*, **64**(5): 11-12, 15.

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iv) Linkages developed

Strong linkages were developed with the foresters, agroforesters and farmers in Haryana and educated them regarding the need of carbon sequestration in mitigating the climate change impacts on environment.

v). Manpower trained, give details.

S.No.	Name	Designation
1	Sh. Raj Kumar	Technical Officer
2	Sh. Sukhdev Prasad	Technical Officer
3	Sh. Sahib Singh	Technical Officer
4	Sh. Dilbag Singh	Technical Officer
5	Sh. Roshan Lal	Technical Officer
6	Sh. Dinesh Kumar	Techincal Assistant
7	Sh. Jagdish Kumar	Techincal Assistant
8	Sh. Ram Kishan	Techincal Assistant

9	Sh. Girraj Prasad Meena	Techincal Assistant
10	Sh. Harikesh	Techincal Assistant
11	Sh. Kartar Singh	Techincal Assistant
12	Sh. K. Ramakrishna	Techincal Assistant
13	Sh. Mange Ram	Techincal Assistant
14	Sh. Satish Kumar	Techincal Assistant
15	Sh. Kailash	Techincal Assistant
16	Sh. Wazir Singh	Techincal Assistant
17	Sh. Lila Ram	Techincal Assistant
18	Sh. Narain Das Ghai	Techincal Assistant
19	Sh. N.S.Ahlawat	Techincal Assistant
20	Sh. Devendra Kumar Yadav	Techincal Assistant
21	Sh. Santosh Kumar	Techincal Assistant
22	Sh. P.K. Dhar	Sr. Technical Officer
23	Dr. Rakesh Singh	Junior Research Fellow
24	Mr. Ajay Kumar Mishra	Junior Research Fellow
25	Mr. Kailash Singh	Junior Research Fellow
26	Ms. Poornima Rai	Junior Research Fellow
27	Dr. G Bardhan	Junior Research Fellow
28	Mr. Charan Singh Meena	Skilled Supporting Staff
29	Mr. Kishan Pal	Skilled Supporting Staff
30	Mr. Mahesh	Field cum lab assistant
31	Mr. Sonu	Field cum lab assistant

Apart from the above, two *Kisan Gosthis* were conducted at farmers' fields in which more than 100 farmers were educated on the benefits of agroforestry with respect to carbon sequestration.

13. Summary of significant S&T Achievements
(Provided in bullet form)

Plantation forestry

- Carbon sequestered by 4-year *Populus deltoides* was 59.38 t/ha (12.9% by roots), whereas, it was 100.9 t/ha (15.2% by roots) for 8-year old *Eucalyptus tereticornis* plantation. Carbon sequestration rate was 10.0 t C/ha/year for *Populus deltoides* and 12.2 t C/ha/year for *Eucalyptus tereticornis* block plantation.

- Soil organic carbon and carbon stock under 7-year old *Populus deltoides* plantation was 0.68% and 17.6 t/ha, respectively which was 54.5 and 49.2 % higher than 1-year old block plantation. Under *Populus deltoides* and *Prosopis juliflora*, SOC during January 2014 increased by 33.5% and 25.1% from the bench mark (September 2011) values, respectively. With increased canopy cover led to reduction of oxidation of organic carbon which resulted in stabilised carbon with the age of the plantation.
- Total carbon in soil increased by 32% from one to four year *Populus* (0.78-1.03 %) and *Eucalyptus* plantation (0.75-0.99 %) at Hara and Raina Farm, respectively.
- In *Populus* as well as *Eucalyptus* plantation total carbon, total organic carbon and oxidizable organic carbon decreased with increasing soil depth but no such trend was found in case of total inorganic carbon.
- Coarse macro-aggregated carbon at the age of 4-year *Populus* and *Eucalyptus* plantation was highest upto the root interference zone as compared to silt and clay associated and fine micro-aggregated carbon.
- Both photosynthetic rate and soil respiration reduced with the plantation age of *Populus deltoides* and *Eucalyptus tereticornis*.

Agroforestry systems

- Different *Populus deltoides* and *Eucalyptus tereticornis* based agroforestry systems [*Populus* (1-year) + turmeric, *Populus* (2-year) + mango, *Populus* (3-year) + pear, *Populus* (4-year) + wheat and *Eucalyptus* (1-year) + sugarcane, *Eucalyptus* (2-year) + sugarcane, *Eucalyptus* (3-year) + wheat, *Eucalyptus* (4-year) + sorghum] were studied at Hara Farm, Yamunanagar and Raina Farm, Kurukshetra to find out the best land use system and their management strategies for maximum sequestration of atmospheric carbon in vegetation and soils, and conservation (protection) of carbon in the soils and what are the drivers that regulate carbon dynamics.
- In *Populus* based agroforestry system, turmeric could be grown for 1st and 2nd year of plantation as it adds 22.2 and 59.3% organic carbon in soil as compared to sole *Populus* (1-year) plantation. In 3rd and 4th year of *Populus* based agroforestry system, pear/mango and turmeric/wheat/pear should be preferred as these systems sequester higher organic carbon as compared to sole *Populus* based plantation.
- *Populus* + wheat had higher organic carbon content (0.68%) followed by *Populus* + pear (0.63%) in the top 15 cm soil layer.
- In *Eucalyptus* based agroforestry system, sugarcane could be grown for ^{1st} and ^{2nd} year of plantation followed by wheat and sorghum in ^{3rd} and ^{4th} year of plantation. These systems showed higher active pools of carbon (MBC and POXC).
- The reduction in photosynthetic rate of maize and sugarcane under 2-year of *Populus deltoides* and *Eucalyptus tereticornis* was 13.3 and 34.6%, respectively as compared to their sole crops.

Agricultural systems

- Two field experiments were conducted with different N management options and tillage and residue management practices to enhance the C-sequestration in popular cropping systems of the region (maize-wheat-greengram and rice-wheat).
- In wheat-greengram-maize cropping system, addition of FYM @ 10 t/ha with recommended dose of N (14.0 t/ha) increased the carbon sequestration by 41.4% as compared to Control treatment (9.9 t/ha).
- C-sequestered by wheat crop was highest where conventional tillage (CT) was done without residue incorporation (5.97 t/ha) and lowest in zero tillage with one-third residue retention (4.13 t/ha). Both the wheat varieties (KRL 213 and HD 2894) sequestered statistically similar carbon in the above ground and below ground biomass.
- Carbon sequestered by rice crop was highest in treatment where rice transplanted was done in puddled conditions with 1/3 wheat residue incorporation (6.33 t/ha) and lowest (5.87 t/ha) whereas tillage and residue management was done as per prevailing farmers' practice of the region (CT with wheat residue removed+ transplanted rice under puddled conditions). Rice variety CSR 36 (6.62 t/ha) sequestered statistically higher carbon than CSR 30 (5.80 t/ha); however, C sequestered by below ground biomass of CSR 30 (0.97 t/ha) was statistically higher than CSR 36 (0.81 t/ha).
- The soil health was assessed after 2-year crop rotation of wheat-green gram-maize under different N management options and found that SOC in 0-15 and 15-30 cm soil depth was highest under N_4 (0.57 and 0.51 %) treatment, where 50% N was supplemented through organic source and rest 50% through inorganic source and lowest under N_7 (0.43 and 0.29 %) treatment where no N was used. Total water stable aggregates (WSA) in 0-15 cm soil depth were highest under N_3 (59.3 %), where one-fourth N was substituted by organic source.
- In tillage and residue management, OC in 0-15 and 15-30 cm soil depth was highest under zero tillage with full residue retention. Coarse macro-aggregated carbon was higher with residue retention/incorporation. Total WSA in 0-15 cm soil depth was highest under zero tillage with full residue retention followed by zero tillage with one-third residue retention.
- After three years of wheat-rice cropping system, SOC under different treatments of tillage and residue management in 0-15 and 15-30 cm soil depth was highest under conventional tillage +Direct Seeded Rice (DSR) and zero tillage +DSR, respectively.

