Technical Bulletin 5/2012

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ICAR

Role of agroforestry for mitigating climate change - some research initiatives

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Published
August, 2012

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Printed at
Veer Bundelkhand Press
Jhansi Ph. : 0510-2332931

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भाकृअनुप
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FOREWORD

Carbon sequestration in soils and woody perennials, and the transfer of carbon credits through market structures, represent one such win-win opportunity. Agroforestry systems offer perhaps the greatest potential to remove large quantities of carbon from the atmosphere. Indeed, such offsets are the only way to remove current atmospheric carbon dioxide as all other mitigation measures can only reduce future emission. There is also considerable evidence that agroforestry provide substantial benefits to rural dwellers, national economies and the environment.

In India, evidence is now emerging that agroforestry systems are promising land use systems that will increase and conserve aboveground and soil C stock to mitigate climate change. It is also obvious that the desired one third tree cover of total geographical area can only be achieved by including trees in farm fields/bunds. Obviously, the future of trees is on the farm. In spite of several potential advantages of agroforestry in terms of environmental benefits, agroforestry systems are not really accepted within the framework of the "Clean Development Mechanism" (CDM) under Kyto Protocol, because agroforestry is a very complex system, there is a lack of techniques for measuring uneven aged mixed tree species, carbon flow and leakages. However, there is need to develop techniques that helps in mapping of agroforestry area and assessing carbon sequestration in agroforestry systems.

I am happy to know that NRCAF, Jhansi has taken an initiative in this direction through various in-house and outside funded projects. The bulletin entitled, "Role of agroforestry for mitigating climate change-some research initiative" is the outcome of those initiatives. I am confident that this bulletin will be of great help to all students and researchers who are involves in the assessment of carbon sequestration in agroforestry projects.

(A.K. Singh)

PREFACE

Carbon sequestration is emerging as a major international policy goal in the context of increasing concerns about global climate change. The idea about mitigating it through forest conservation and management was discussed as early as in the 1970s. But it was in the 1990s that international action was initiated on climate change. To meet the global environment restoration commitments, agroforestry is ideal options to increase productivity of wastelands, increase tree cover outside the forest, and reduce human pressure on forests under different agro-ecological regions of India. An IPCC special report released in May 2000 titled Land Use, Land Use Change, and Forestry indicates that conversion of unproductive croplands and grasslands to agroforestry have the best potential to soak up atmospheric carbon.

Most of the carbon market trade involve emission reduction credits but there is also growing interest in the use of trees for absorbing carbon dioxide from the atmosphere. In India, some of the promising trees species are being grown by the farmers as commercial agroforestry and they are managing their own ways. In spite of all, the farmers are not getting the benefit of carbon market. Because these systems does not comes under afforestation or reforestation or improvement of degraded land through agroforestry that's why the estimate of carbon stock in the system does not qualify for CDM project. However, the estimate gives the carbon sequestration potential of the system under present scenario in which farmers adopt agricultural practices traditionally or improved one. The NRCAF is working on carbon sequestration since 2000 with various in-house and outside funded projects. Based on research methodologies adopted and results achieved in various project, a bulletin has been prepared and it will be help full for students, researchers, NGO's and others those are interested in carbon sequestration study in agroforestry.

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Jhansi, August, 2012

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Background

Worldwide agricultural area with potential for agroforestry is 356-499 million hectares. A considerable amount of this area is located in India. Agroforestry is known for their potential benefits such as helping to attain food security, increasing farm income, restoring and maintaining aboveground and belowground biodiversity, acting as corridors between protected forests, maintain watershed hydrology, reducing pressure on forest and achieving to national goal of one third area under tree cover. Agroforestry intervention, because of their ability to provide economic and environmental benefits, are considered to be the best measures in making communities to adapt and become resilient to the impact of climate change. Agroforestry can play a significant role in the adaptation to climate change because it improves microclimate, protect the soil loss, improve soil fertility, reduce carbon emission and increase carbon sequestration. The most, if not all agroforestry systems have the potential to sequester carbon. With adequate management of trees under agroforestry systems, a significant fraction of the atmospheric C could be captured and stored in plant biomass and in soils. The average C storage by agroforestry practices has been estimated as 9, 21, 50 and 63 Mg C ha^{-1} in semi-arid, sub-humid, humid and temperate regions (Schroeder, 1994). For smallholder agroforestry systems in the tropics, potential carbon sequestration ranges from 1.5 to 3.5 Mg C ha^{-1}. In agroforestry systems, C sequestration is a dynamic process and can be divided into two phases. At establishment, many systems are likely to be source of GHGs (loss of C and N from vegetation and soil). Then follow a quick accumulation phase and a maturation period when substantial amount of C are stored in the boles, stems, roots of trees and in the soil. At the end of the rotation period, when the trees are harvested and land returned to cropping (sequential system), part of the C would be released back to the atmosphere. Therefore, effective sequestration can only be considered if there is a positive net C balance from an initial stock after a few decades.

In India, evidence is now emerging that agroforestry system are promising land use system to increase and conserve aboveground and soil C stock to mitigate climate change. The average potential of agroforestry has been estimated to be 25 tonnes C ha^{-1} over 96 m ha (Sathaye and Ravindranath, 1998). In this way the total potential of agroforestry in India to store C is about 2400 million tonnes. In another estimate, Dhyani *et al*.(2009) reported that the area under agroforestry is 8.2% of total reported geographical area (305.6 m ha) and it contribute 19.3% of total C stock under different land uses (2755.5 m t C). Although there is variation in the estimation of area under agroforestry and C stock made by scientist involve in this area but there is good indication of agroforestry for gaining popularity for mitigating climate change because desired tree cover can only be achieved by including trees in farm field/bunds.

In spite of all these obvious potential advantages of agroforestry in terms of ecology and CO_2 mitigation but agroforestry system is not really accepted within the framework of the Clean Development Mechanism"(CDM) under Kyto protocol. The main reasons for this are the problems to measure and calculate the carbon flows and to estimate potential leakages.

Climate change study and their importance to Indian agriculture

India is large country with diverse climate, seasons, crops and farming system. Indian agriculture is highly dependent on monsoon because 68% land area sown is exposed to drought and about 77.6% of the total lands of 329 million ha is drought prone. The South-West monsoons account for 86% of total rainfall occurring in 100-120 days with several intermittent dry spell. Water availability is having close link with rainfall. The per capita availability of land is decreasing and India is having poor coping mechanism and low penetration of risk management products.

Impact of climate change in general and potential impact on agriculture

Rapid climate change and its effect is fast becoming one of the prime events of the 21st century. It is real and is accelerating across the globe. As the effects of this change combine with over population and weather crises, climate disruptions will affect more people than does any war. The year 2009 was the warmest year on record since 1901. In response, our planet has been changing with warming winds and rising seas. At the poles and in mountains, ice is under fire and glaciers are receding down into the temperature zone, change is rearranging the boundaries of life. The plants and animals with whom we share the planet are adopting and moving, some even going extinct, because they have no choice. The impact of climate and potential impacts on Indian agriculture as presented by various reports and publication are as follows;

— Productivity of most cereals would decrease due to increase in temperature, CO_2 and decrease in water availability.

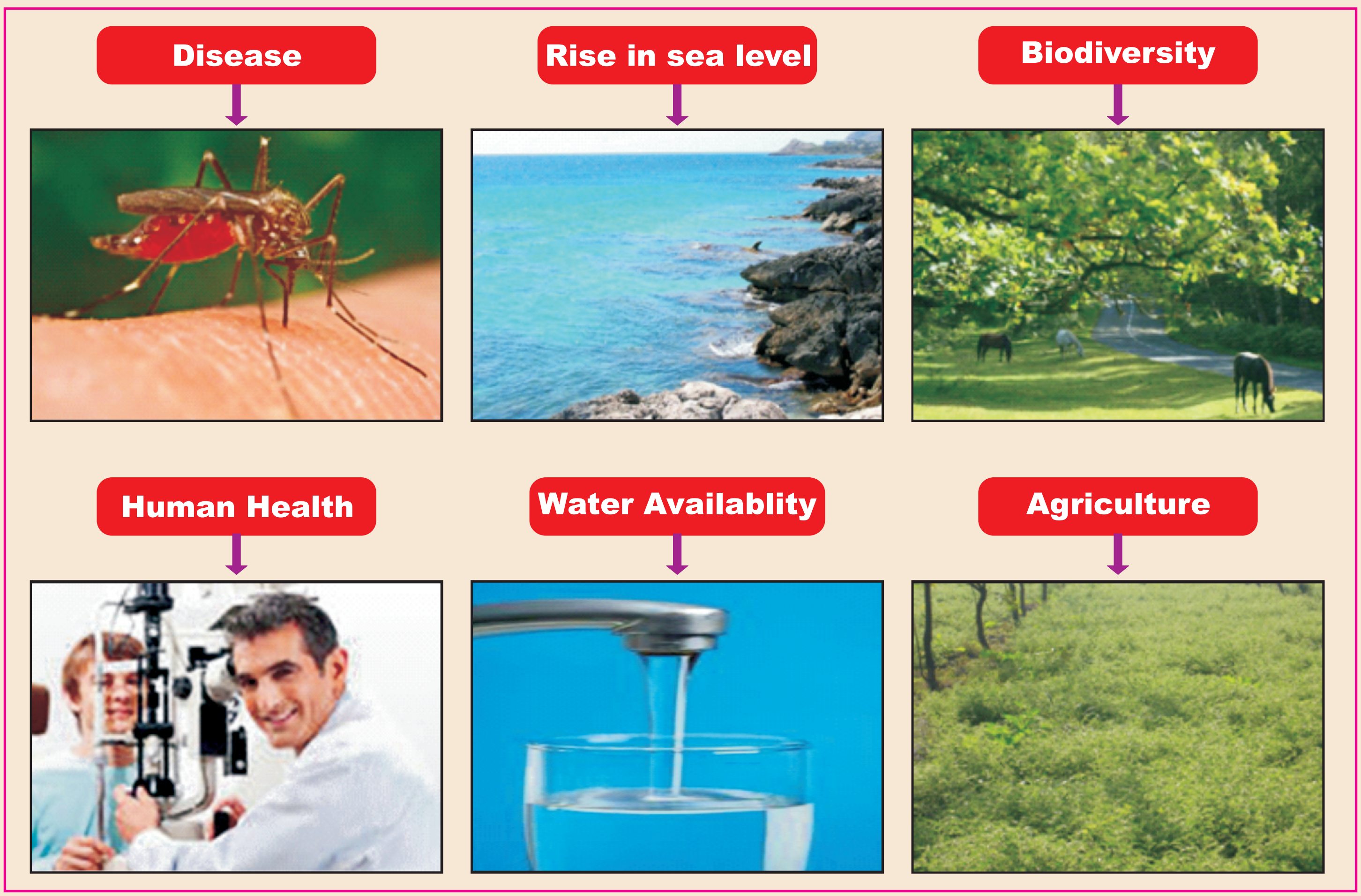
— A projected loss of 10-40% in crop production by 21st Century.

— 1°C increase in temperature may reduce yields of major food crops by 3-7%.

— Length of growing period in rainfed areas is likely to reduce, especially in peninsular regions.

— Increase climate extreme-likely to increase production variability

— Increase in CO_2 to 550ppm increases yields of rice, wheat, legumes and oil seed by 10-20%.



The major focus of climate change study

There are three/ four major issues, which are being addressed by the scientists working on climate change. These issues are impact assessment, vulnerability, adaptation strategies and mitigation.

Impact assessment

Damage of residence due to Floods

Damage of mango orchard due to cold wave in northern part of India

Adaptation strategies

Increase water availability through watershed

Mitigating climate change

Growing of trees in agroforestry to store carbon in biomass through photosynthesis

The study

National Research Centre for Agroforestry (NRCAF) is pioneer organization of ICAR, New Delhi working on climate change particularly on mitigation since 2005 with an ICAR ad-hoc scheme entitled “Carbon and Nitrogen dynamics in *Albiziaprocera* based agroforestry system”. After completion of this project another project was initiated on CO_2 sequestration potential of agroforestry system under irrigated and rainfed conditions with the financial assistance of Department of Science and Technology, Ministry of Science and Technology, Government of India, New Delhi. The NRCAF also became a partner of Network project on “Impact, adaptation and vulnerability to Indian Agriculture to Climate Change” during 2009-2011. Presently this Centre is actively involved in the project on National Initiative on Climate Resilient Agriculture (NICRA). The major responsibility given to this Centre is mapping of agroforestry area using remote sensing and GIS technique and estimation of carbon sequestration potential of agroforestry through predictive models. For which, the scientist involve in the project are using CO2FIX model. Since we are working on agroforestry practices adopted by the farmers on agricultural lands that does not come under afforestation or reforestation or improvement of degraded land through agroforestry that's why the estimate of carbon stock in the system does not qualify for CDM project. Another important point is that the farmers manage the trees in own ways and also import the soil from their field for domestic purposes. These are the main difficulties to measure and calculate the real carbon flows and leakages from the system. However, the estimate gives the carbon sequestration potential of the system under present scenario in which farmers adopt agricultural practices traditionally or improved one.

Project- I

Carbon and nitrogen dynamics in *Albiziaprocera* based agroforestry system

A field experiment was conducted during Feb., 2005 to April, 2008 to quantify the role of trees and crops on carbon storage in soil and biomass. The experimental site is situated at 25° 27' N latitude, 78° 35' E longitudes and altitude 271 m above the mean sea level. The total rainfall during 2005, 2006 and 2007 were 440.7, 373.2 and 554.8mm with 30 rainy days and major part of rain was received during July, August and September (Fig 1). The soil of the experimental field is inter-mixed black and red soil group of Bundelkhand regions covered under the order of Alfisol, having 45.20%, 21.70% and 31.40% sand, silt and clay, respectively at 0-15cm soil depth and 46.0%, 22.60% and 33.10% sand, silt and clay at 15-30 soil depth, respectively. The experiment consisted of three pruning regimes, viz 70% canopy pruning, 50% canopy pruning and control (unpruned tree), two crop sequences (blackgram-mustard and greengram – wheat) and pure tree (without crop) and pure crop (without tree). The experiment was conducted in split plot design with three replications.