14. Project Budget *(Final)*

Funds sanctioned:	Rs. 5828763.0
Funds released:	Rs. 5404934.0
Funds utilized:	Rs. 5501154.0
Amount to be reimbursed:	**Rs. 96220.0**

15. Suggestions for Utilization of Project Outcome, *(Give tangible road map, name specific Industrial Units)*

Project results clearly established the role of *Populus deltoides* and *Eucalyptus tereticornis* based agroforestry or as block plantation in increasing the carbon sequestration and carbon stock in the soil. In agricultural systems also supplementation of organic residue in maize-wheat-moong and incorporation/retention of rice residue improved the soil carbon stock and physical properties of the soil. These results are needed to be up-scaled through line departments for educating the farmers and adopting of good agricultural practices developed through this project.

Date (Signature of PI)

PROJECT COMPLETION REPORT
Part B- Comprehensive Report

(The Comprehensive Report should be precise in details and self contained)

1. Project Title: **Carbon sequestration potential in plantation forestry and agricultural land uses for mitigating climate change and increasing crop productivity on Gangetic basin**

2. Product/Process as an outcome of the project, identify Beneficiaries.

- Estimation of the atmospheric carbon fixation (photosynthesis) rate by the tree and agricultural crops, and its partitioning in different plant parts under the selected agro-ecosystems.
- Estimation of the carbon pool and rate of accumulation of carbon in aboveground and belowground plant parts in the selected agro-ecosystems.
- Measurement of carbon inputs (leaf, twig and root litters) in the soils in the selected agro-ecosystems.
- Estimation of sand and silt soil organic carbon (mineralizable carbon), and clay organic carbon (recalcitrant carbon) in the selected agro-ecosystems.
- Estimation of microbial biomass carbon (MB-C) in the soils of the selected agro-ecosystems.
- Estimation of soil respiration (CO_2 production) from the selected agro-ecosystems.
- Finding out drivers (fertilizer, mulching, and tillage) that promote carbon sequestration in plants and soils, and reduce soil respiration in the selected agro-ecosystems.

Beneficiaries: Foresters and farmers of irrigated areas of India for large scale adoption through State Department of Agriculture and Cooperation for improving soil carbon sequestration and mitigating the adverse effect of climate change.

3. Scientific Description of the Product/Process. Give Specifications/Standards for the same: *Details are being given in methodology section*

4. Methodology adopted for Development of the product/process (State briefly in 300 words).

i. **Carbon content (%):** CHNS analyzer used for carbon estimation in root and shoot biomass. The dried samples were grind with Wiley mill grinder and passed through a 0.150 mm sieve for carbon analysis (Brown & Thilenius 1976; Anderson & Ingram 1993).

ii. **Above ground biomass of crops:** The weight of total produce harvested from net plot of each treatment was recorded after sun drying and expressed as biological yield in t ha^{-1}.

iii. **Below ground biomass of Crops**: For root biomass samples were collected from sampled row at 90 and at harvest stage in 1 meter row length by excavating to a depth of

30 cm with a narrow, flat-bladed shovel and handsaw. Soil containing roots was gently rotate and dispersed through tap water, then passed through a series of sieves to collect roots, dried under the sun, kept in the electric oven at 65 ^{O}C for complete drying and their weight was recorded when samples attained a constant weight. The weight was expressed in t ha^{-1}.

iv. **Microbial Biomass Carbon:** Fumigation method as outlined by Jenkinson and Powlson (1976).

v. **Available N:** Alkaline $KMnO_4$ method (Subbiah and Asija, 1956).

vi. **Available P:** Olsen's 0.5 *M* $NaHCO_3$ extractable (Olsen *et al.* 1954).

vii. **Available K:** Ammonium acetate exchangeable potassium (Toth and Prince, 1949).

viii. **Micro nutrients**: DTPA extraction AAS (Lindsay and Norvell, 1978)

ix. **EC :** In supernatant liquid (Jackson, 1973)

x. **pH:** In supernatant liquid (Jackson, 1973)

xi. **SOC (%): (**Nelson and Sommers,1996)

xii. **TIC and TOC:** (Jackson, 1973)

xiii. **SOC stock in soil:** Bulk Density × SOC (%) × Soil Depth (m) × 10

xiv. **Carbon pool in vegetation**: carbon pool in trees measured as: Standing biomass of trees × concentration of CO_2 in the biomass. Standing biomass of trees will be measured by volume method (tree volume × wood density). Concentration of CO_2 in biomass will be estimated by C, H, N autoanalyser (Puri, 2002).

xv. **Aggregate Size Distribution**: Aggregate fractionation was done by wet sieving method (Kemper and Rosenau, 1986) using Yoder's apparatus.

xvi. **Water Stable Aggregate Percentage:** Water stable aggregate percentage was calculated by determining the weight of soil on sieve without dispersion and after dispersion.

$$\text{WSA \%} = \frac{[(\text{weight of soil + sand}) \times i - (\text{weight of sand}) \times i]}{\text{Weight of sample}}$$

where, i is sieve size

xvii. **Aggregate Ratio:** By using wet sieving method aggregates were fractioned into water stable macro-aggregates (>0.25 mm) and micro-aggregates (<0.25 mm) categories and their ratio was designated as aggregate ratio.

$$\text{AR} = \frac{\text{Percentage of water stable macro-aggregates}}{\text{Percentage of water stable micro-aggregates}}$$

xviii. **Mean Weight Diameter and Geometric Mean Diameter:** Mean weight diameter (MWD) and geometric mean diameter (GMD) of the WSA was estimated following Van Bavel (1949) method.

$$\text{MWD} = \frac{\sum_{i=1}^{n} XiWi}{\sum_{i=1}^{n} Wi} \qquad \text{GMD} = \exp\left[\frac{\sum_{i=1}^{n} Wi \log Xi}{\sum_{i=1}^{n} Wi}\right]$$

Where, Wi= Weight of soil at each sieve; Xi= Diameter of the sieve

xix. **Permanganate oxidizable carbon (POXC):** As per method of Weil et al. (2003).

xx. **Nitrogen management experimental details:** Seven N management options were evaluated for enhancing C-sequestration in wheat-green gram-maize cropping system.

xxi. **Tillage and residue management experimental details:** Four tillage and residue management treatments were tested under two varieties of each wheat and rice crop in a system with the purpose of improving C-sequestration and soil health.

5. Scientific/Technological Formulation giving underlying Basis (Provide sufficient details)

- ✓ During September 2012, mean DBH and height of *Eucalyptus tereticornis* was found to be 6.81 cm and 8.37 m, respectively, at the age of 1-year, which reached up to 23.8 cm and 25.2 m, respectively, at the age of 8-year. Whereas, in March 2013, mean DBH and height were found to be 9.33 cm and 11.7 m, respectively at the age of 1-year, which reached up to 24.2 cm and 25.7 m, respectively, at the age of 8-year (Fig. 1).
- ✓ Soil carbon stock increased by 40.6 and 11.5% in top soil layer and lowest depth, respectively under 8-year plantation compared to 1-year plantation during September 2012, whereas the increment was 38.6 and 28.4 % at upper and lowest depth during March 2013. Across soil depths during September 2012, mean soil carbon stock was 7.42 Mg C ha^{-1} when plantation age was 1-year which increased to 9.91 Mg C ha^{-1} under 8-year plantation, which was 33.6 % higher. Whereas, during March 2013, the soil carbon stock was 8.09 Mg C ha^{-1} under 1-year *Eucalyptus* plantation and reached to 10.3 Mg C ha^{-1} at the age of 8-year, which was higher by 27.2 % (Fig. 2).
- ✓ Irrespective of tree canopy cover, stock, POXC and MB-C decreased with increased soil depth. MB-C under canopy edge was lower by 30.8 and 9.10 % as compared to canopy gap and mid canopy, respectively (Fig. 3).
- ✓ During September 2012, mean DBH and height of *Populus deltoides* were found to be 5.50 cm and 7.80 m, respectively, at the age of 1-year, which reached up to 17.50 cm and 22.30 m, respectively, at the age of 7-year. Whereas, in March 2013, mean DBH and height were found to be 8.90 cm and 8.59 m, respectively at the age of 1-year, which reached up to 21.60 cm and 23.1 m, respectively, at the age of 7-year (Fig. 4).
- ✓ In September 2012, carbon stock in above and below ground biomass was estimated to be 39.9 Mg C ha^{-1} and 6.28 Mg C ha^{-1}, respectively, at the rotation period of 7-year, which was almost 10 times higher than 1-year plantation. But in March 2013, the estimated carbon stock in above and below ground was 64.2 Mg C ha^{-1} and 10.1 Mg C ha^{-1}, respectively for the same period of rotation, which was 8 times higher than 1-year plantation. From September 2012 to March 2013, increment in total carbon stock was 61.2% at the age of 7-year (Fig. 5).
- ✓ CO_2 assimilation was 169.2 and 272.7 t ha^{-1} during September 2012 and March 2013, respectively by 7-year *Populus deltoides* which helps to reduce carbon footprint hence promising option for mitigating climate change (Fig. 6).
- ✓ With the age of *Eucalyptus* coppice, carbon stock and MB-C increased upto 45-60 cm, where distribution of root was maximum (Fig. 7).

- ✓ Carbon stock and MB-C in both the period of study was highest under *Populus* followed by *Prosopis* (Fig. 8 and Fig. 9). Periodic study of carbon stock and MB-C under fruit orchard (Mango, Guava and Jamun) revealed that Mango had higher carbon stock in both the study period followed by Jamun (Fig. 10). Whereas, MB-C was highest under Jamun followed by Mango (Fig. 11).
- ✓ *Eucalyptus* based agroforestry system (*Eucalyptus* (1-year) +sugarcane, *Eucalyptus* (2-year) +wheat, *Eucalyptus* (3-year) +sorghum, and *Eucalyptus* (4-year) +wheat) had higher carbon stock as compared to sole crops (Fig. 12).
- ✓ *Populus* (1-year) + maize and *Eucalyptus* coppice (2-year + wheat) had higher carbon stock as compared to sole plantation and sole crops (Fig. 13). Permanganate oxidizable carbon (POXC) as an active pool was highest under *Populus* (4-year) + turmeric and *Eucalyptus* (4-year) + sorghum as compared to sole plantation (Fig. 14).
- ✓ Coarse macro aggregated carbon was highest in N_4 treatment, where 50% of the N dose was replaced by FYM in top 0-15 cm soil depth compared to other treatments (Fig 15).
- ✓ Carbon stock was maximum at 0-15 cm soil depth under N_2 (11.7 Mg ha^{-1}) closely followed by N_4 (11.4 Mg ha^{-1}). Whereas, at 15-30 cm soil depth carbon stock was maximum under N_4 (12.09 Mg ha^{-1}) followed by N_2 (9.30 Mg ha^{-1}) treatment. In another experiment with residue and tillage management, farmers practice showed lowest carbon stock (Fig. 16)
- ✓ In wheat-green gram-maize, maximum MB-C was recorded with N_1 treatment during both the months of observation (Fig. 17). Among the treatments, lowest values of MB-C were recorded in the no nitrogen treatment during both the year and month (2012 and 13).
- ✓ OC in 0-15 and 15-30 cm soil depth was highest under T_4 (zero tillage with full residue retention). Total carbon in 0-15 and 15-30 cm soil depth was highest under T_1 (conventional tillage with one- third residue incorporation) treatment. TC as well as OC had almost similar values in soil samples taken from both the wheat varieties (Fig. 18).
- ✓ In general soil carbon stock, POXC and MB-C and decreased with soil depth. *Populus* (4 year) + wheat had 30.8 % higher soil carbon stock as compared to sole wheat crop. Whereas, *Eucalyptus* (4 year) + wheat had 29.3 % higher soil carbon stock as compared to sole wheat crop (Fig. 19 and 20).
- ✓ POXC was positively correlated with MBC, although the strength of the relationship varied with the land use (Fig. 21and 22). *Eucalyptus* (4-year) + wheat (R^2 = 0.796) had stronger relationship than *Populus* (4-year) + wheat (R^2 = 0.606). *Populus* (4-year) + wheat (R^2 = 0.845) had stronger relationship than *Eucalyptus* (4-year) + wheat (R^2 = 0.712).
- ✓ MB-C and SOC were positively correlated in both *Populus* and *Eucalyptus* based agroforestry systems (Fig. 21and 22), however, the relationship was comparatively stronger for *Populus* (4-year) + wheat (R^2 = 0.718) than *Eucalyptus* (4-year) + wheat (R^2 = 0.592).

6. Further Work required, if any to get full Benefits or enhance Utilization.

Since carbon sequestration and carbon build up in the soil is very slow process therefore, it would be better to have such project for longer duration (at least for five years) for continuous monitoring of changes in the soil carbon stock to ascertain and validate the effect of agronomic/scientific interventions to improve the soil carbon sequestration.

Based upon 3 year study it can be recommended that

- *Populus deltoides* and *Eucalyptus tereticornis* based agroforestry or as block plantation increased the carbon sequestration and carbon stock in the soil.
- In agricultural systems supplementation of organic residue in maize-wheat-moong system and incorporation/retention of rice residue improved the soil carbon stock and other physical properties of the soil.
- These results needs to be up scaled through line departments for educating the farmers and adoption of good agricultural practices developed through this project.

Signature of the PI ………………………………………..

Date: 2nd March 2015

Name of the PI : Dr Parveen Kumar, Principal Scientist (Agronomy)

Email: pkumarcssri@gmail.com

Telephone no.: 0184-2209321 (O); 09468409209 (cell)

Place: Karnal

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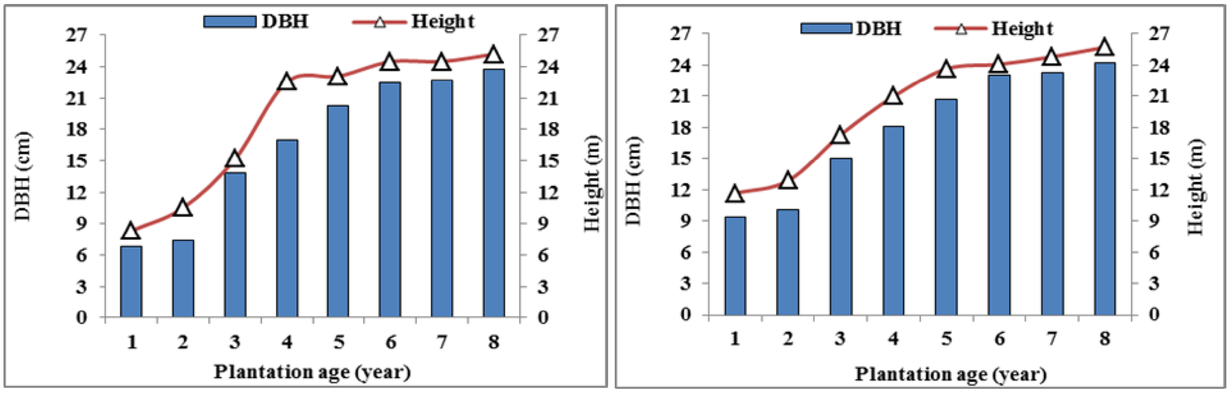
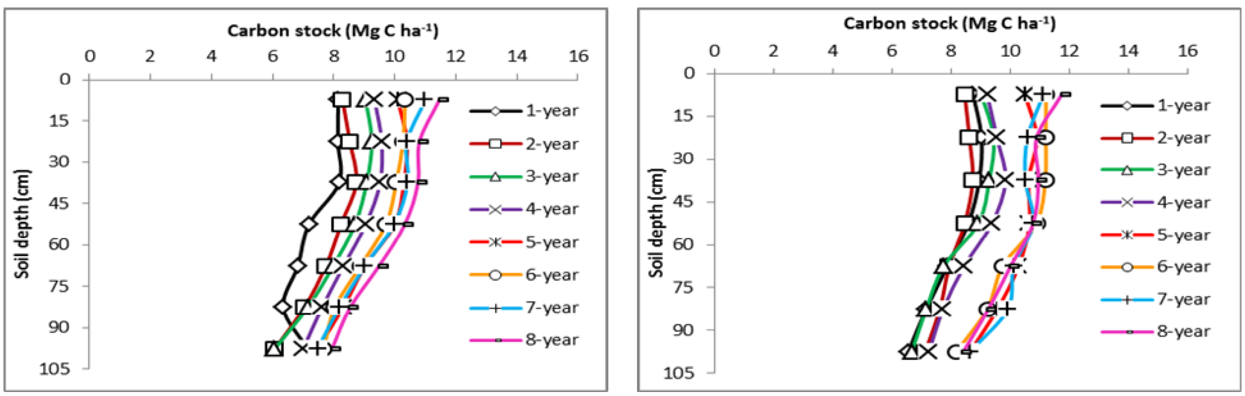