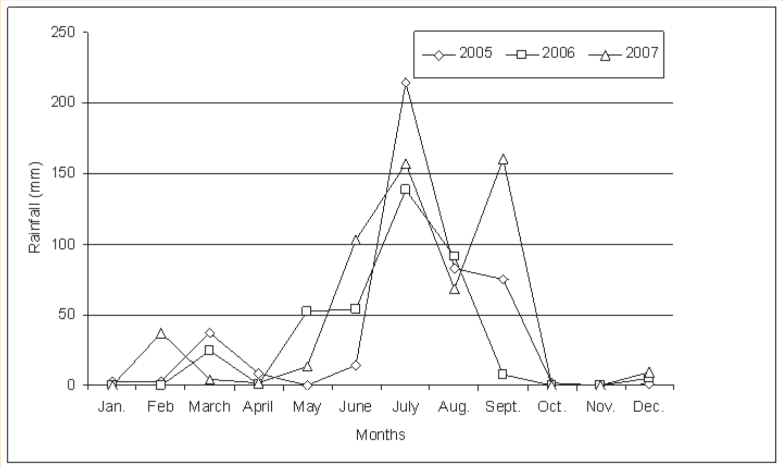


Fig 1. Monthly rainfall during 2005 to 2007

Study approaches

Aboveground biomass of tree

Tree growth (diameter at breast height and height) of all the trees was measured once in a year; first observation was taken in August and second in February to estimate live biomass of trees by using allometric equation. On the basis of diameter at breast height (dbh), the trees were grouped in higher, medium and lower range. In this way total 72 trees were selected to estimate above ground biomass, 24 trees each from 70% canopy pruned, 50% canopy pruned and control (unpruned tree) and 12 trees from pure tree (without crop). Trees were cut close to the ground with manual saw and main bole, branches, foliage were separated and weighed accordingly. For estimating dry biomass of these parts 5cm thick 2 to 3 discs were taken at 0.5 to 1.0 m interval according to length of main bole and branches (Fig 2). These discs were kept in polythene bag immediately to avoid moisture loss. After taking fresh weight, these were dried at 80°C till to constant weight to determine moisture content. In case of foliage about 3 fresh samples approximately having 1kg weight were collected to estimate dry biomass (Fig 2). After taking the fresh weight, these samples were transferred from polythene bag to paper bags and dried in oven at 80°C till to constant weight to determine moisture content. On the basis of moisture content in each components trees and herbaceous layer, dry biomass of each component was calculated and total dry biomass was obtained by summing the dry biomass of all the components. The steps involve in estimation of biomass of trees and crops are given as flow chart, which gives a brief idea for estimation of biomass in agroforestry project (Fig 3).

Fig 2. Samples of main bole, branches, twigs and foliage to determine moisture content

Above ground live biomass accumulation in tree component was predicted by using allometric equation [$Y = a\,(dbh)^b$, where Y = biomass, dbh is the diameter of the tree at breast height and a and b are intercept and slope coefficients, respectively].

Litter fall

Litter fall of trees was collected in each plot at monthly intervals using the litter traps 0.5m^2 areas (Fig 4). The monthly litter fall data was pooled for annual values.

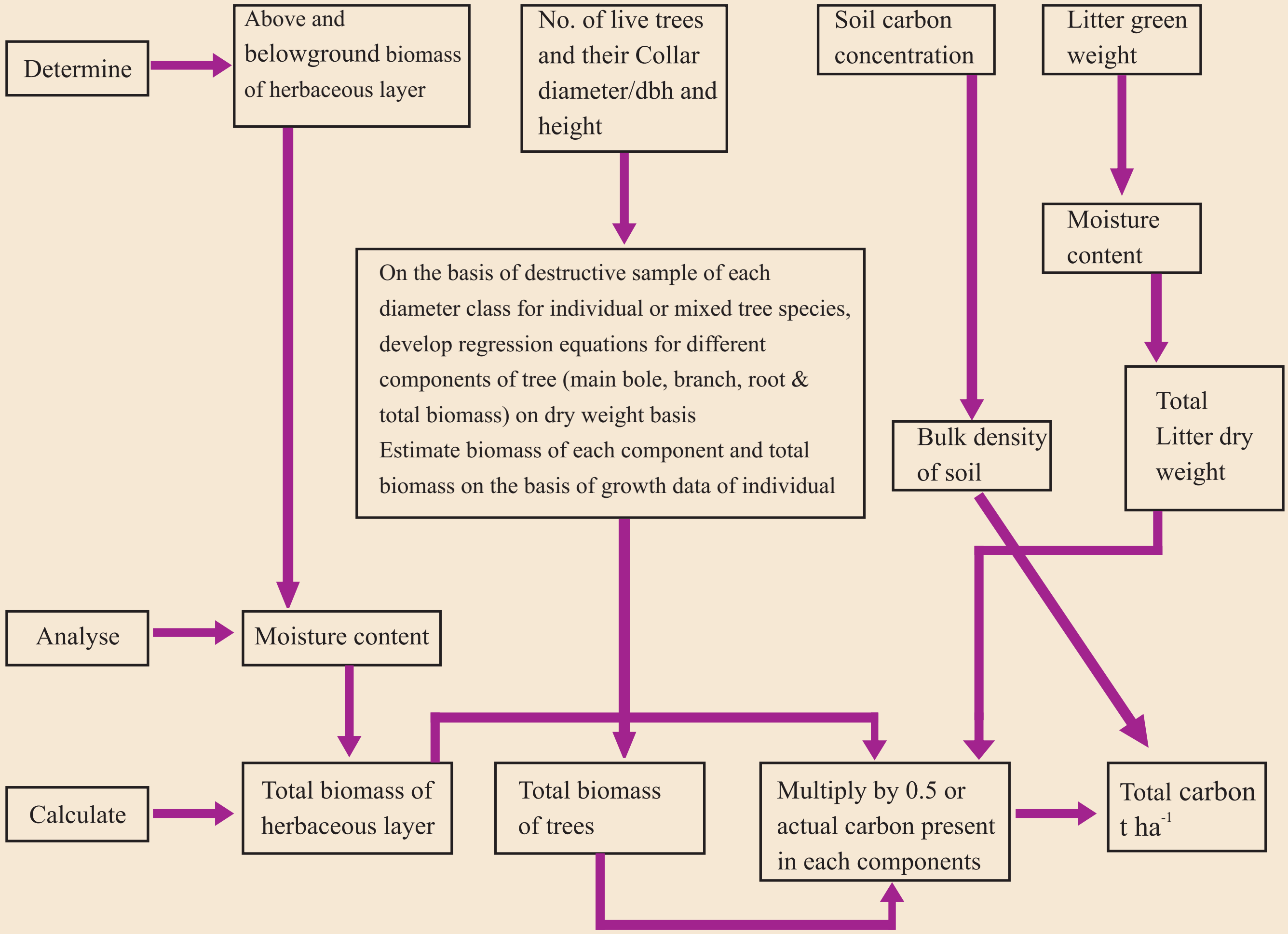


Fig 3. Flowchart for monitoring changes in major carbon pools in agroforestry system

Fig 4. Litter traps placed below the tree canopy at various distances from tree base

Belowground biomass of tree

From destructive sampled trees, roots of six trees from each pruning regimes were excavated manually. The samples of primary and secondary roots were collected to determine the moisture content. On the basis of moisture content, total dry root biomass was estimated. Based on above and below ground dry biomass of tree, root: shoot ratio was determined in harvested tree. Root: shoot ratio was 0.44, 0.46, 0.49 and 0.47 for 70, 50% canopy pruning, control (unpruned tree) and pure tree (without crop), respectively. On the basis of root: shoot ratio, standing live root biomass was predicted by using same model used for above ground biomass.

Fine root biomass at 0-15, 15-30 and 30-60 cm soil depths was recorded during cropping period in all treatments. Five monoliths (size 0.25 m × 0.25 m ×0.60 m) per replicate were taken (Fig 5) and placed in a labeled plastic bucket and soaked in water overnight. After complete washing, the roots were filtered with 0.5 mm sieve and sorted out into fine and small roots. Roots were kept in a petri dish to wash again with distilled water. All live and dead roots were sorted out and placed on soaking paper for few minutes to minimize the water content. The root samples were dried at 70 °C up to constant weight and weighed.

Fig. 5 Roots were excavated to determine the belowground biomass (right) and for fine roots monolith were taken at various distances from tree base (left)

Biomass of herbaceous layer

Aboveground biomass

Aboveground live biomass including floor litter (Fig 6) of herbaceous layer was recorded at monthly interval. A quadrate (50 cm × 50 cm) was laid on the ground at 0.5m, 1.0 m, 2.0 m, and 3.0 m from tree base and vegetation (crop and weed) that originated inside the sampling frame was clipped and placed in the plastic bags to avoid moisture loss during transportation of sample from field to laboratory. Floor litter on the soil surface was also collected in each of the sampling frame used for measuring herbaceous vegetation. These samples were washed with clean water to remove dust particles on the foliage. After air-drying, the samples were dried in oven at 70ºC till constant weight.

Fig 6. Floor litter of herbaceous layer

Belowground biomass

Belowground root biomass of herbaceous layer at 0-30 cm soil depth was also recorded every month during cropping period. A monolith (size 0.25m × 0.25m ×0.30m) was taken (Fig 7) from the each aboveground clipped biomass site and placed in a labeled plastic bucket and soaked in water overnight. After complete washing, the roots were filtered with 0.87 mm sieve and sorted out roots were kept in a petri dish to wash again with distilled water. All live and dead roots were sorted out and placed on soaking paper for few minutes to minimize the water content. The samples were kept in oven for drying at 70 °C upto constant weight.

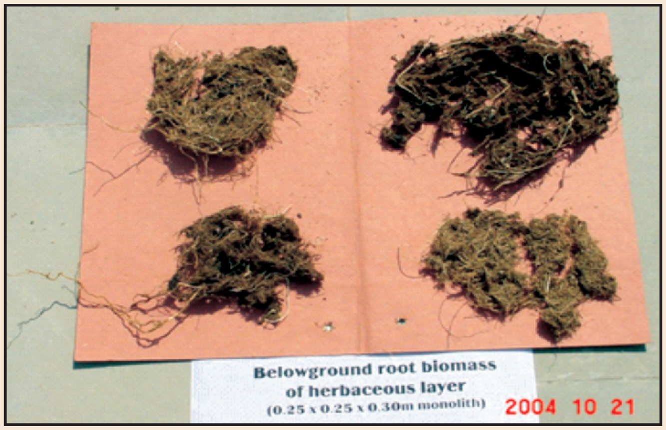


Fig 7. Monolith for estimation of root biomass in herbaceous layer in (left) and after washing of monolith, root biomass can be seen in left (right)

Analysis of Carbon and nitrogen in biomass

The carbon and nitrogen in aboveground and belowground biomass of tree and herbaceous layer were analyzed by EuroEA 3000 elemental analyzer. The C and N accumulation in tree and herbaceous layer were computed by multiplying component wise biomass with their respective C and N concentration. The sum of C and N content of different components of tree represented standing state of a stand. Carbon and nitrogen concentration in different components of tree and herbaceous layer is given in Table 1.

Table1. Carbon and nitrogen content (%) in different components of tree and herbaceous

Tree component		C	N
Main bole		47.57	0.84
Branch		48.93	1.08
Leaf		44.84	3.13
Litter fall		43.28	1.42
Coarse root		46.78	1.26
Fine root		48.59	2.59
Blackgram	Crop	42.88	1.68
	Weed	42.27	1.47
	Floor litter	41.34	1.67
	Root	43.08	1.36
	Grain	43.93	3.15

Greengram	Crop	41.85	1.62
	Weed	43.50	1.43
	Floor litter	40.05	1.46
	Root	43.29	1.52
	Grain	44.07	3.08
Wheat	Crop	44.27	1.02
	Weed	42.51	1.08
	Floor litter	40.76	0.90
	Root	45.99	1.04
	Grain	43.16	1.87
Mustard	Crop	44.12	1.44
	Weed	41.67	1.31
	Floor litter	40.01	0.98
	Root	45.34	1.49
	Grain	53.47	3.11

Results

Tree biomass

Pruning of tree was done every year in last week of Oct./ first week of Nov. before sowing of rabi crops. The pruned branch was taken out from the system for fuel purpose and foliage was mixed in the soil as organic manure. The annual pruned biomass obtained from 70 and 50% canopy pruning is given in Table 2. Pruned biomass was higher in greengram – wheat than blackgram – mustard crop sequence during 2005 but it was higher in blackgram – mustard crop sequence during 2006 and 2007. In 70% canopy pruning, leaf and branch biomass was 29% and 32% higher than 50% canopy pruning, respectively.

Table 2. Pruned biomass (t ha^{-1}) from 70 and 50% canopy pruning

Pruning regimes	Component	2005		2006		2007	
		B-M	G-W	B-M	G-W	B-M	G-W
70% canopy pruning	Leaf	0.80 (0.004)	0.99 (0.002)	1.12 (0.03)	1.05 (0.02)	1.32 (0.04)	1.25 (0.03)
	Branch	1.03 (0.01)	1.06 (0.003)	1.34 (0.07)	1.22 (0.04)	1.54 (0.07)	1.31 (0.06)
50% canopy pruning	Leaf	0.24 (0.004)	0.27 (0.003)	0.34 (0.02)	0.31 (0.03)	0.54 (0.03)	0.51 (0.04)
	Branch	0.30 (0.004)	0.37 (0.01)	0.44 (0.03)	0.40 (0.03)	0.64 (0.04)	0.60 (0.06)

Note: B-M= Blackgram-Mustard and G-W= Greengram-Wheat crop sequence
Figure in parentheses is SE (±) of the mean

Standing live biomass was predicted by using allometric equations, which express dry weights of individual tree components as a function of dbh, had high R^2 values and accounted for 0.97, 0.93, 0.95, 0.98 and 0.98 of the variance in 70% canopy pruning; 0.95, 0.96, 0.97, 0.98 and 0.98 of the variance in 50% canopy pruning; 0.95, 0.98, 0.96, 0.99 and 0.99 of the variance in control (unpruned) and 0.97, 0.98, 0.90, 0.99 and 0.99 of the variance in pure tree (without crop) for main bole, branch, foliage, root and total biomass, respectively (Fig. 8a-d).