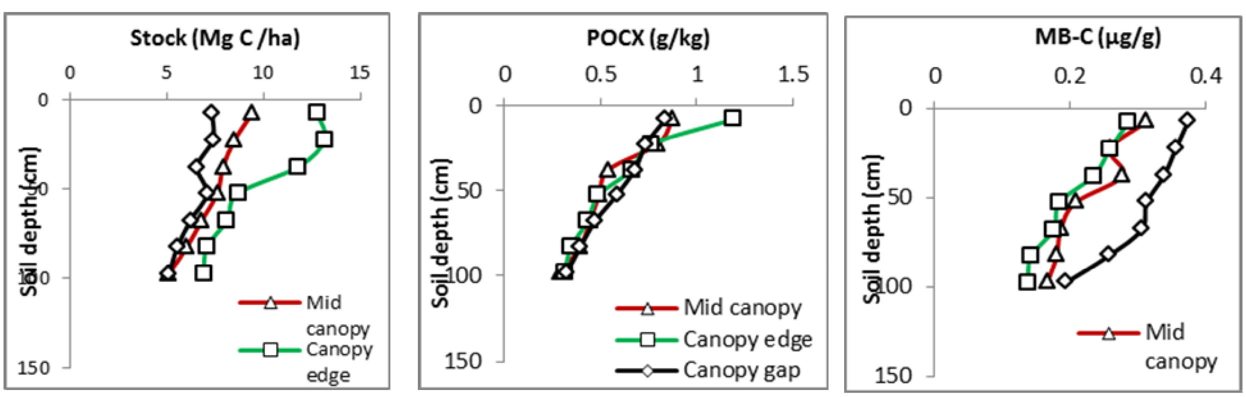
(a) (b)

Figure 1. Increment in DBH and height with plantation age of *Eucalyptus tereticornis* during September 2012 (a) and March 2013 (b).



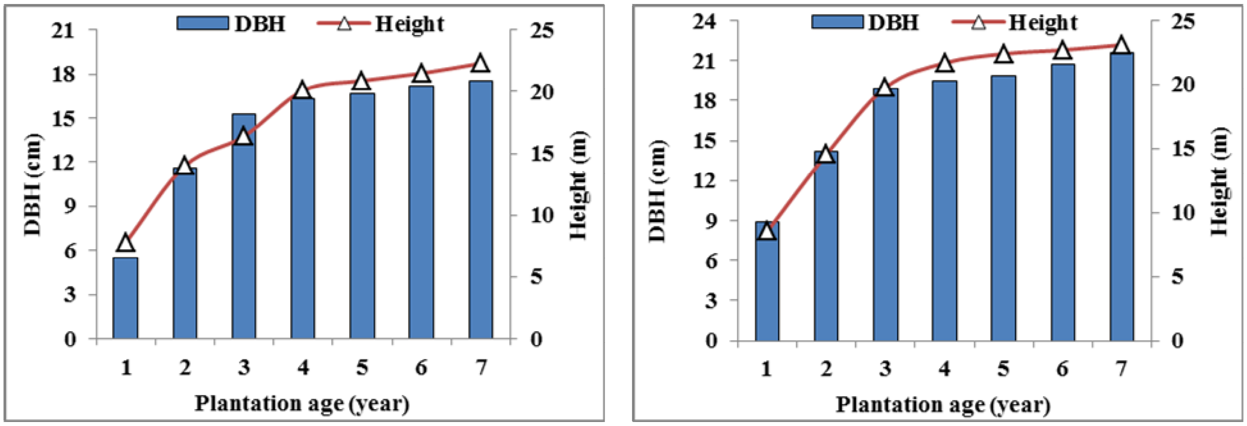
(a) (b)

Figure 2. Soil carbon stock under different age of *Eucalyptus tereticornis* during September 2012 (a) and March 2013 (b).



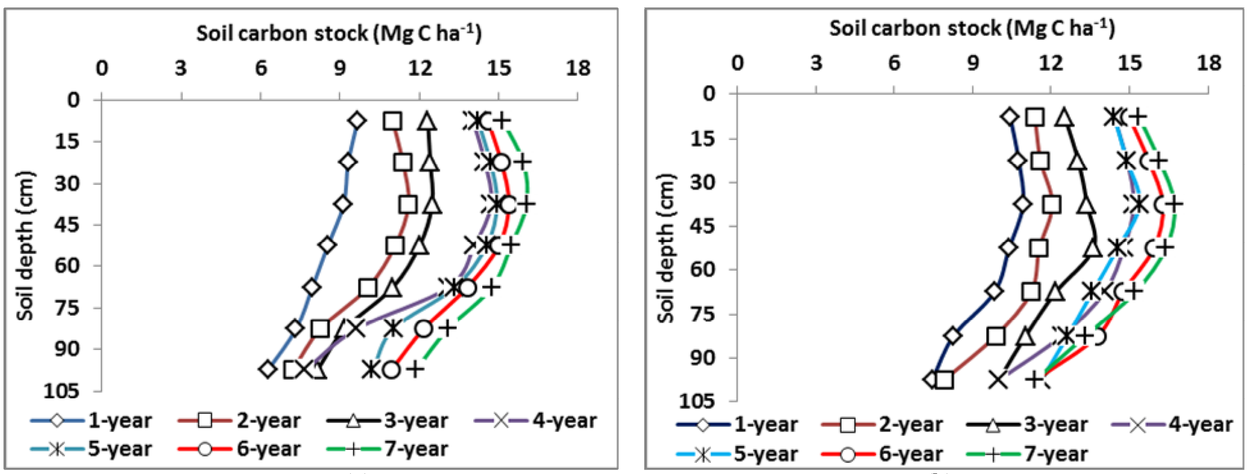
(a) (b) (c)

Figure 3. Carbon stock, POXC and MB-C in different soil depths under 6-year old *Eucalyptus tereticornis* based plantation forestry



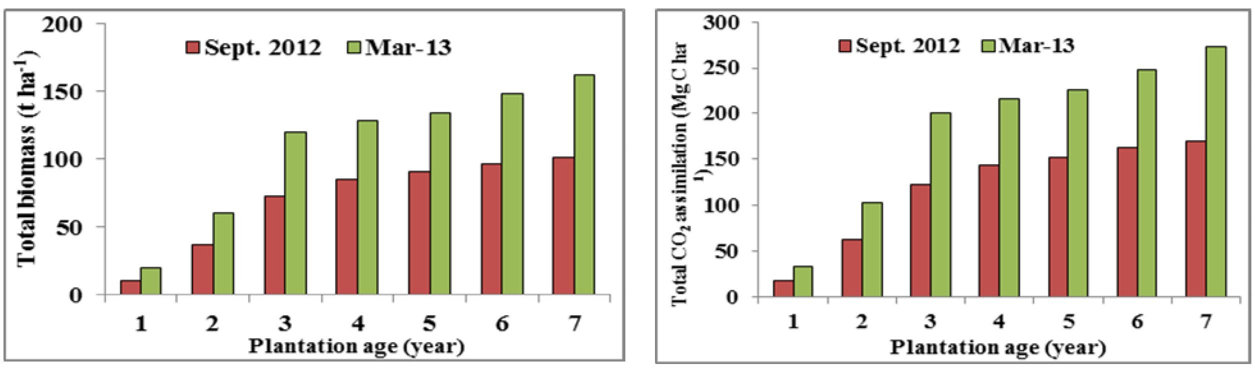
(a) (b)

Figure 4. Increment in DBH and height with stand age of *Populus deltoides* during September 2012 (a) and March 2013 (b)



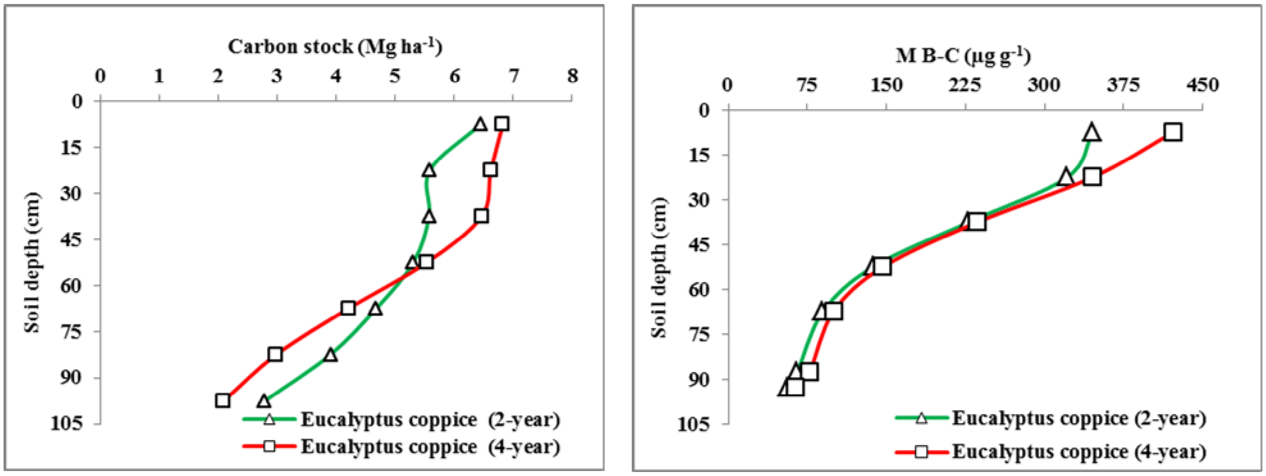
(a) (b)

Figure 5. Soil carbon stock under different age of *Populus deltoides* during September 2012 (a) and March 2013 (b)



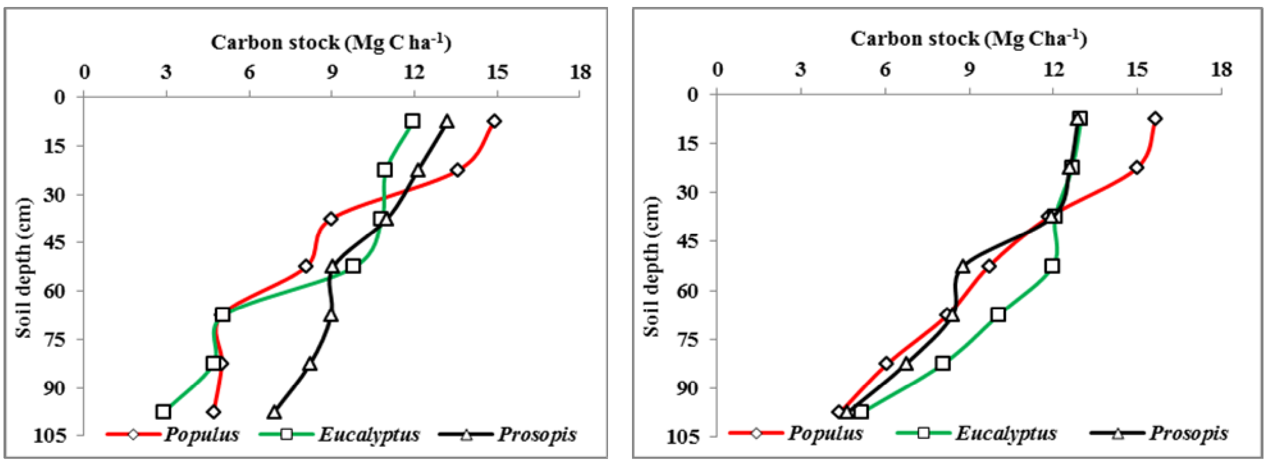
(a) **(b)**

Figure 6. Total biomass and CO_2 assimilation under different plantation age of *Populus deltoids*



(a) **(b)**

Figure 7. Carbon stock and MB-C under 2 and 4-year *Eucalyptus* coppice at Raina farm, Kurukshetra



(a) **(b)**

Figure 8. Carbon stock under plantation forestry during September 2013 and January 2014

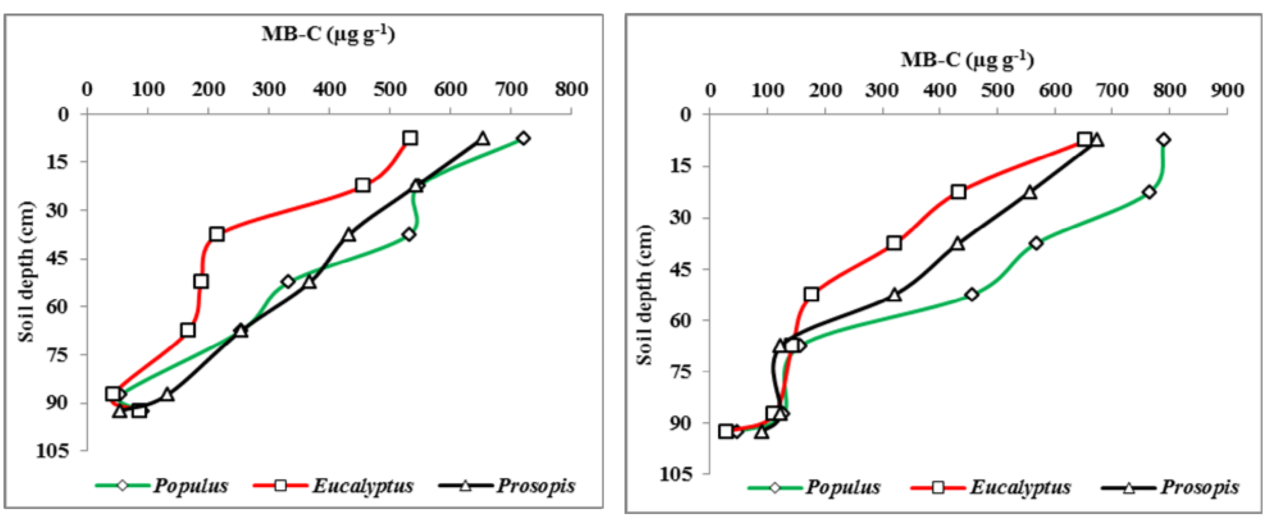


Figure 9. MB-C under plantation forestry during September 2013 and January 2014

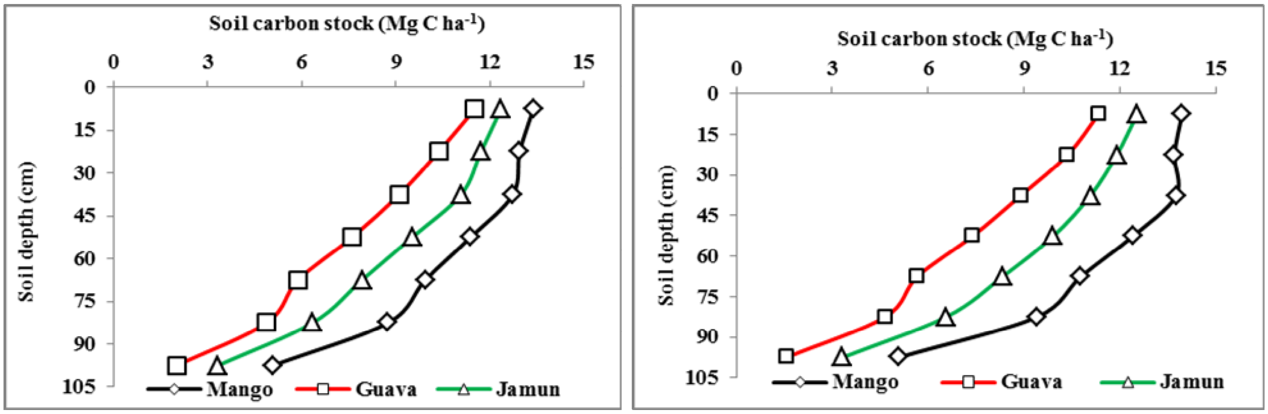


Figure 10. Carbon stock under fruit orchard during September 2013 and January 2014