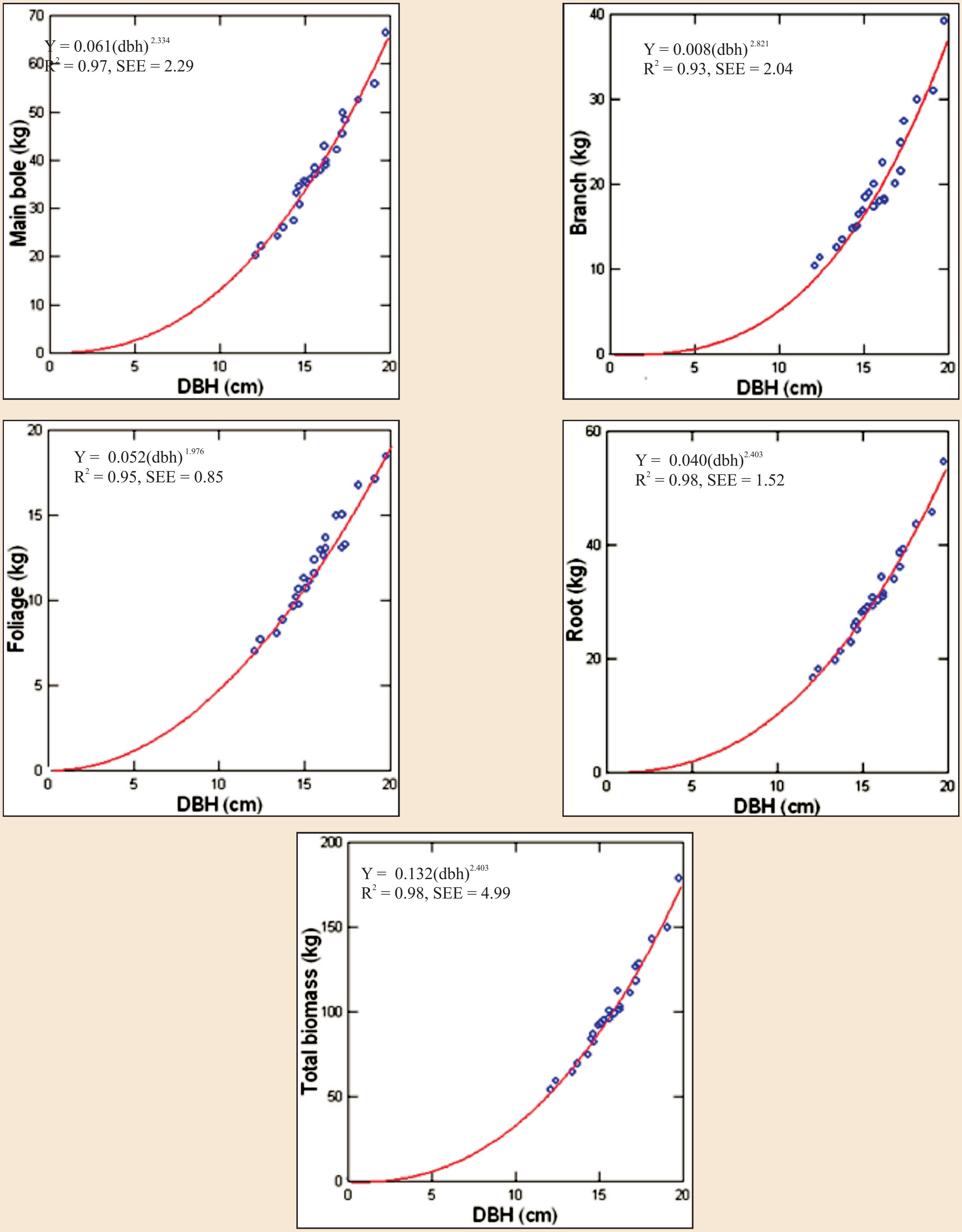


Fig.8 (a) Relationship between biomass and dbh of 70% canopy pruning (No. of sampled trees = 24)

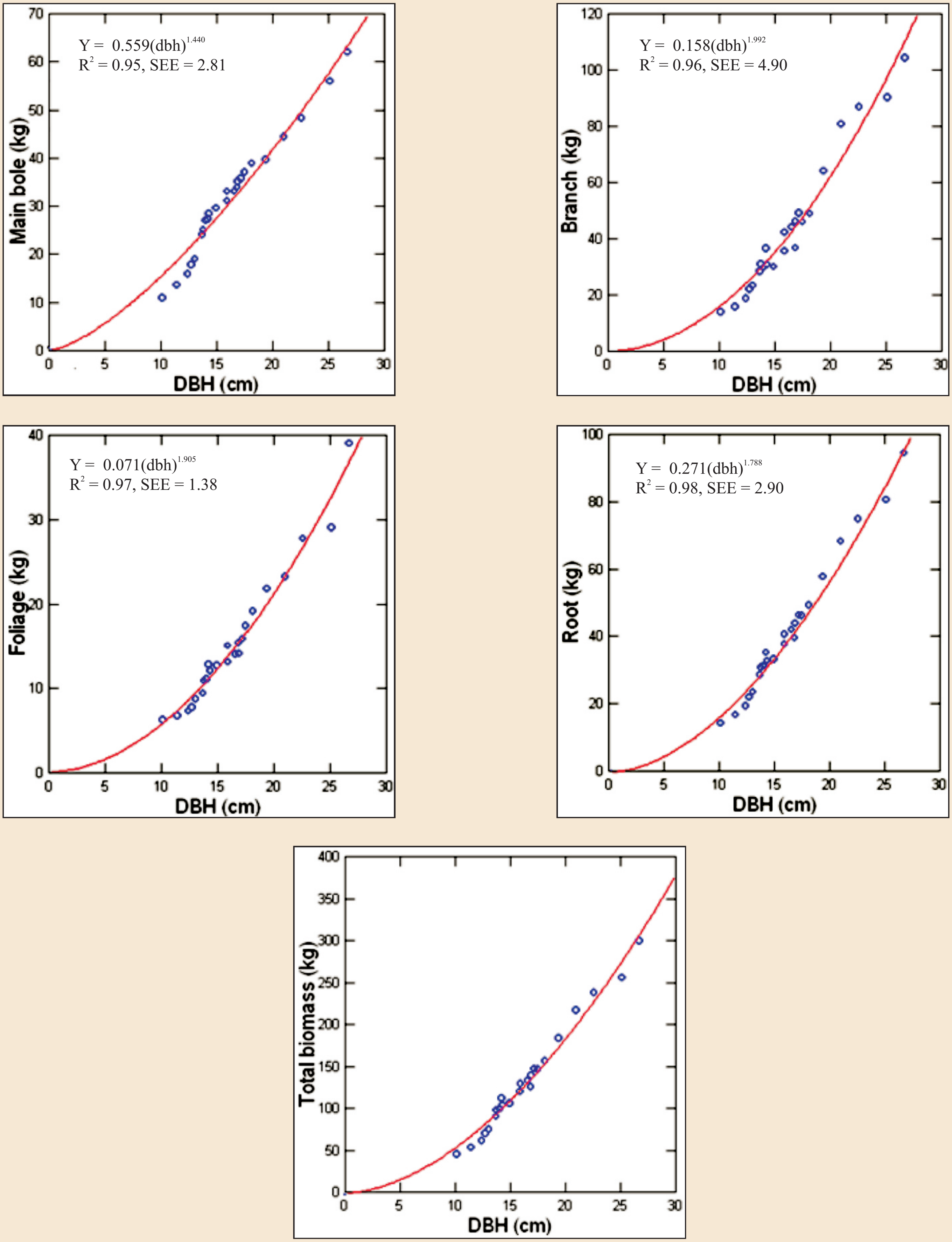


Fig.8 (b) Relationship between biomass and dbh of 50% canopy pruning (No. of sampled trees = 24).

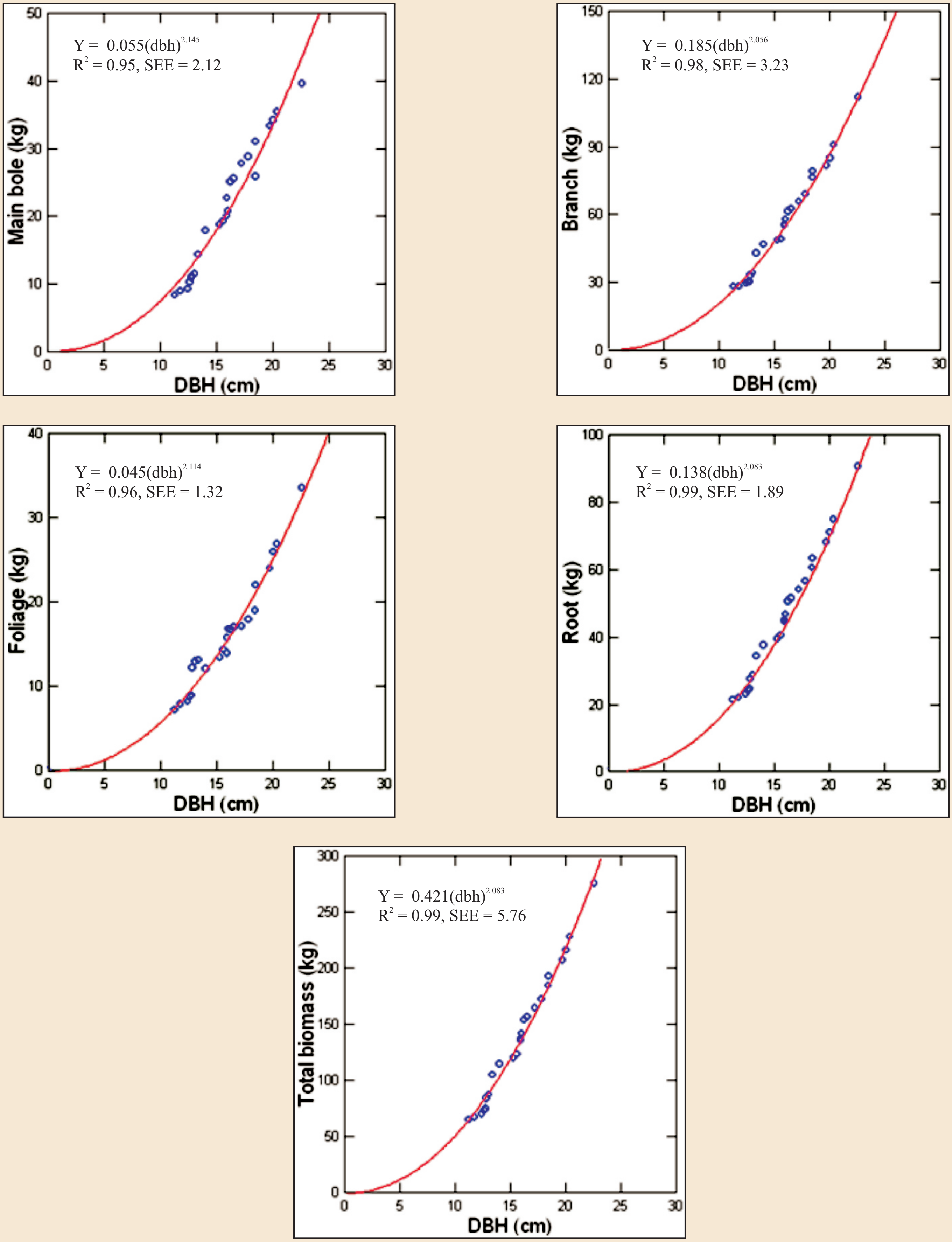


Fig.8(c) Relationship between component biomass and dbh of control (unpruned trees). No. of sampled trees = 24

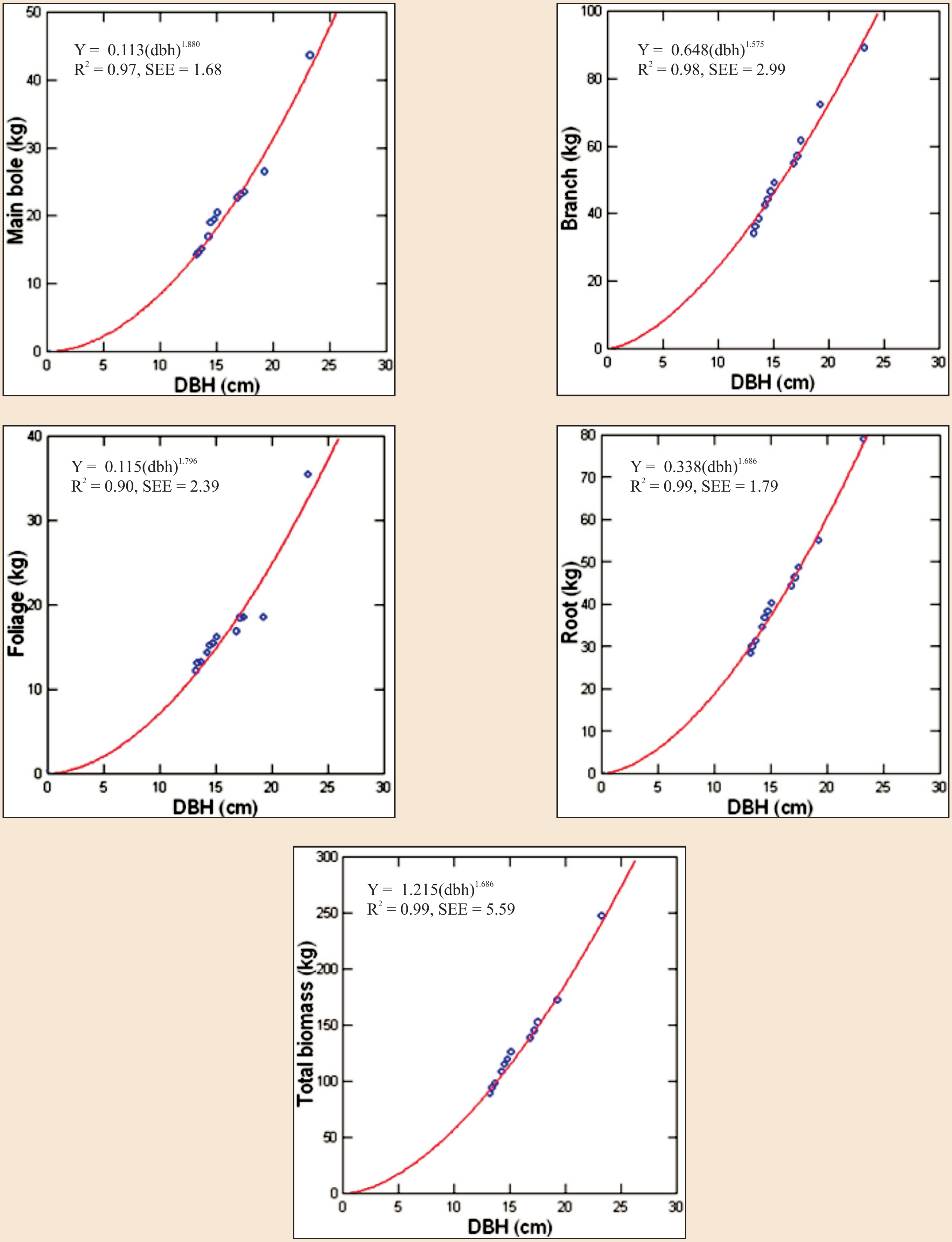


Fig.8 (d). Relationship between component biomass and dbh of pure tree (without crop). No. of sampled trees = 12

Changes in biomass accumulation of *A. procera* over different age is shown in Table 3, which clearly indicates that standing biomass increased with the tree age but increment in biomass accumulation was almost stable at different age of the tree. Allocation of biomass in different tree components was in the order of branch > root > main bole > foliage. Of the total biomass, branch biomass accounted for 25–33%. Total biomass did not exhibit significant variation due to crop sequences, except 6 and 7-years age. Total biomass of tree at 5-years age was 26.11 and 25.90 t ha^{-1} in blackgram – mustard and greengram –wheat crop sequence, respectively and the biomass accumulation at the age of 8- years was 70.2 and 67.5 t ha^{-1} in blackgram – mustard and greengram – wheat crop sequence, respectively.