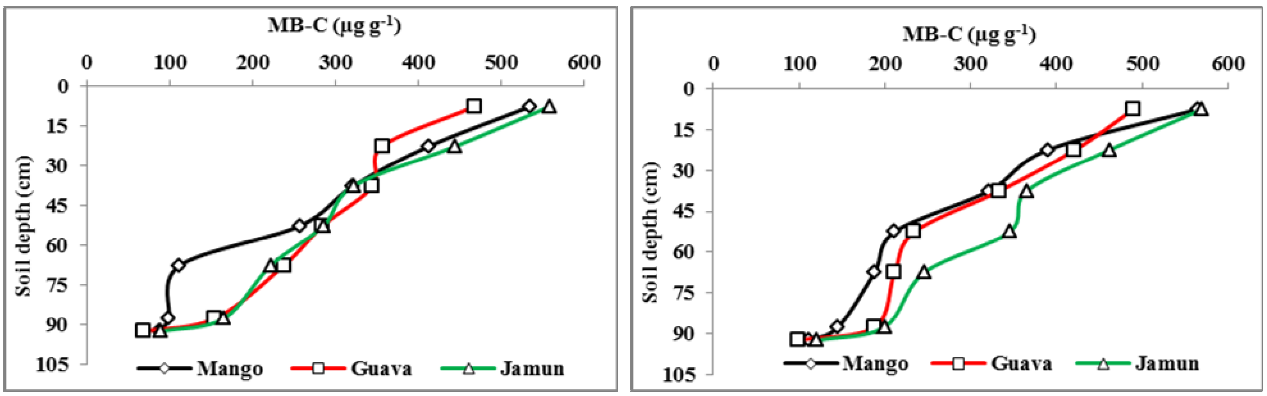
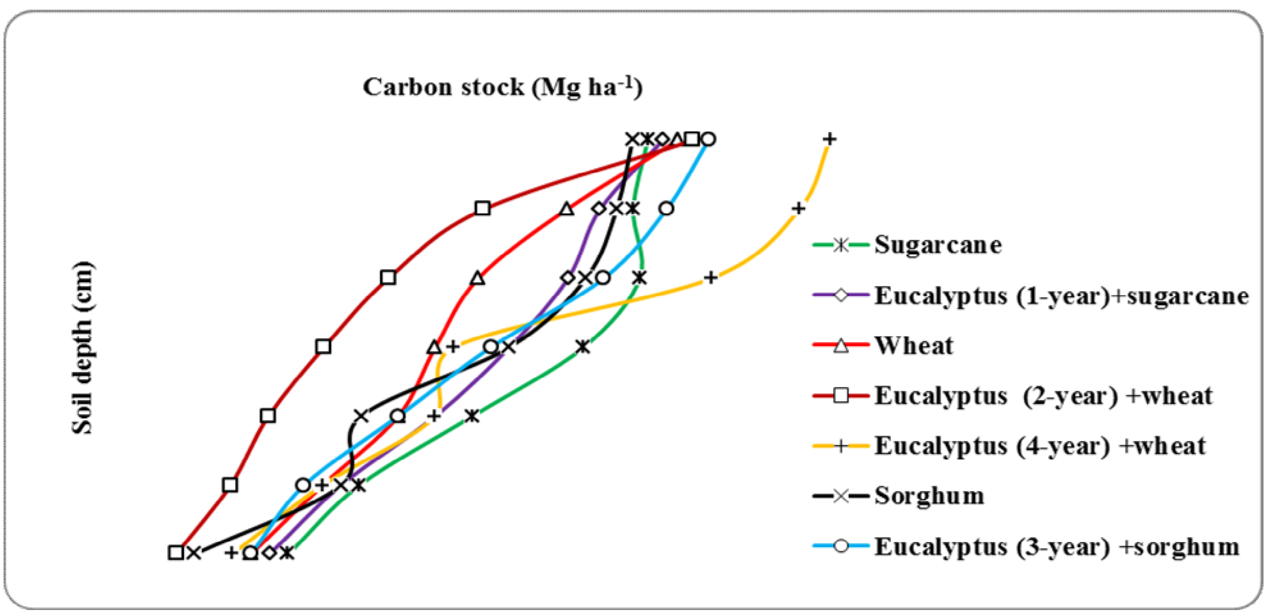


Figure 11. MB-C under fruit orchard during September 2013 and January 2014



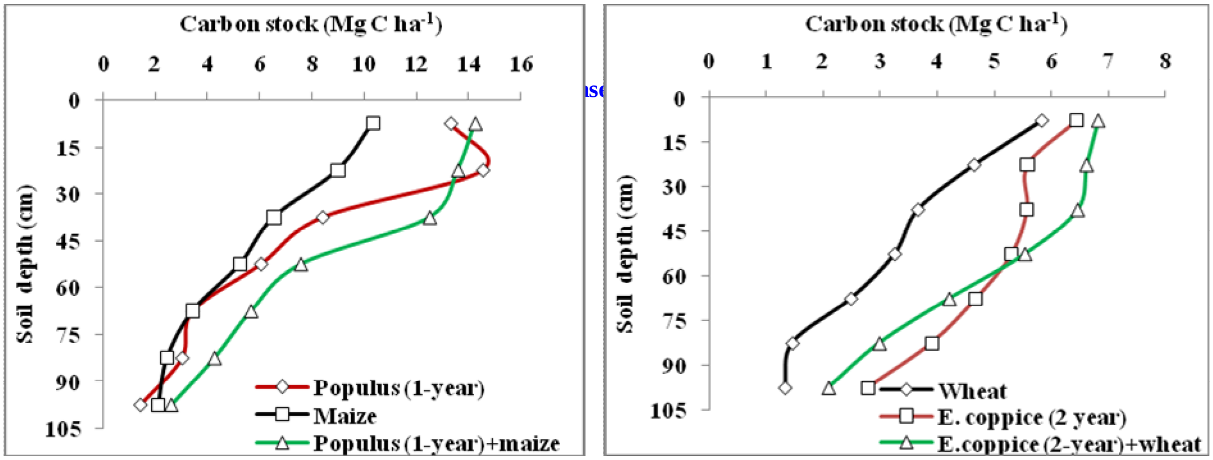


Figure 13. Carbon stock under *Populus* and *Eucalyptus* based agroforestry systems at DST research farm

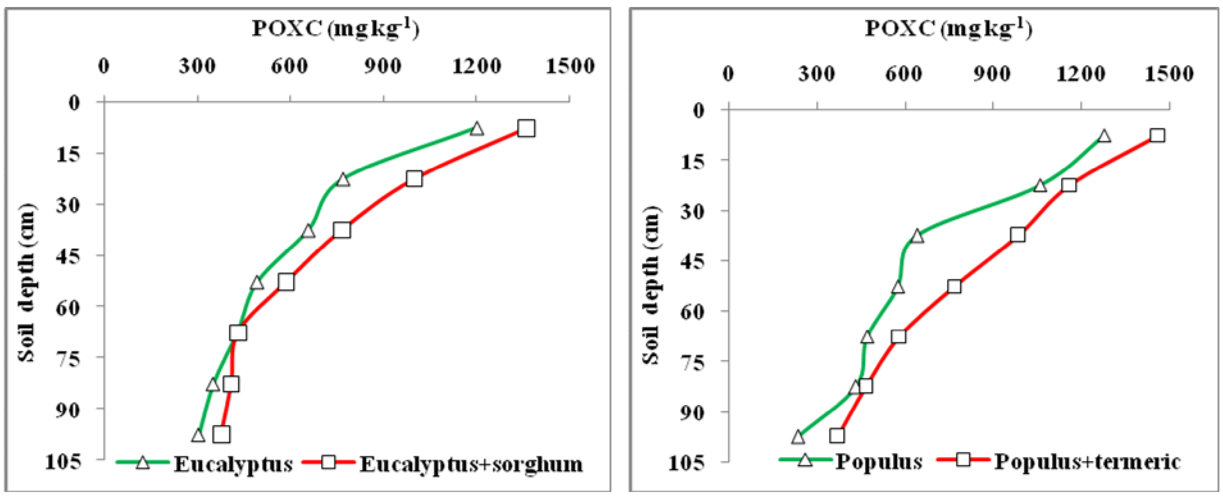


Figure 14. POXC under *Populus* and *Eucalyptus* based agroforestry systems at DST research farm