Among pruning regimes, tree biomass was significantly ($P \leq 0.05$) higher in control (unpruned) than 50 and 70% canopy pruning. Biomass accumulation in various tree components was in the order of branch > root > main bole > foliage in control (unpruned) and 50% canopy pruning but in 70% canopy pruning the biomass accumulation in different tree components was in the order of main bole > root > branch > foliage. In control (unpruned), branch biomass represented about 40–41%, roots 33%, main bole 15–16% and foliage 11–12% of the total tree biomass at different age of the tree. In 50% canopy pruning, share of branch biomass was also maximum (31–33%) of the total tree biomass, followed by roots 31–32%, main bole 24–26% and foliage 11–12%. However in 70% canopy pruning, the contribution of main bole was maximum (38–39%) of the total biomass, followed by roots 30%, branch 17–20% and foliage 12–13% at different age of the tree (Table 3).

The biomass of pure tree (without crop) was 23–41% and 6–14% less than control (unpruned) and 50% canopy pruning in the agroforestry system, respectively but it gave 6–48% higher biomass than 70% canopy pruning in the same system. The change in biomass accumulation with age was similar to that of tree grown in agroforestry system (Table 3).

Table 3. Biomass (t ha^{-1}) accumulation in different component of *A. procera*at different age

Age (years)	Tree component	Crop sequences		LSD (0.05)	Canopy pruning			LSD (0.05)	Pure tree
		B–M	G-W		70%	50%	Control		
5.0	Foliage	3.1	3.1	0.0	2.4	3.1	3.7	0.1	3.3
	Branch	8.3	8.3	NS	3.1	8.7	13.1	0.2	10.6
	Main bole	6.4	6.4	NS	6.9	7.3	4.9	0.2	4.0
	Root	8.3	8.2	0.1	5.4	8.8	10.6	0.2	8.4
	Total	26.1	25.9	0.1	17.7	27.9	32.4	0.6	26.3
6.0	Foliage	4.5	4.4	0.1	3.7	4.3	5.3	0.3	4.5
	Branch	12.2	12.0	0.1	5.8	12.1	18.4	0.9	13.9
	Main bole	9.4	9.2	NS	11.6	9.3	7.0	0.6	5.5
	Root	12.1	11.9	NS	9.2	11.8	15.0	0.8	11.2
	Total	38.2	37.4	NS	30.2	37.5	45.7	2.5	35.1

7.0	Foliage	6.0	5.8	NS	4.8	5.8	7.2	0.3	5.6
	Branch	16.8	16.3	NS	8.4	16.6	24.8	0.9	17.1
	Main bole	12.5	12.2	NS	15.8	11.7	9.6	0.5	7.0
	Root	16.4	16.0	NS	12.6	15.7	20.2	0.8	14.0
	Total	51.8	50.3	NS	41.7	49.7	61.7	2.3	43.7
8.0	Foliage	8.0	7.8	0.1	6.2	7.6	9.9	0.4	7.3
	Branch	23.2	22.4	0.4	11.9	22.1	34.2	1.3	21.4
	Main bole	16.73	15.9	0.6	21.1	14.4	13.4	0.7	13.2
	Root	22.2	21.4	0.4	17.0	20.3	28.1	1.1	17.8
	Total	70.2	67.5	1.2	56.2	64.6	85.7	3.5	59.7

Litter biomass

Litter production did not exhibit significant variation due to crop sequence during 2005 – 06 and was almost similar in both the crop sequences (Table 4). However, it was significantly ($P \leq 0.05$) higher in blackgram – mustard (1001.45 and 1102.48 kg ha^{-1} year^{-1}) than greengram – wheat crop sequence during 2006 – 07 and 2007-08, respectively. The influence of pruning is very much obvious from the data given in Table 4, which indicates that litter production was significantly ($P \leq 0.05$) highest in control (unpruned) followed by 50 and 70% canopy pruning. Litter production in control (unpruned) was two and half times higher than 70% canopy pruning, respectively. In pure tree (without crop), litter production was 18% less than control (unpruned) under agroforestry system.

Table 4. Litter fall production (kg ha^{-1} year^{-1}) of *A. procera* under different treatments

Crop sequence	Year		
	2005 – 06	2006 – 07	2007 - 08
Blackgram – mustard	882.23	1001.45	1102.48
Greengram – wheat	882.10	975.40	1062.03
LSD (0.05)	NS	14.08	12.34
Crop sequence			
70% canopy pruning	511.96	586.54	699.86
50% canopy pruning	847.07	980.36	1043.92
Control (unpruned)	1287.47	1398.39	1502.98
LSD (0.05)	5.86	10.26	18.46
Pure tree (without crop)	1091.69	1191.07	1290.19

Biomass of herbaceous layer

The total biomass of herbaceous layer (sequence wise during kharif and rabi) in 70% canopy pruning was significantly higher than 50% canopy pruning and control (unpruned tree). The biomass of herbaceous layer in greengram –wheat crop sequence was significantly higher than blackgram-mustard crop sequence. The biomass of pure crop (without tree) was higher than that of agroforestry system (Table 5). The significant variation in biomass under different crop sequence was due to its nature of crop but significant variation under different pruning regime is due to higher availability of growth resources under 70 and 50% canopy pruning.

Table 5. Biomass of herbaceous layer (t ha^{-1})

Year	component	Crop sequences		LSD (0.05)	Canopy pruning			LSD (0.05)	Pure crop (without tree)	
		B-M	G-W		70%	50%	Control		B-M	G -W
2005 -06	Aboveground	3.98	4.09	0.01	4.95	4.74	2.42	0.14	6.96	6.75
	Root	0.39	0.40	0.001	0.48	0.47	0.23	0.02	0.70	0.76
	Grain	0.35	0.98	0.01	0.83	0.79	0.37	0.03	1.11	2.25
	Total	4.72	5.47	0.02	6.26	6.00	3.02	0.16	8.77	9.76
2006 -07	Aboveground	3.39	3.55	0.03	4.36	4.00	2.05	0.12	5.78	6.05
	Root	0.35	0.36	0.001	0.45	0.41	0.21	0.07	0.58	0.71
	Grain	0.24	0.82	0.03	0.70	0.61	0.28	0.10	0.83	2.08
	Total	3.98	4.73	0.04	5.51	5.02	2.54	0.13	7.19	8.84
2007 -08	Aboveground	3.74	3.42	0.002	5.82	3.24	1.67	0.08	8.55	7.25
	Root	0.45	0.41	0.005	0.68	0.40	0.20	0.11	1.03	0.87
	Grain	0.44	0.50	0.001	0.75	0.45	0.20	0.05	0.89	1.73
	Total	4.63	4.33	0.02	7.25	4.09	2.07	0.09	10.47	9.85

Biomass carbon in tree

Changes in carbon accumulation with age of the tree have been given in Table 6. The carbon accumulation under different crop sequence did not vary much at 5-years age and it was 12.28 to 12.39 t C ha^{-1} in both the crop sequences. The rate of increase in carbon at 6- years age was 5.47 to 5.74 t C ha^{-1} and at 7-years age the rate was 6.12 to 6.42 t C ha^{-1} in both the crop sequences. However, the annual increment in carbon accumulation was 2.46 to 3.45 t C ha^{-1} $year^{-1}$ at different age of the tree. Of the total carbon accumulation, above and belowground biomass accounted for 68.7% and 31.3%, respectively. Pruning of tree had significant ($P \leq 0.05$) effect on carbon accumulation. Carbon accumulation in 70% canopy pruning was about 37% less than control (unpruned) at different age of the tree. Carbon accumulation in 50% canopy pruning was higher than 70% canopy pruning and differences in carbon accumulation between these two were about 4 t C ha^{-1} at 5, 6 , 7 and 8- years age of the tree. But the difference was very less at 8-years age of tree. Contribution of different tree components in carbon accumulation varied with the amount of pruning. The contribution of main bole was higher in 70% canopy pruning whereas the contribution of branches was higher in 50% canopy pruning and control (unpruned). The carbon accumulation in pure tree (without crop) was less than the trees grown in agroforestry system.

Table 6. Biomass carbon (t ha^{-1}) in *A. procera* at different age

Age (years)	Tree component	Crop sequences		LSD (0.05)	Canopy pruning			LSD (0.05)	Pure tree (without crop)
		B-M	G-W		70%	50%	Control		
5.0	Foliage	1.38	1.37	0.01	1.07	1.39	1.67	0.03	1.47
	Branch	4.08	4.04	NS	1.51	4.24	6.42	0.10	5.19
	Main bole	3.05	3.03	NS	3.28	3.48	2.35	0.02	1.90
	Root	3.88	3.84	0.02	2.52	4.10	4.97	0.09	3.93
	Total	12.39	12.28	0.07	8.38	13.21	15.41	0.29	12.49
6.0	Foliage	2.00	1.96	0.04	1.66	1.92	2.36	0.12	2.01
	Branch	5.98	5.87	0.09	2.83	5.92	9.01	0.42	6.81
	Main bole	4.49	4.37	NS	5.51	4.43	3.34	0.27	2.62
	Root	5.67	5.55	NS	4.30	5.52	7.01	0.37	5.25
	Total	18.14	17.75	NS	14.30	17.79	21.72	1.16	16.69
7.0	Foliage	2.69	2.61	NS	2.15	2.59	3.20	0.12	2.53
	Branch	8.24	7.99	NS	4.12	8.11	12.12	0.41	8.34
	Main bole	5.95	5.81	NS	7.52	5.56	4.55	0.25	3.34
	Root	7.68	7.46	NS	5.91	7.33	9.47	0.35	6.53
	Total	24.56	23.87	NS	19.70	23.59	29.34	1.11	20.74
8.0	Foliage	3.61	3.49	0.06	2.75	3.42	4.47	0.18	3.27
	Branch	11.33	10.96	0.19	5.86	10.83	16.74	0.63	10.46
	Main bole	7.96	7.56	0.28	10.05	6.86	6.38	0.33	6.91
	Root	10.40	10.02	0.18	7.97	9.50	13.14	0.52	8.31
	Total	33.29	32.02	0.58	26.63	30.61	40.73	1.64	26.41

Carbon in litter biomass was almost equal in both the crop sequences during 2005 – 06. However, it was significantly ($P \leq 0.05$) higher (433.4 and 477.15 kg ha^{-1} year^{-1}) in blackgram – mustard than greengram – wheat crop sequence during 2006–07 and 2007-08, respectively. Among the pruning regimes, total carbon in litter fall was significantly ($P \leq 0.05$) highest (557.22, 605.22 and 650.49 kg C ha^{-1} year^{-1} during 2005 – 06, 2006 – 07 and 2007-08, respectively) in control (unpruned) followed by 50 and 70% canopy pruning during all the years. In pure tree (without crop), total carbon in litter biomass was 24% to 21% less than trees in the agroforestry system during different years.

Herbaceous layer

The carbon accumulation in above and belowground biomass of herbaceous layer under different crop sequence have been given in Table 7, which showed that greengram-wheat crop sequence had significantly higher biomass than blackgram-mustard crop sequence. The carbon accumulation in herbaceous layer was significantly higher (LSD $\leq$0.05) in 70% canopy pruning than 50% canopy pruning and control (unpruned tree). The significant variation in crop sequence was due to its nature of crop. The carbon accumulation in pure crop (without tree) was 1.8 times higher than the carbon accumulation in crop grown in agroforestry.

Table 7. Carbon in the biomass of herbaceous layer (t ha^{-1})

Year	component	Crop sequences		LSD (0.05)	Canopy pruning			LSD (0.05)	Pure crop (without ree)	
		B-M	G-W		70%	50%	Control		B-M	G-W
2005 - 06	Aboveground	1.67	1.71	0.005	2.07	1.98	1.01	0.06	2.91	2.82
	Root	0.16	0.17	0.005	0.21	0.20	0.10	0.01	0.31	0.32
	Grain yield	0.18	0.43	0.01	0.37	0.36	0.17	0.01	0.54	0.98
	Total	2.02	2.31	0.01	2.65	2.54	1.28	0.07	3.76	4.12
2006 - 07	Aboveground	1.42	1.48	0.005	1.82	1.67	0.86	0.05	2.42	2.53
	Root	0.15	0.16	0.001	0.19	0.18	0.09	0.01	0.25	0.30
	Grain yield	0.12	0.36	0.01	0.31	0.27	0.13	0.04	0.40	0.91
	Total	1.69	2.00	0.01	2.32	2.12	1.08	0.06	3.07	3.74
2007 - 08	Aboveground	1.56	1.43	0.01	2.44	1.35	0.70	0.09	3.58	3.03
	Root	0.20	0.17	0.01	0.29	0.17	0.09	0.03	0.45	0.37
	Grain yield	0.21	0.22	0.001	0.35	0.21	0.09	0.01	0.44	0.75
	Total	1.97	1.82	0.01	3.08	1.73	0.88	0.05	4.47	4.15

Carbon input

The total carbon input in tree at 6-years age was 5.47 to 5.75 t ha^{-1} yr^{-1} and at age of 8- years, it was 8.15 to 8.73 t ha^{-1} yr^{-1}. It indicates that carbon input increase with increasing growth of tree. Of the total carbon input in tree component, contribution of root, main bole, branch and foliage was 35, 37, 23 and 9% in 70% canopy pruning, 37, 20, 37 and 11% in 50% canopy pruning and 37, 15, 40 and 11% in control (unpruned tree), respectively (Table 8).The total carbon input in herbaceous layer was maximum (2.65, 2.32 and 3.08 t ha^{-1} yr^{-1} during 2005-06, 2006-07 and 2007-08, respectively) in 70% canopy pruning and lowest in control (unpruned tree). These values are significantly varied with each other. The contribution of different components herbaceous layer in carbon input was in the order of aboveground>grain>root in different crop sequences.

Export of carbon and nitrogen from the system

The annual export of carbon and nitrogen from the system have been given in Table 9, which revealed that the exit of carbon and nitrogen was maximum in 70% canopy pruning and lowest in control (unpruned tree) during all the years. It indicates that nutrient uptake, return, retention was higher in control (unpruned tree) than 70 and 50% canopy pruning.

Table 8. Carbon input (t ha^{-1} yr^{-1}) in different components of tree in *Albiziaprocera* based agroforestry system

Age (years)	Tree component	Crop sequences		LSD (0.05)	Canopy			LSD (0.05)	Pure tree
		B-M	G-W		70%	50%	Control		
6.0	Foliage	0.62	0.59	0.01	0.53	0.59	0.69	0.03	0.54
	Branch	1.90	1.83	NS	1.68	1.32	2.59	0.06	1.62
	Main bole	1.44	1.34	NS	0.95	2.23	0.99	0.14	0.72
	Root	1.79	1.71	NS	1.42	1.78	2.04	0.06	1.32
	Total	5.75	5.47	NS	4.58	5.92	6.31	0.83	4.20

7.0	Foliage	0.69	0.65	0.004	0.49	0.67	0.84	0.01	0.52
	Branch	2.26	2.12	NS	1.29	2.19	3.11	0.21	1.53
	Main bole	1.46	1.44	NS	2.01	1.13	1.21	0.18	0.72
	Root	2.01	1.91	NS	1.61	1.81	2.46	0.33	1.28
	Total	6.42	6.12	NS	5.40	5.80	7.62	1.02	4.05
8.0	Foliage	0.92	0.8	0.001	0.06	0.73	1.78	0.08	0.58
	Branch	3.09	2.97	0.003	1.74	2.72	4.62	0.19	2.12
	Main bole	2.01	1.75	0.01	2.53	1.3	1.83	0.12	3.57
	Root	2.72	2.56	0.01	2.06	2.17	3.67	0.08	1.78
	Total	8.73	8.15	0.28	6.93	7.02	11.39	1.33	5.67

Carbon sequestered from the system

Carbon sequestered in the system after 3-years of project period have been given in Table 10, which showed that overall carbon sequestered under different crop sequences irrespective of pruning regimes was 23.58 to 24.79 t carbon ha^{-1} and under different pruning regimes, the trees without pruning had sequestered 27.97 t carbon ha^{-1}, and trees with 70 and 50% canopy pruning sequestered 22.96 and 21.33 t carbon ha^{-1}, respectively.

Table 9. Export of carbon and nitrogen (kg ha^{-1} yr^{-1}) from *A. procera* based agroforestry system

Element	Plant component	Crop sequence		Canopy pruning		
		B-M	G-W	70%	50%	Control
2005-06						
Carbon	Pruned branch of tree	2544..3	3082.59	4379.23	1247.71	-
	Aboveground biomass of herbaceous layer	1670.0	1710.0	2070.0	1980.0	1010.0
	Grain yield	180.0	430.0	370.0	360.0	170.0
	Total	4394.30	5222.59	6819.23	3587.71	1180.0
Nitrogen	Pruned branch of tree	56.16	68.04	96.66	27.54	-
	Aboveground biomass of herbaceous layer	56.95	51.14	66.27	63.58	32.29
	Grain yield	10.88	24.30	21.90	20.94	9.92
	Total	123.99	143.48	184.83	112.06	42.21
2006-07						
Carbon	Pruned branch of tree	3571.89	3327.24	5308.90	1590.22	-
	Aboveground biomass of herbaceous layer	1420.0	1480.0	1820.0	1670.0	860.0
	Grain yield	120.0	360.0	310.0	270.0	130.0
	Total	5111.89	5167.24	7438.90	3530.22	990.0

Nitrogen	Pruned branch of tree	78.84	73.44	117.18	35.10	-
	Aboveground biomass of herbaceous layer	48.54	44.38	58.41	53.65	27.31
	Grain yield	7.49	20.31	18.22	16.04	7.44
	Total	134.87	138.13	193.81	104.79	34.75
2007-08						
Carbon	Pruned branch of tree	4550.49	4305.84	6287.50	2568.82	-
	Aboveground biomass of herbaceous layer	1560.0	1430.0	2440.0	1350.0	700.0
	Grain yield	210.0	220.0	350.0	210.0	90.0
	Total	6320.49	5955.84	9077.5	4128.80	790.00
Nitrogen	Pruned branch of tree	100.44	95.04	138.78	56.70	-
	Aboveground biomass of herbaceous layer	53.43	42.73	78.60	43.66	22.00
	Grain yield	13.62	12.35	20.95	12.46	5.54
	Total	167.49	150.12	238.33	112.82	27.54

Table 10.Carbon sequesteredin *A.procera* based agroforestry system

Treatment	Carbon stock at beginning of the project (2005)		Carbon at end of the project (2008)			Carbon sequestered during project period (3yrs)			Total ($t\ ha^{-1}$)
	Tree ($t\ ha^{-1}$)	SOC ($t\ ha^{-1}$)	Tree	Herbaceous layer ($t\ ha^{-1}$)	SOC ($t\ ha^{-1}$)	Tree ($t\ ha^{-1}$)	Herbaceous layer ($t\ ha^{-1}$)	SOC ($t\ ha^{-1}$)	
Crop sequence									
B-M	12.39	12.15	33.29	1.89	14.15	20.90	1.89	2.00	24.79
G-W	12.28	11.93	32.02	2.04	13.73	19.74	2.04	1.80	23.58
Canopy pruning									
70%	8.38	12.60	26.63	2.68	14.63	18.25	2.68	2.03	22.96
50%	13.21	12.38	30.61	2.13	14.18	17.40	2.13	1.80	21.33
Control	15.41	11.48	40.73	1.08	13.05	25.32	1.08	1.57	27.97
Pure tree	12.49	13.28	26.41	-	13.73	13.92	-	0.45	14.37
Pure crop	-	11.25	-	4.31	11.48	-	4.31	0.23	4.54

Project -II

CO_2 sequestration potential of agroforestry system under irrigated and rainfed conditions

The project was initiated on well-established experiments under agrisilviculture and agrihorticulture system at NRCAF farm. The details about experiment are given in Figure 1 a & b and Table 1.

Figure 1a. *Albizia procera* + wheat in left and *Dalbergia sissoo* + mustard in right under irrigated condition

Figure 1b. *Emblica officinalis* + greengram in left and *Hardwickia binata* in right under rainfed condition

Table 1. Experiment details

Agroforestry system/tree component	Crop components		Tree density	No. of tree ha^{-1}	Age of tree/year of planting
	Kharif	Rabi			
Agrisilviculture					
Albizia procera	Green gram Black gram	Wheat mustard	8m x 4m	312	8 years (July 2000)
Dalbergia sissoo	Blackgram	mustard	8m x 4m	312	14 years (July 1994)
Emblica officinalis	Greengram	-	10m x 10m	100	12 years (August 1996)
Hardwickia binata	Blackgram		10m x 5m	200	17 years (August 1991)

Above and belowground biomass

The details about estimation of above and belowground biomass has been given in the project-I on page 5-8 .Root: shoot ratio was used to estimate root biomass for standing trees (Table 2).

Table 2. Root: shoot ratio of tree

Name of Tree	Age of tree (Year)	Spacing	DBH/CD (cm)	Above ground biomass kg $tree^{-1}$	Below ground biomass kg $tree^{-1}$	Root : shoot Ratio
Dalbergia sissoo	14	8m x 4m	22.80	174.28	49.08	0.28
Albizia procera	8	8m x 4m	23.25	204.65	100.42	0.49
Emblica officinalis	12	10m x10m	17.48(CD)	76.84	27.03	0.35
Hardwickia binnata	17	5m x 5m	20.07	140.78	40.17	0.29

Allomatric equations were developed for each component of tree and these equations were used for extrapolating the standing live biomass of trees (Table 3).

Table 3. Regression equations for biomass estimation

Tree	Tree component	Allomatric equation	R^2	Tree	Tree component	Allomatric equation	R^2
Dalbergia sissoo (n=42)	Bole	$0.832(DBH)^{1.593}$	0.97	*Albizia procera* (n=32)	Bole	$0.038(DBH)^{2.505}$	0.98
	Branch	$0.026(DBH)^{2.332}$	0.99		Branch	$0.012(DBH)^{2.690}$	0.96
	Leaves	$0.041(DBH)^{1.845}$	0.97		Leaves	$0.025(DBH)^{2.237}$	0.97
	Root	$0.198(DBH)^{1.760}$	0.99		Root	$0.031(DBH)^{2.494}$	0.99
	Total biomass	$0.904(DBH)^{1.760}$	0.99		Total biomass	$0.102(DBH)^{2.494}$	0.99
Emblica officinalis (n=30)	Bole	$0.232(DBH)^{2.046}$	0.99	*Hardwickia binata* (n= 30)	Bole	$0.056(CD)^{2.000}$	0.99
	Branch	$0.002(DBH)^{3.142}$	0.98		Branch	$0.262(CD)^{0.941}$	0.99
	Leaves	$0.002(DBH)^{3.514}$	0.99		Leaves	$0.152(CD)^{1.605}$	0.99
	Root	$0.036(DBH)^{2.337}$	0.99		Root	$0.622(CD)^{1.313}$	0.99
	Total biomass	$0.158(DBH)^{2.338}$	0.99		Total biomass	$0.994 (CD)^{1.285}$	0.99

Note: n= No. of sampled tree

Carbon content in different plant parts

Methodology for analysing C content in different components of *Albizia procera* and herbaceous layer has been described in Project-I on page 8. The same methodology was used for following tree species and the C concentration in each component of tree is given in Table 4.

Table 4. Carbon content in different plant parts of trees

Carbon Content (%) in différent plant parts					
Trees	**Bole**	**branch**	**Leaf**	**Root**	**Leaflitter**
Hardwickia binata	45.84	45.86	44.37	44.96	44.68
Dalbergia sissoo	45.19	47.49	46.37	44.61	43.52
Emblica officinalis	48.10	47.77	46.15	47.40	45.64

Soil organic carbon

On the basis of secondary data available with various experiments, a base line of the project was developed for individual experimental fields which were included for the present study. The SOC content varied from 0.32 to 0.55 % in various field at 0-15 cm soil depth and in 15-30 cm soil depth it varied from 0.28 to 0.43 %. The cropping history of each experiment was also recorded to know the carbon input from available vegetation before initiation of the present study. The initial soil organic carbon (SOC) in different experiments is given in Table 5.

Table 5. Status of soil organic carbon (SOC) at the beginning of the project (during 2008)

Agroforestry system	Soil organic carbon (%)					
	0-15cm soil layer			15-30 cm soil layer		
	Min.	Max.	Mean	Min.	Max.	Mean.
Agrisilviculture						
Dalbergia sissoo	0.50	0.58	0.53±0.01	0.31	0.38	0.35±0.01
Albizia procera	0.49	0.60	0.54±0.01	0.38	0.50	0.43±0.01
Hardwickia binata	0.50	0.63	0.55±0.01	0.30	0.45	0.39±0.01
Agrihorticulture						
Emblica officinalis	0.30	0.35	0.32±0.005	0.26	0.30	0.28±0.004

Tree biomass

Allomatricequations are given in Table 3 and these equations were used to estimate standing live biomass of trees (Table 6) before initiation of the project. The biomass of trees at this stage was treated as base line.

Table 6. Biomass and carbon in different tree species at beginning of the project (2008)

Tree species	Tree/ha	Age (year)	Tree biomass (t ha^{-1})	Carbon(t ha^{-1})
Dalbergia sissoo	312	14	69.71	31.74
Albizia procera	312	08	68.87	33.07
Hardwickia binata	200	17	78.12	35.53
Emblica officinalis	100	12	12.39	5.89

Changes in biomass, soil organic carbon, carbon sequestered and CO_2 equivalent carbon sequestered were estimated by using CO2 fix (CO2FIXV3.1) model developed by M.J. Schelhaas, P.W. van Esch, T.A. Groen, B.H.J. de Jong, M. Kanninen, J. Liski, O. Masera, G.M.J. Mohren, G.J. Nabuurs, T. Palosuo, L.Pedroni, A. Vallejo, T. Vilén during 2004. The details about the model are given in Project –III on page33 .

In order to simulate biomass the model uses as input the growth rate of stem volume, which was derived from yield table developed through allometric equations. The relative growth rate of bole branches, leaf and roots are calculated in respect of dry biomass of main stem. Results are presented for each system for biomass (above and belowground), soil carbon, total carbon in plant and soil, carbon sequestered, CO_2 equivalent carbon sequestered in the system. Simulation period for each system adapted as per rotation cycle of individual tree species (Table 7). *Albizia procera* based agroforestry system had sequestered 173.27 t C ha^{-1} at age of 30-years but other systems like *Dalbergia sissoo* and *Hardwickia binata* could sequester only 79.43 and 73.28 t C ha^{-1} at the same age. However, the tree density varied in each system. Similarly aonla based system had sequestered only 18.41 t C ha^{-1} at 25-years age. It indicates that *Albizia procera* being a fast growing tree species is able to produce more biomass as compared to other trees at same age.