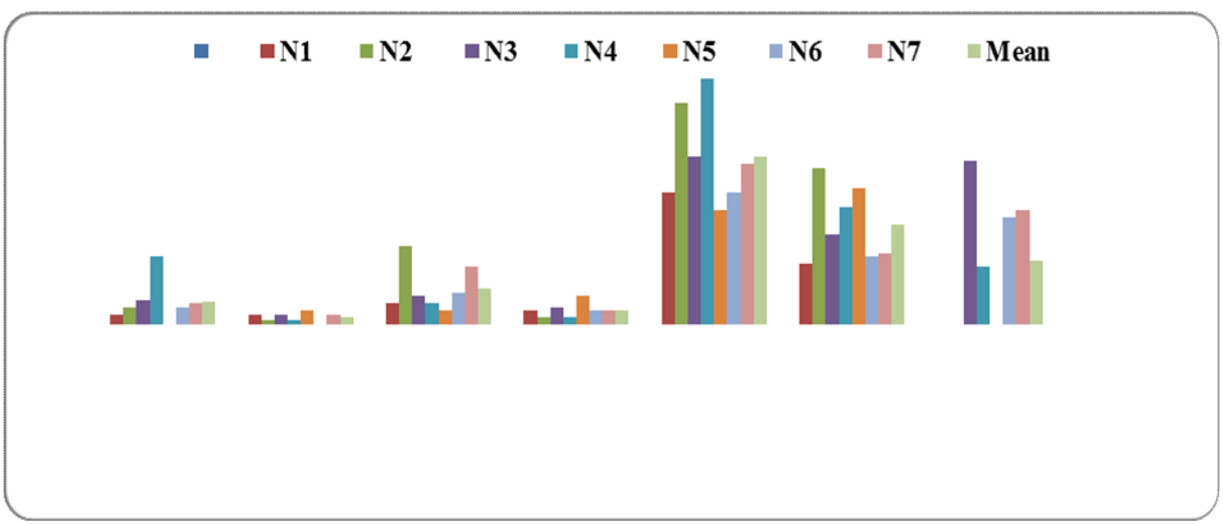


Figure 15. Particulate carbon in various size particles of WSA under N management options

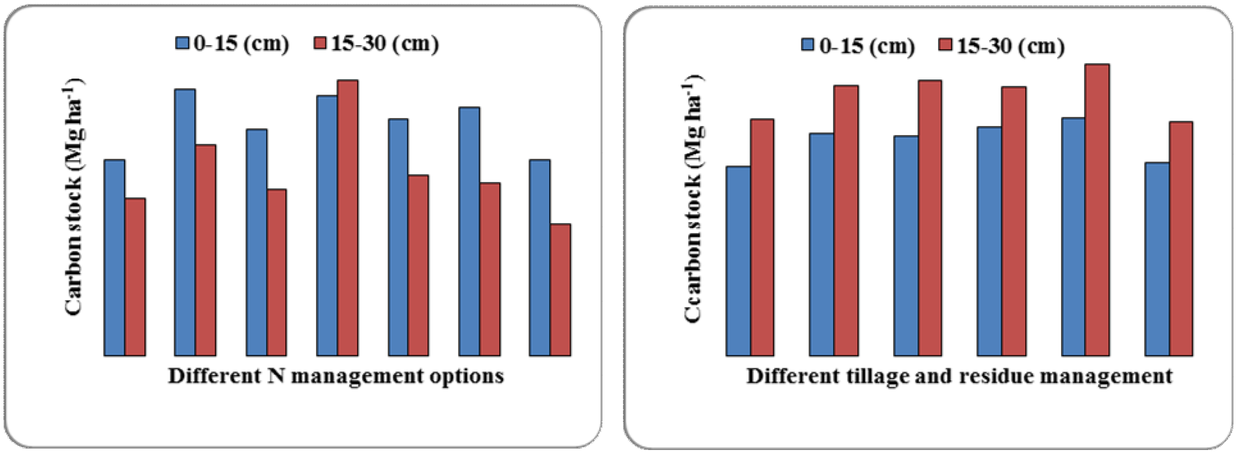


Figure 16. Carbon stock under different N-management options and tillage and residue management practices

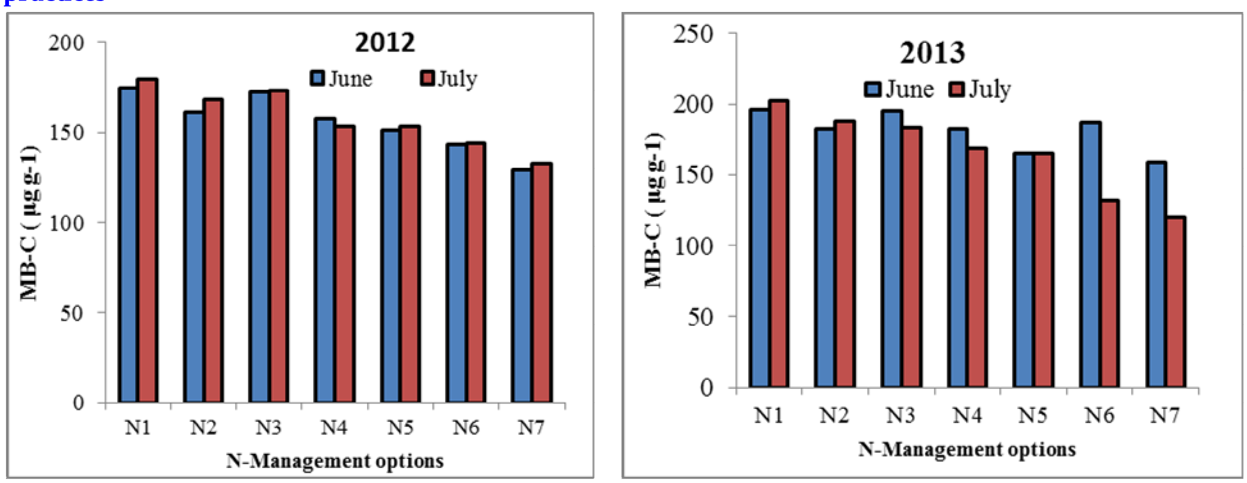


Figure 17. Microbial biomass carbon under different N management for the month of June and July for the year 2012 and 2013

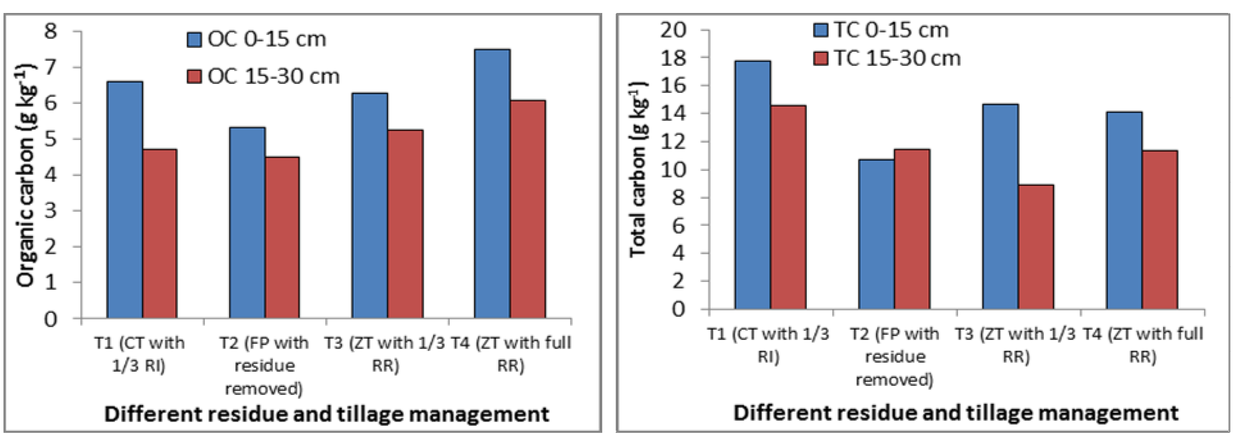


Figure 18. Organic and total carbon under different residue and tillage management practices after two year of rice-wheat crop rotation during 2013