Table 7. Projection of biomass, soil carbon, carbon sequestered and CO_2 equivalent carbon sequestered in different agroforestry systems

***Dalbergia sissoo* (under irrigated condition)**						
Age (years)	**20**	**25**	**30**	**35**	**40**	**45**
Tree biomass (t ha^{-1})	75.55	101.85	120.13	129.85	133.61	134.86
Crop biomass (t ha-1)	3.82	3.80	3.75	3.70	3.65	3.61
Soil carbon (t ha^{-1})	16.89	18.48	20.16	21.62	22.92	23.86
C sequestered (t ha^{-1})	54.80	69.0	79.43	85.53	88.62	90.15
CO_2 equivalent C sequestered (t ha^{-1})	200.92	252.99	291.24	313.62	324.93	330.55
***Hardwickia binata* (under rainfed condition)**						
Age (years)	**25**	**30**	**35**	**40**	**45**	**50**
Tree biomass (t ha^{-1})	90.47	125.03	157.12	183.33	204.40	211.39
Crop biomass (t ha-1)	0.59	0.58	0.57	0.56	0.56	0.56
Soil carbon (t ha^{-1})	11.07	13.01	15.44	18.12	21.02	23.30
C sequestered (t ha^{-1})	54.76	73.28	91.11	106.37	119.38	125.02
CO_2 equivalent C sequestered (t ha^{-1})	200.79	268.70	334.08	390.02	437.73	458.39

Albizia procera (under irrigated condition)						
Age (years)	**10**	**15**	**20**	**25**	**30**	-
Tree biomass (t ha^{-1})	153.62	266.53	302.32	305.61	308.15	-
Crop biomass (t ha-1)	6.90	6.24	5.69	5.22	4.89	-
Soil carbon (t ha^{-1})	13.76	13.96	17.53	21.02	23.02	-
C sequestered (t ha^{-1})	90.80	144.88	147.84	170.21	173.27	-
CO_2 equivalent C sequestered (t ha^{-1})	332.32	530.26	541.09	622.96	634.16	-
Emblica officinalis (underrainfed condition)						
Age (years)	**15**	**18**	**21**	**25**	-	-
Tree biomass (t ha^{-1})	13.80	14.48	15.32	16.20	-	-
Crop biomass (t ha-1)	0.55	0.52	0.49	0.48	-	-
Soil carbon (t ha^{-1})	9.88	10.06	10.17	10.43	-	-
C sequestered (t ha^{-1})	17.05	17.26	17.67	18.41	-	-
CO_2 equivalent C sequestered	62.40	63.15	64.67	67.51	-	-

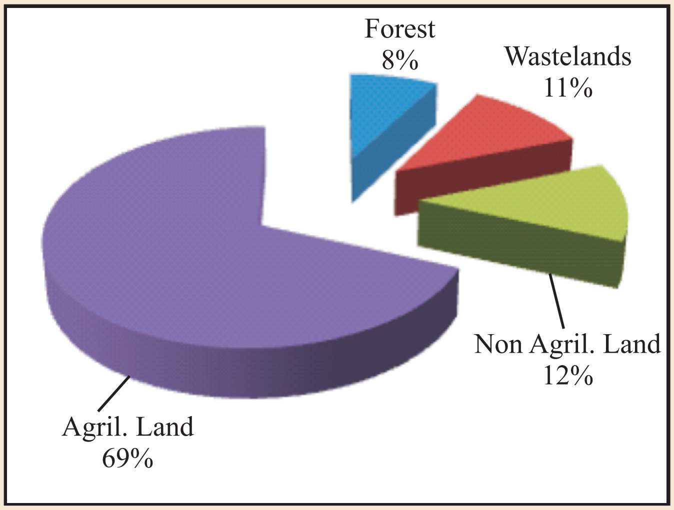
Project -III

Impact, adaptation and vulnerability to Indian Agriculture to Climate Change

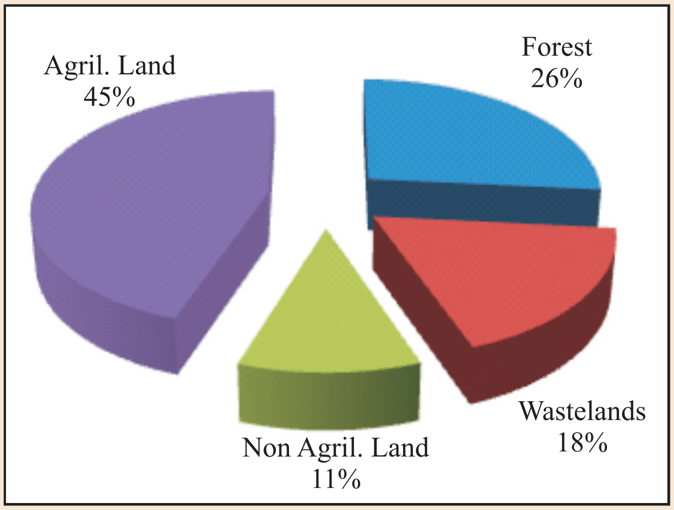
Assessment of carbon sequestration potential of agroforestry practices in Bundelkhand regions and North Eastern Plains and Eastern Plains of U.P. (Middle Gangetic Plains) was done through predictive model (CO2FiX).

General description of study area

Bundelkhand regions spread over 13 districts out of which 7 districts belong to Uttar Pradesh and 6 districts to Madhya Pradesh. The study was under taken in 7 districts (Lalitpur, Jhansi, Mahoba, Chitrakoot, Banda, Hamirpur, Jalaun) of Uttar Pradesh and 3 districts of Madhya Pradesh (Tikamgarh, Datia and Chhatarpur). The trees occur either on field bunds or scattered in the fields. In Bundelkhand, there are mixed planatation of different tree species and all trees are naturally grown and about 39 tree species occur in the farmer's field. Farmers grow rice, soybean, blackgram, greengram, groundnut, sesame and pigeonpea in *Kharif* and in *Rabi*, they grow wheat, barley, chickpea, lentil, pea, mustard and taramira. In some districts farmers grow sugarcane while in other districts the farmers are also growing blackgram and greengram as *zaid* crop are being grown. The details of land use pattern of Bundelkhand have been given in Figure 1. The agriculture lands in Bundelkhand (UP) are 69% of total geographical area (2958534 ha) but in Bundelkhand (MP) the agriculture lands is 45% of total geographical area (4117178 ha). The forest in Bundelkhand (MP) is higher 26% of total geographical area and in Bundlekhand (UP) the forest is only 8% of total geographical area.



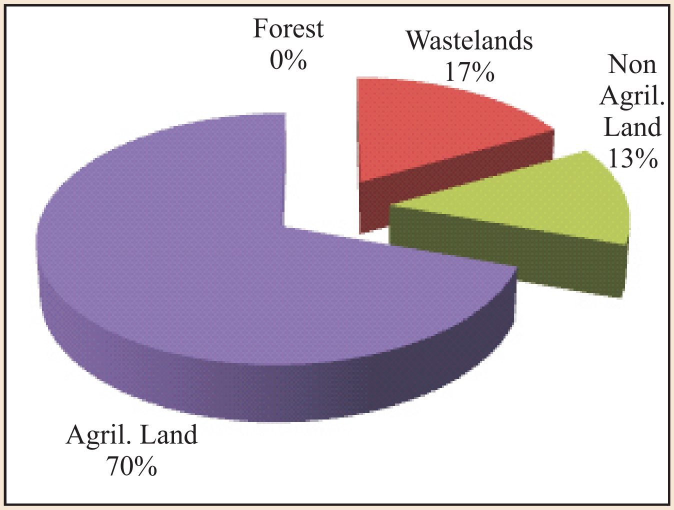
A



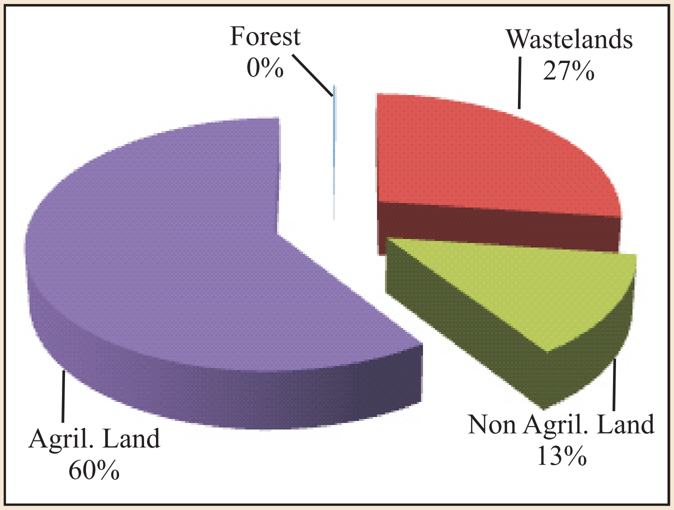
B

Fig.1 Land use pattern of Bundelkhand region (A= Districts of U.P. and B= Districts of M.P.)

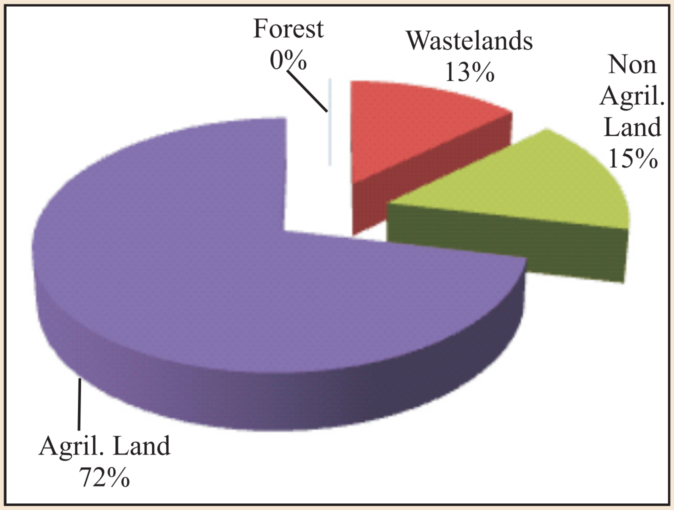
Jaunpur, Pratapgarh, Azamgarh and Basti district come under North Eastern Plains and Eastern Plains of Uttar Pradesh (Middle Gangetic Plains). The forest area in these districts ranges from 0.02 to 0.16 %, wastelands 7.8 to 26.9%, Non-agriculture lands 13.1 to 15.3 and agriculture lands 59.6 to 75.7% out of total reported area. The details of land use pattern of these districts have been given in Figure 2. Farmers grow rice, blackgram, greengram, sesame and pigeonpea in *kharif* and in *Rabi*, wheat, barley, chickpea, lentil, pea, mustard, sugarcane and potato are grown. Farmers also grow blackgram and greengram as *zaid* crop.



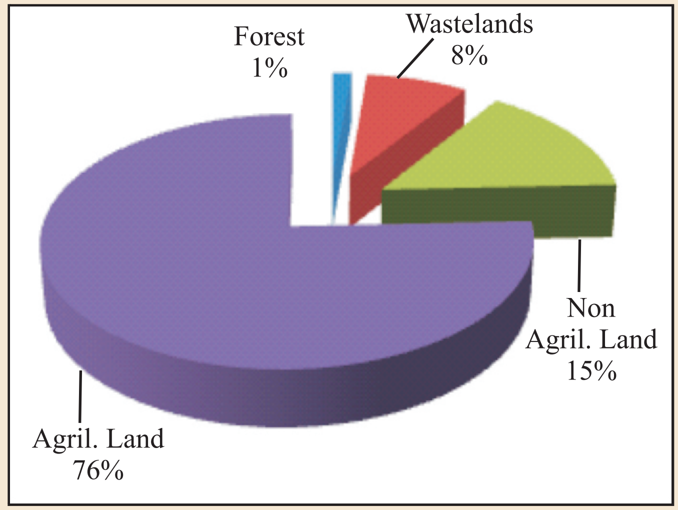
Jaunpur



Pratapgarh



Azamgarh



Basti

Fig.2 Land use pattern of different districts of North Eastern Plains and Eastern Plains (U.P.) of Middle Gangetic Plains

Study approach

Compendium of ITK related to agroforestry and climate change

Indigenous technical knowledge (ITK) refers to that knowledge which is generated and transmitted by communities over times in an effort to cope with their own agro-ecological and socio-ecological environments. It is transmitted through stories, folk songs, literature and practice. It develops through experience sharing and normally passes on through generation by oral expression and persists in an unwritten form. ITK structures are like scientific theories in that they generalize from concrete experience, but unlike theories they are not systematic formulation. Rather, they involve the adjustment of forms of human livelihood to the environment in which they are embedded. The knowledge, innovation and practices of indigenous people and traditional communities are part and parcel of their cultures. It is important to collect information on the ITK not just in terms of the description or proper management and harvesting of a product, but also in terms of the maintenance of ecological process and biodiversity linked to traditional economic activities such as cultivation or animal husbandry.

Questionnaires are prepared related to climate change (rainfall prediction, change in temperature, change in rainfall pattern and other climatic variations and their impact on trees as well as on agriculture) and farmers are interviewed and interacted at village level in different blocks of surveyed districts. The view of farmers and proverbs related to climate were recorded in the local language and translated into English. The proverbs are commonly used by the farmers regarding prediction of rain, temperature, crop yield, fruit yield and changes in tree behaviour in the region. The opinions of farmers were also recorded related to climate change and their impact on agriculture.

The proverbs related to climate change are very scanty but lot of proverbs cited by elder of villagers related to agriculture, prediction of rain/drought or natural calamities. Since the proverbs are based on long term observation generated by elders on agriculture they may not give good indication for the recent events of so called "Climate Change". The materials collected may be critically examined and analyzed to understand if the proverbs have implication for "Climate Change". Besides this Centre, other centre/groups will also be covering on agriculture aspects, our strength will be recognized, if we add information on perennial components, trees, fruit plants, bamboos etc.. In general observation that Climate Change may affect more on tree physiology, reproductive aspects and so on. Phenology is one parameter, which is a good indication in this regards. So proverbs related to these aspects will add to the knowledge.

Survey of study area

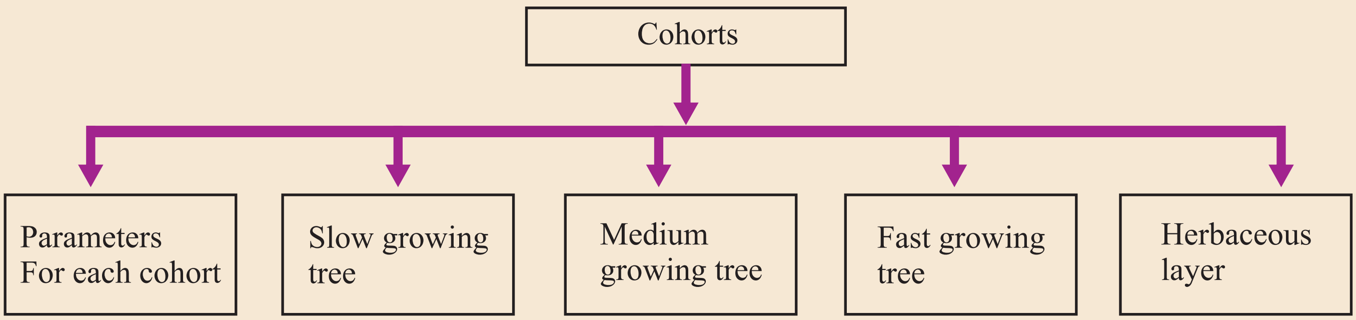
A field survey of selected districts was done to know the agroforestry practices adopted by the farmers, tree density, tree species exist on the farmers field, tree growth etc. for which, number of blocks were identified in each district and after selection of blocks, number of villages were identified to conduct the survey. Since, each block is having large number of villages and it was not possible to cover each and every village, a sample of six villages per block was selected for the field survey in such a way that they truly represent the whole block to which they belong. The survey was conducted on the basis of transect walk in the village. The village head, local farmers and village youth were associated in the transect walk to have a clear picture of the village. The sampling on farm lands involves enumeration of all trees on farmlands, farm bunds, culturable wastelands etc. All trees more than 1.5 m tall or more than 5 cm dbh were enumerated. The data was obtained for the number of trees for each tree species and the diameter at breast height (dbh) for each tree. In this way, the data was generated for different tree species and their intensity for a particular village. These tree species were classified as slow, medium and fast growing depending upon their growth habit and mean annual increment(MAI). The number of trees per hectare was calculated for slow, medium and fast growing trees per village. This was multiplied with the total number of villages per block and thus calculated for all the blocks of a particular district.