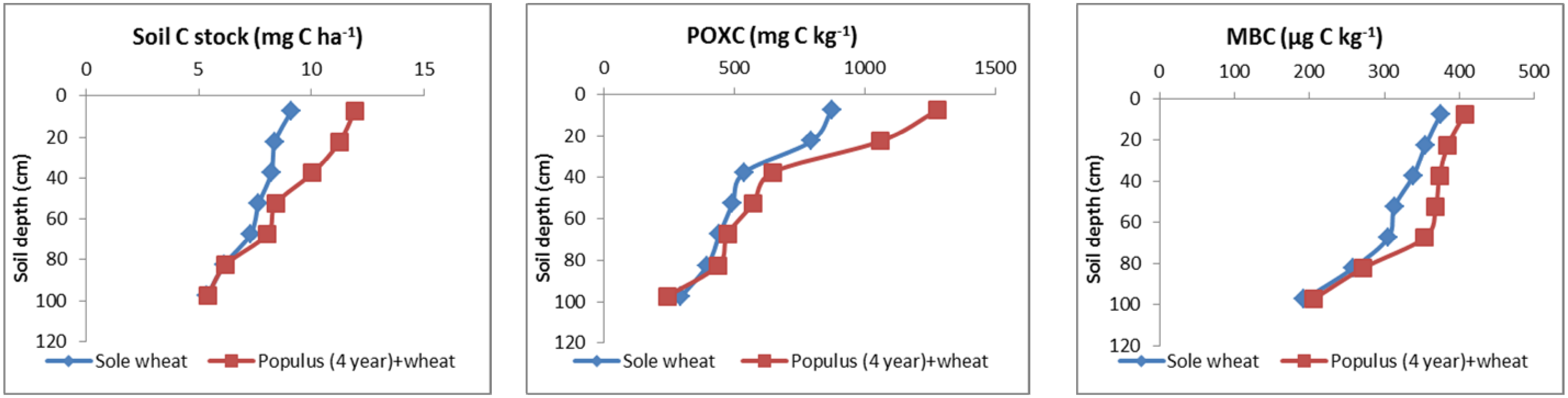


Figure 19. Effect of *Populus* based agroforestry system on soil carbon stock, POXC and MBC in different soil depths

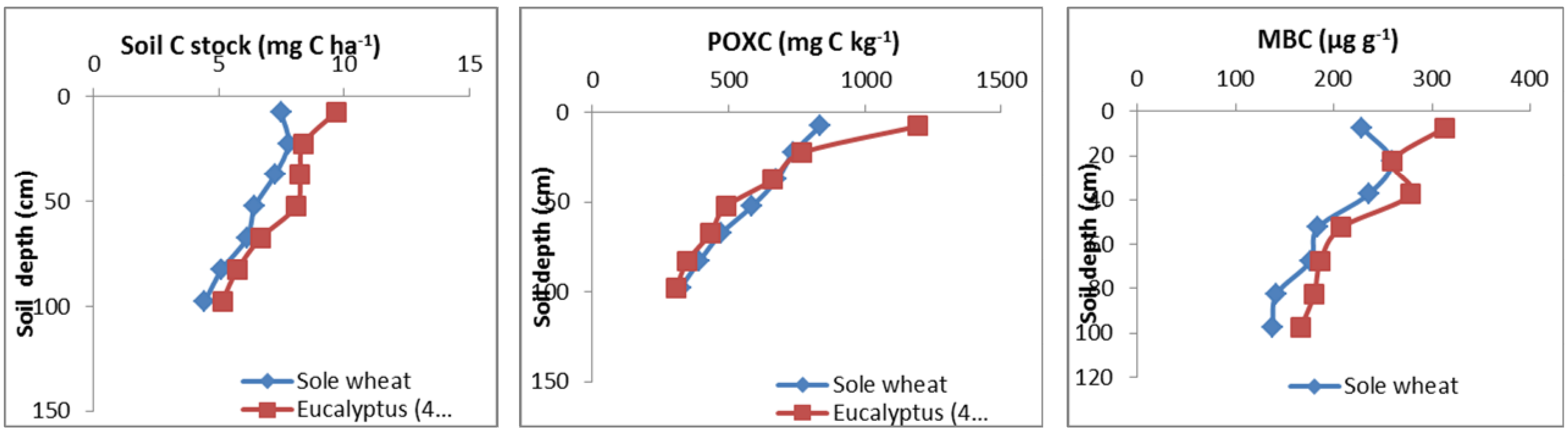
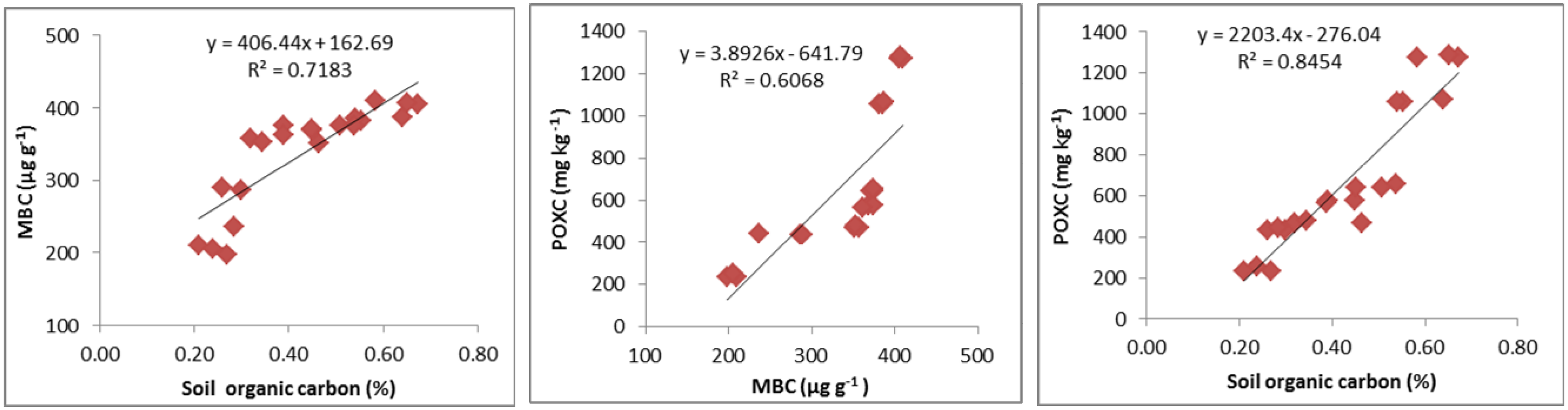


Figure 20. Effect of *Eucalyptus* based agroforestry system on soil carbon stock, POXC and MBC in different soil depths

Figure 21. Relationship between different labile forms of carbon under *Populus deltoides* based agroforestry systems



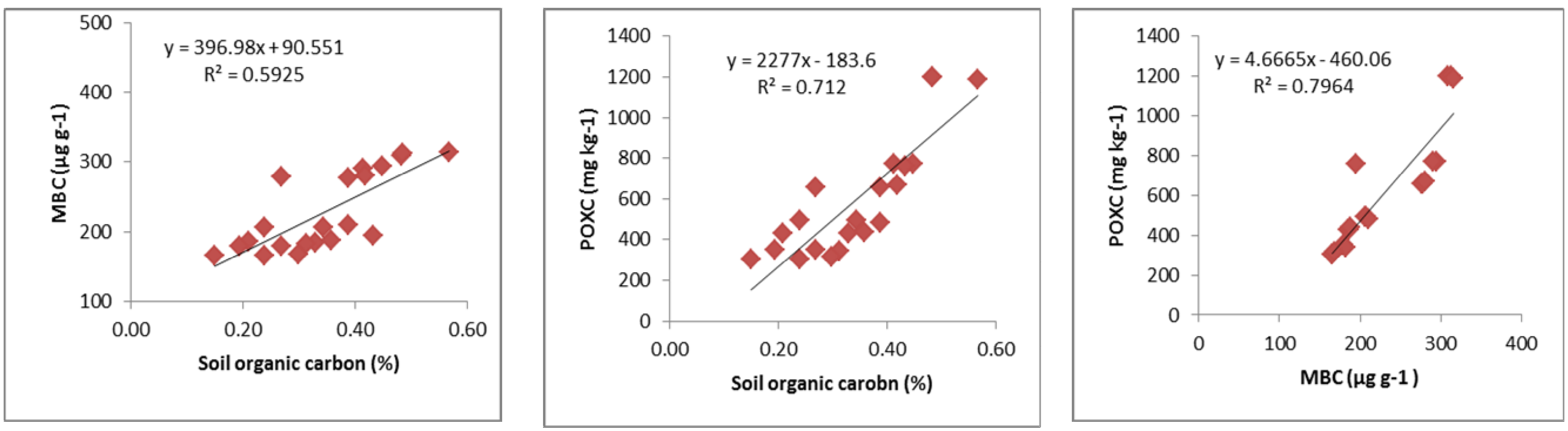


Figure 22. Relationship between different labile forms of carbon under *Eucalyptus tereticornis* based agroforestry systems