Agroforestry practices adopted by the farmers

Parameterization of predictive model

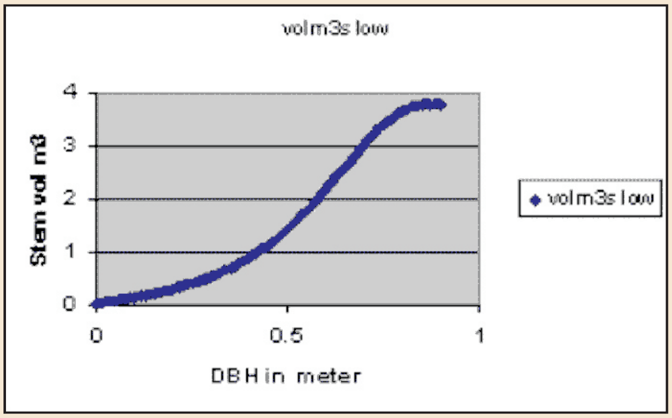
Parameterization of CO2FIX model

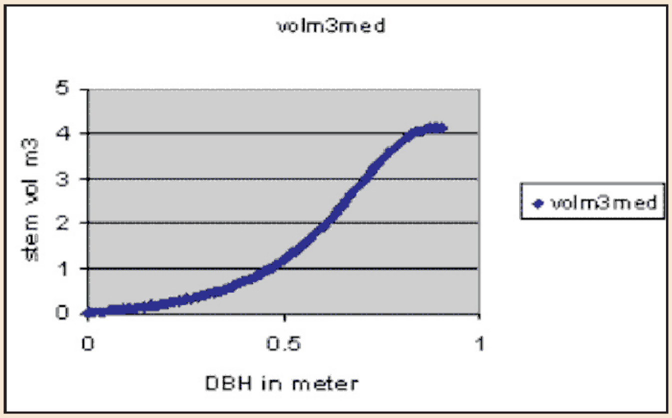
CO2FIX model is a flexible tool that can be applied to model multispecies and uneven aged stands. The model used here is a "cohort model" where each cohort is defined as a group of individual trees or as group of tree species. Each cohort has growth, mortality, turnover and thinning/harvest. The parameters used for each cohort are given in Figure 3. The driving factor of each cohort in the biomass module is the stem wood production in volume per hectare. Tree growth equations, available in FSI-2009 report for the species found in survey, were used to generate the dbh (m) and stem volume (m^3/tree) data. The individual species wise generated data sets were then clubbed into single files for the slow, medium and fast growing species separately. These three data sets pertaining to slow, medium and fast growing species were independently used to fit non-linear functions for stem volume-dbh relationships. These tree wise absolute stem volume-dbh relationships were then converted into hectare wise stem volume-dbh relationships (Figure 4), by multiplying tree wise stem volume from the average number of trees found in a village in a specified category (slow/medium/fast). This dbh was transformed back into age to obtain hectare wise stem volume–age relationships. Ultimately, these absolute stem volume values were converted into CAI (current annual increment) values of stem volume by taking the difference of current year value from preceding year value (Table 1).



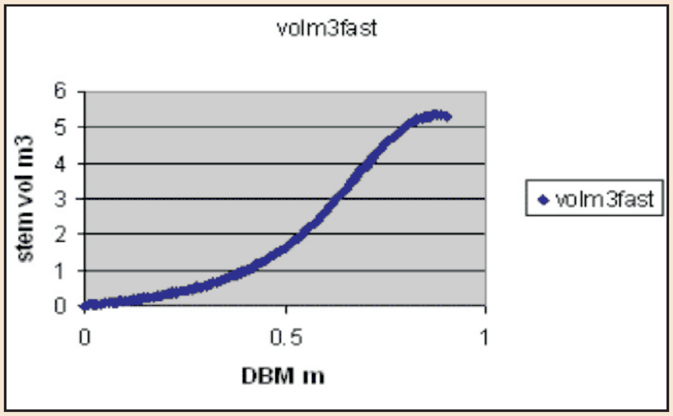
- Average age of tree at beginning of the project (yr)
- Corresponding dbh (cm)
- Thinning/harvest (year)
- Thinning/harvest (Age of tree)
- Amount of tree harvest (in fraction)
- Rotation (year)
- Wood density (tones m^{-3})
- Initial carbon content in biomass at project site
- Carbon content in different components of trees and herbaceous layer (% of dry weight)
- Turnover rate per year (in fraction)
    Foliage, Branches,Roots
- Use of stem, branch and leave (in fraction)
    Stem log wood
    Stem slash
    Branch log wood
    Branch slash
    Foliage slash
    Foliage slash soil

Fig.3. Cohorts parameters





V=1/(-14.07+7.61*dbh^0.5+6.73/dbh^0.5) V=1/(-11.013+6.04*dbh^0.5+5.264/dbh^0.5)



V=1/(-10.42+5.66*dbh^0.5+4.97/dbh^0.5)

Fig.4. Stem volume and dbh relationship for slow, medium and fast growing tree species

Table 1. Current Annual Increment (CAI) at different age in slow, medium and fast growing tree species

Age (Yr)	CAI m^3 Slow growing tree	Age (Yr)	CAI m^3 Medium growing tree	Age (Yr)	CAI m^3 Fast growing tree
5	0.009	5	0.012	5	0.015
10	0.009	10	0.016	10	0.026
15	0.011	15	0.023	15	0.045
20	0.013	20	0.032	20	0.079
30	0.017	25	0.046	25	0.118
40	0.023	30	0.061	30	0.125
50	0.032	35	0.079	35	0.033
60	0.047	40	0.085		
70	0.064	45	0.070		
80	0.087	50	0.037		
90	0.102	55	0.035		
100	0.097				

The harvested data available for different tree species (classified under the slow, medium and fast growing categories/cohorts) at National Research Centre for Agroforestry, Jhansi was used to find out the relative growth of foliage, branch and root with respect to stem. These relative proportions were parameterized in CO2FIX model for branch, foliage and root growth.

In order to simulate the crop component, the crop was considered as a 'tree' with a very small stem volume, no branches and a lot of foliage and roots. The relative growth of crop component is A*0.09*0.01 = B. Where, 0.09 is wood density of crop stem (tonnes m^{-3}), 0.01 is current annual increment of crop stem ($m^3 ha^{-1} yr^{-1}$), B is dry biomass per hectare and A is foliage growth relative to stem in terms of dry matter growth rate. If aboveground biomass of crop is 2.29 t ha^{-1} then relative growth of foliage will be 2.28÷0.09*0.01=2544. Similarly, belowground production is 0.23 tonnes dry biomass ha^{-1}. Characteristic for cropland systems is having high turnover rates in foliage and roots, in this case set at 0.9 for both.

Results

ITK related to agroforestry and climate change

The ITKs related to climate change in Bundelkhand region and Middle Gangetic plains are almost same but dialects are different. In few cases the thinking of farmers and their experiences related to prediction of rainfall/drought/ natural calamities are different**.** The view of farmers from different districts of Bundelkhand and Middle Gangetic Plains are compiled and given as follows:

Some facts/ new observations regarding rain/drought in Budelkhand region

1. When flowering starts in *Saccharumspontaneum,* it means the rain would be terminated.
2. If millipede coming out from soil, it indicates that rainfall is ended.
3. If Pea-cock is shouting it means rain will begin.
4. Cuckoo starts speaking then rain will occur.
5. Monitor lizard stopped speaking then there is end of rain.
6. If new flushes come in the month of June then rain willbegun.
7. Head of chameleon is reddish then rainfall begins.
8. Wind blowing started East side then fruit will have increased sweetness.
9. White ibis are seen on the road and field, it means rain is ended.
10. Black throated weaver (Baya) birds started making the net; it means rain will be terminated.
11. Rainbow seeing in the sky, it means rain will be ended.
12. Net making started by spiders, it means rain will be terminated.
13. Due to climate change few nee/m trees yielded fruits twice in a year.
14. Flowering was observed in November in few mango trees. Normally flowering starts in January.

Some facts/ new observations regarding rain/drought in Middle Gangetic Plains

1. If clouds come in day, and night is cloudless then there is no hope of rain.
2. If chameleon moves toward top of the tree or top of any place, there is a chance of heavy rain.
3. If wind blows with high speed from East-West direction with touching the surface of soil, it is indication of beginning of rain.

4. If wind blow from east direction in the month of December and January their is good chance of aphids on mustard.
5. If clouds are reddish in December / January it indicates, if there is rain. There is chance of hail storm
6. In April/May, if wind blows continuously from East to West direction, there is more chance of drought.
7. If birds take bath in soil dust and ant carries her eggs, it indicates that there is good chance of rain.
8. If there is good rain in adraNakcchtra and no rain in MrigNakcchtra, it indicates that there will be no rain/ less rain during the year.
9. If clouds are red – yellow during rainy season in the evening, there is least chance of rain.
10. If day is hot but there is dew in night, there is no chance of rain.
11. If wind blows from east- west direction in Bhado (Sep./Oct.) their is good chance of rain during these months.
12. During rainy season, if wind blows from south to north direction there is a little chance of rain, but in other season there is a hope for good rain.
13. In rainy season, if rainbow form in the evening, it indicates that there is a hope for similar to rain in morning.
14. When flowering starts in *Saccharumspontaneum*during Augustit means the rain would be terminated.
15. The brown clouds rain. The dark black clouds look very dangerous, but do not rain.

Tree density in Bundelkhand and Middle Gangetic Plains

In Bundelkhand region, tree density varied from 4.31 to 15.95 trees per hectare in districts of U.P. Similarly, it varied from 12.02 to 15.99 trees per hectare in different districts of M.P. However, in Bundelkhand regions, on an average 11.57 trees per hectare exist on famers field in different districts of U.P. and 13.81 trees per hectare in different districts of M.P. (Table 2). In different districts of Middle Gangetic Plains, the tree density varied from 6.39 to 10.50 trees per hectare (Table 3).

Table 2. Tree density in Bundelkhand region

Districts	No. of trees/ha			Total
	Slow	Medium	Fast	
Jhansi	3.29	7.01	1.27	11.56
Lalitpur	4.79	8.10	3.07	15.95
Hamirpur	2.96	5.12	0.46	8.53
Jalaun	0.73	2.76	0.81	4.31
Banda	1.60	4.25	1.71	7.56
Mahoba	5.72	4.52	1.56	11.80
Chitrakoot	5.64	7.25	1.68	14.57
Datia	4.30	6.67	1.05	12.02
Chhatarpur	6.02	6.41	0.99	13.42
Tikamgarh	8.31	7.02	0.66	15.99
Mean	4.34	5.91	1.33	11.57

Table 3. Tree density in different districts of Middle Gangetic Plains

No. of trees per hectare				
District	Slow	Medium	Fast	Total
Jaunpur	3.65	4.95	1.90	10.50
Pratapgrah	3.31	4.27	2.36	9.94
Azamgarh	0.67	2.35	3.97	6.67
Basti	1.0	3.37	2.02	6.39

Contribution of different tree species in total tree population

In Bundelkhand region, the most commonly occurring tree species are *Acacia nilotica, Zizyphus mauritiana, Azadirachta indica, Butea monosperma, Madhuca latifolia, Acacia leucophloea and Leucaena leucocephala*. The contribution of these species in total tree population is 9.0 to 19.73 % (Table 4). In North Eastern Plains and Eastern Plains of U.P. (Middle Gangetic Plains), the most common tree species are *Emblica officinalis, Mangifera indica, Madhuca latifolia, Azadirachta indica, Acacia nolotica, Eucalyptus tereticornis and Tectona grandis*. The contribution of these species in total tree population is 7.8 to 15.9% (Table 5&6). In Bundelkhand region, mostly mixed tree species occur on farmer's field but in Middle Gangetic Plain, one or two tree species occurs on farmer's field. In Pratapgarh district, aonla is most popular fruit tree and systematically planted by the farmers and they are growing crops in between row of aonla.

Table 4. Contribution of different tree species in total tree population in Bundelkhand regions

S. N.	Districts of U.P.		Districts of M.P.	
	Tree	Contribution (%)	Tree	Contribution (%)
1	Babool *(Acacia nilotica)*	19.73	Dhak *(Butea monosperma)*	16.00
2	Ber *(Zizyphus mauritiana)*	14.60	Neem *(Azadirachta indica)*	11.00
3	Neem *(Azadirachta indica)*	10.29	Ber *(Zizyphus mauritiana)*	10.00
4	Rewnja *(Acacia leucophloea)*	9.76	Babool *(Acacia nilotica)*	9.21
5	Subabul *(L. leucocephala)*	9.12	Mahua *(Madhuca latifolia)*	8.15
6	Khajur *(Phoenix sylvestris)*	5.04	Reonja *(Acacia leucophloea)*	4.20
7	Dhak *(Butea monosperma)*	4.20	Chirowl *(Holoptelia itegrifolia)*	4.10
8	Chirowl *(Holoptelia integrifolia)*	3.59	Mango *(Mangifera indica)*	4.01
9	Mahua *(Madhuca latifolia)*	3.40	Arjun *(Terminalia arjuna)*	3.52
10	Shisham *(Dalbergia sissoo)*	2.97	Saja *(Terminalia alata)*	3.41
11	Mango *(Mangifera indica)*	2.76	Khair *(Acacia catechu)*	3.31
12	Arjun *(Terminalia arjuna)*	2.11	Khajur *(Phoenix sylvestris)*	3.00
13	Eucalyptus *(E. tereticornis)*	1.61	Subabool *(L. leucocephala)*	2.45
14	Jamun *(Syzygium cumini)*	1.43	Shisham *(Dalbergia sissoo)*	2.26
15	Khair *(Acacia catechu)*	1.39	J.jalebi *(Inga dulcis)*	2.18
16	Hingota *(Balanitesa egyptiaca)*	1.26	Aonla *(Emblica officinalis)*	1.0
17	Safedsiris *(Albizia procera)*	1.09	Others	<1.0
18	Others	<1.0		

Table 5. Contribution of different tree species in total tree population in Middle Gangetic Plains

S.N.	Districts			
	Pratapgarh		Jaunpur	
	Tree	Contribution (%)	Tree	Contribution (%)
1	Aonla *(Emblica officinalis)*	13.59	Mango *(Mangifera indica)*	11.69
2	Mango *(Mangifera indica)*	12.74	Mahua *(Madhuca latifolia)*	9.38
3	Mahua *(Madhuca latifolia)*	9.52	Neem *(Azadirachta indica)*	9.17
4	Neem *(Azadirachta indica)*	9.02	Babul *(Acacia nilotica)*	8.20
5	Babul *(Acacia nilotica)*	8.25	Ber *(Zizyphus mauritiana)*	7.22
6	Dak *(Butea monosperma)*	5.67	Jamun *(Syzygium cumini)*	6.36
7	Khajur *(Phoenix sylvestris)*	4.72	Dak *(Butea monosperma)*	5.02
8	Shisham *(Dalbergia sissoo)*	4.17	Kaitha *(Limonia acidissima)*	4.88
9	Eucalyptus *(Eucalyptus spp.)*	3.95	Shisham *(Dalbergia sissoo)*	4.69
10	Ber *(Zizyphus mauritiana)*	3.89	chirowl *(Holoptelea integrifolia)*	4.30
11	Chilbil/chirowl *(Holoptelea integrifolia)*	3.32	Semal *(Bombax ceiba)*	4.06
12	Bael *(Aegle marmelos)*	3.27	Aonla *(Emblica officinalis)*	3.92
13	Jamun *(Syzygium cumini)*	3.18	Lasoda *(Cardia mixa)*	3.89
14	Lasoda *(Cardia mixa)*	3.11	Arjun *(Terminalia arjuna)*	3.54
15	Arjun *(Terminalia arjuna)*	3.09	Bael *(Aegle marmelos)*	3.37
16	Subabul*(L. leucocephala)*	2.60	Eucalyptus *(Eucalyptus spp.)*	2.89
17	Imli *(Tamarindus indica)*	2.34	Imli *(Tamarindus indica)*	2.65
18	Kaitha *(Limonia acidissima)*	1.87	Khajur *(Phoenix sylvestris)*	2.41
19	JangliJalebi *(Inga dulcis)*	1.31	Subabul *(Luecaena leucocephala)*	1.99
Note: The species those have less than 1% contribution are not mentioned				

Table 6. Contribution of different tree species in total tree population in Middle Gangetic Plains

S.No.	Districts			
	Azamgarh		Basti	
	Tree	Contribution (%)	Tree	Contribution (%)
1	Eucalyptus *(E. tereticornis)*	15.9	Eucalyptus *(E. tereticornis)*	16.9
2	Mango *(Mangifera indica)*	12.9	Mango *(Mangifera indica)*	12.7
3	Poplar *(Populus deltoides)*	11.0	Teak *(Tectona grandis)*	7.8
4	Neem *(Azadirachta indica)*	8.2	Poplar *(Populus deltoides)*	7.7
5	Jamun *(Syzygium cumini)*	6.2	Neem *(Azadirachta indica)*	4.8
6	Babul *(Acacia nilotica)*	5.6	Shisham *(Dalbergia sissoo)*	4.2
7	Ber *(Zizyphus mauritiana)*	5.5	Siris *(Albizia sp.)*	3.8
8	*Bael* (*Aegle marmelos)*	5.0	Babul *(Acacia nilotica)*	3.0
9	*Shisham (Dalbergia sissoo)*	*4.0*	Jamun *(Syzygium cumini)*	*2.9*
10	Karanj *(Pongamia pinnata)*	2.9	Subabul *(Leucaena leucocephala)*	2.7
11	Kathal *(Artocarpus heterophylus)*	2.5	Mahua *(Madhuca latifolia)*	2.5
12	Teak *(Tectona grandis)*	2.1	Bael *(Aegle marmelos)*	2.5
13	Siris *(Albizia sp.)*	1.8	Aonla *(Emblica officinalis)*	2.4
14	Amrud *(Psidium guazava)*	1.7	Ber *(Zizyphus mauritiana)*	2.0
15	Arjun *(Terminalia arjuna)*	1.5	Kaitha *(Feronia limonia)*	2.0
16	Aonla *(Emblica officinalis)*	1.3	Semal *(Bombax ceiba)*	1.9
17	Khajur *(Phoenix sylvestris)*	1.1	J.Jalibi *(Inga dulsis)*	1.8
18	Kadam *(Anthocephalus cadamba)*	1.0	Dhak *(Butea monosperma)*	1.8
19	Semal *(Bombax ceiba)*	1.0	Kathal *(Artocarpus heterophylus)*	1.7
20	Others	<1.0	Others	<1.0

Note: The species those have less than 1% contribution is not mentioned

Status of soil organic carbon and tree biomass insurveyed districts

The information on soils was collected from Assistant Director Agriculture (Soil) of each district during survey. The soils of Bundelkhand are broadly classified into two groups viz. red and black. Red soils are divided into Rakar and Parwa type of soils whereas, Black soils into Mar and Kabar soils type. The soil organic carbon varied from 0.26 to 0.46% in different districts of U.P. and it varied from 0.23 to 0.68% in different districts of M.P. (Table 7). The biomass (above and below ground) in trees varied from 7.48 to 29.95 t ha^{-1} at beginning of the project in different districts of U.P. The soil of Middle Gangetic Plains are clay loam and sandy loam and soil organic carbon varied from 0.28 to 0.49% at 0-15cm soil depth (Table 8). Tree biomass at the beginning of the project varied from 5.33 to 18.81 t ha^{-1}.

Table 7. Soil organic carbon status in different districts of Bundelkhand

Districts of UP	Organic carbon (%)	Districts of MP	Organic carbon (%)
Jhansi	0.32	Datia	0.23
Lalitpur	0.46	Damoh	0.68
Jalaun	0.26	Sagar	0.44
Hamirpur	0.30	Panna	0.33
Mahoba	0.40	Chhatarpur	0.51
Chitrakoot	0.32	Tikamgarh	0.34
Banda	0.35	-	-
Mean	0.34	-	0.42

Source: http://ict.agri.net.in/district

Table 8. Soil organic carbon in different districts of Middle Gangetic Plains

Jaunpur		Pratapgarh		Azamgarh		Basti	
Blocks	OC (%)	Blocks	OC (%)	Blocks	OC (%)	Blocks	OC (%)
Patti Sadar	0.29	Karanjkala	0.35	Palhani	0.35	Parasrampur	0.49
Mandhata	0.30	Shahgang	0.30	Rani keSarai	0.35	BastiSadar	0.48
Kalakankekar	0.28	Sikrara	0.30	Mirzapur	0.35	Harraiya	0.47
Lalgang	0.35	Rampur	0.40	Ahroula	0.35	Rudhauli	0.43
Kunda	0.28	Jalalpur	0.30	Pawai	0.37	Vikramjot	0.45
Gaura	0.31	Khuthan	0.34	Phulpur	0.35	Kaptanganj	0.48
Shivgarh	0.30	Baksha	0.34	Lalganj	0.35	Bahadurpur	0.49
Vihar	0.33	Machhlishar	0.33	Jahanaganj	0.35	Saughat	0.44
Mean	**0.31**		**0.33**		**0.35**		**0.46**

Source: http://ict.agri.net.in/district

Biomass, soil carbon and carbon sequestered in agroforestry practices

The Simulation of biomass (above and belowground) of tree and crop, soil carbon and carbon sequestered was done for 21-years in each district on per hectare and average values of the districts have been presented in Table 9. Biomass, soil carbon and carbon sequestration potential in Bundelkhand region were 29.61, 9.34 and 23.13 t ha^{-1}, respectively during 2010 and it is projected that after 21-years, soil carbon may increase upto 18.19 t ha^{-1} and carbon sequestered in the system would be 37.33 t C ha^{-1}.

Table 9. Biomass, soil carbon and carbon sequestered (t ha^{-1}) in agroforestry practices under Bundelkhand region

Year	Biomass	Soil carbon	Carbon sequestered
2010	29.61	9.34	23.13
2012	31.33	14.10	28.69
2014	32.61	15.31	30.53
2016	33.84	15.80	31.61
2018	34.93	16.23	32.56
2020	35.51	16.63	33.45
2022	37.02	17.01	34.36
2024	38.20	17.41	35.33
2026	39.44	17.80	36.32
2028	40.72	18.19	37.33
2030	41.38	18.38	37.84

The simulation of biomass, soil organic carbon and carbon sequestered was done for 24-years in district Jaunpur, Pratapgarh, Azamgarh and Basti of Uttar Pradesh. On an average biomass, soil carbon and carbon sequestered in these districts were 18.99, 9.19 and 18.08 t ha^{-1} during 2011, respectively and after 24-years, the carbon sequestration potential may increase up to 32.78 t C ha^{-1} (Table 10).

Table 10. Biomass, soil carbon and carbon sequestration(t ha^{-1}) potential of agroforestry practices in Eastern and North Eastern plains of U.P. (average of four districts)

Year	Biomass	Soil carbon	C Sequestered
2011	18.99	9.17	18.08
2013	20.16	13.98	23.43
2015	20.87	15.89	25.69
2017	21.54	16.56	26.71
2019	22.23	17.02	27.50
2021	22.92	17.48	28.29
2023	23.64	17.89	29.05
2025	24.34	18.51	30.00
2027	25.02	18.90	30.72
2029	25.65	19.29	31.42
2031	26.32	19.65	32.09
2033	27.03	19.99	32.78

Project-IV

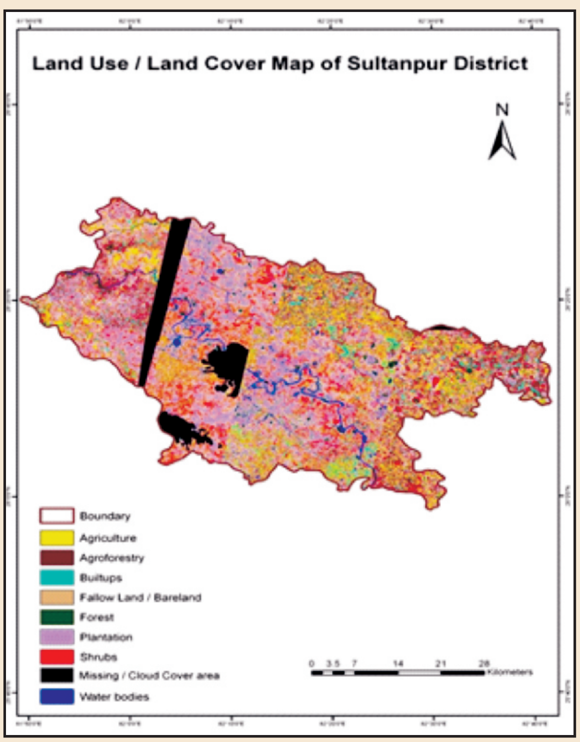
National Initiative on Climate Resilient Agriculture

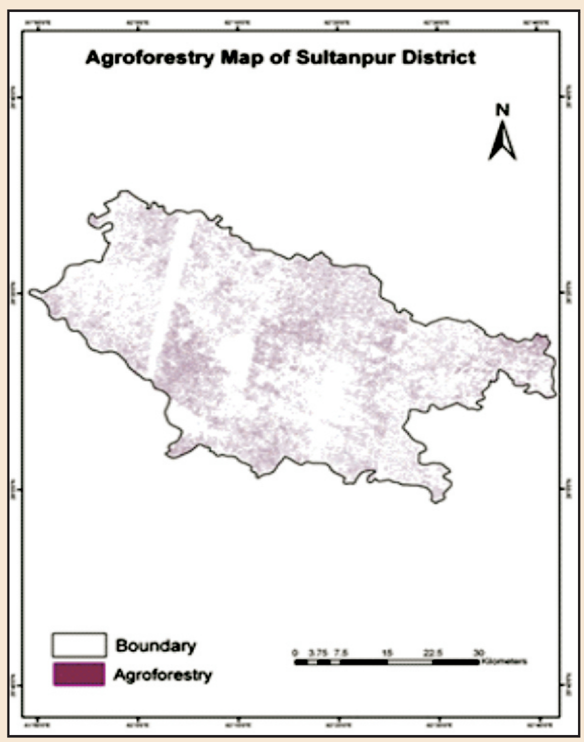
(Assessment of carbon sequestration potential of agroforestry systems)

Carbon sequestration potential of agroforestry practices adopted by the farmers was studied in Indo-Gangetic plains. For which, Sultanpur, Vaishali, North Dinajpur and Ludhiana districts were selected from Upper, Middle, Lower and Trans Gangetic plains, respectively. A field survey of selected districts was done to know the agroforestry practices adopted by the farmers, tree density, tree species existing on the farmers field, tree growth etc.

Remote Sensing and GIS techniques were used for mapping agroforestry area in above districts, for which high resolution satellite imageries (LISS IV), digitized district maps with village boundaries and toposheets of all the districts were procured. Geometric correction of the satellite imageries was carried out with the help of scanned and geo-referenced Survey of India (SOI) toposheets. The satellite imageries were first classified using unsupervised classification method in ERDAS IMAGINE software and then supervised classification method was applied. Another approach of fuzzy classification was also used but hybrid approach was found better. Land use land cover maps were generated for all the districts and land use statistics were computed.

The desired toposheets of Sultanpur, Vaishali, Ludhiana and North Dinajpur districts was digitized in Arc GIS. Digitized area of Sultanpur, Vaishali, Ludhiana and North Dinajpur district is 232400, 368500, 368500, 307059 ha, respectively. The remote sensing images (IRS-P6/LISS IV) procured from NRSC, Hyderabad has some missing area. So the land use and land cover classification has been done on remote sensing data excluding missing area. According to hybrid approach, the land uses and land covers in the Sultanpur, Vaishali, Ludhiana and North Dinajpur district is presented in Table 1. According to this classification, the area under agroforestry comes out to be 7977.58 ha (3.43 %), 22926.0 ha (11.26%), 54821.7 ha (14.87%), 13543.07 ha (4.41%), respectively in these districts. The figure given in per cent based on total geographical area of each district. Considerable area was found under mixed plantations, which was about 44.2 per cent. The land use and land cover and agroforestry map of surveyed districts have been given in Figure 1. The classification accuracy for this approach was about 87 per cent.





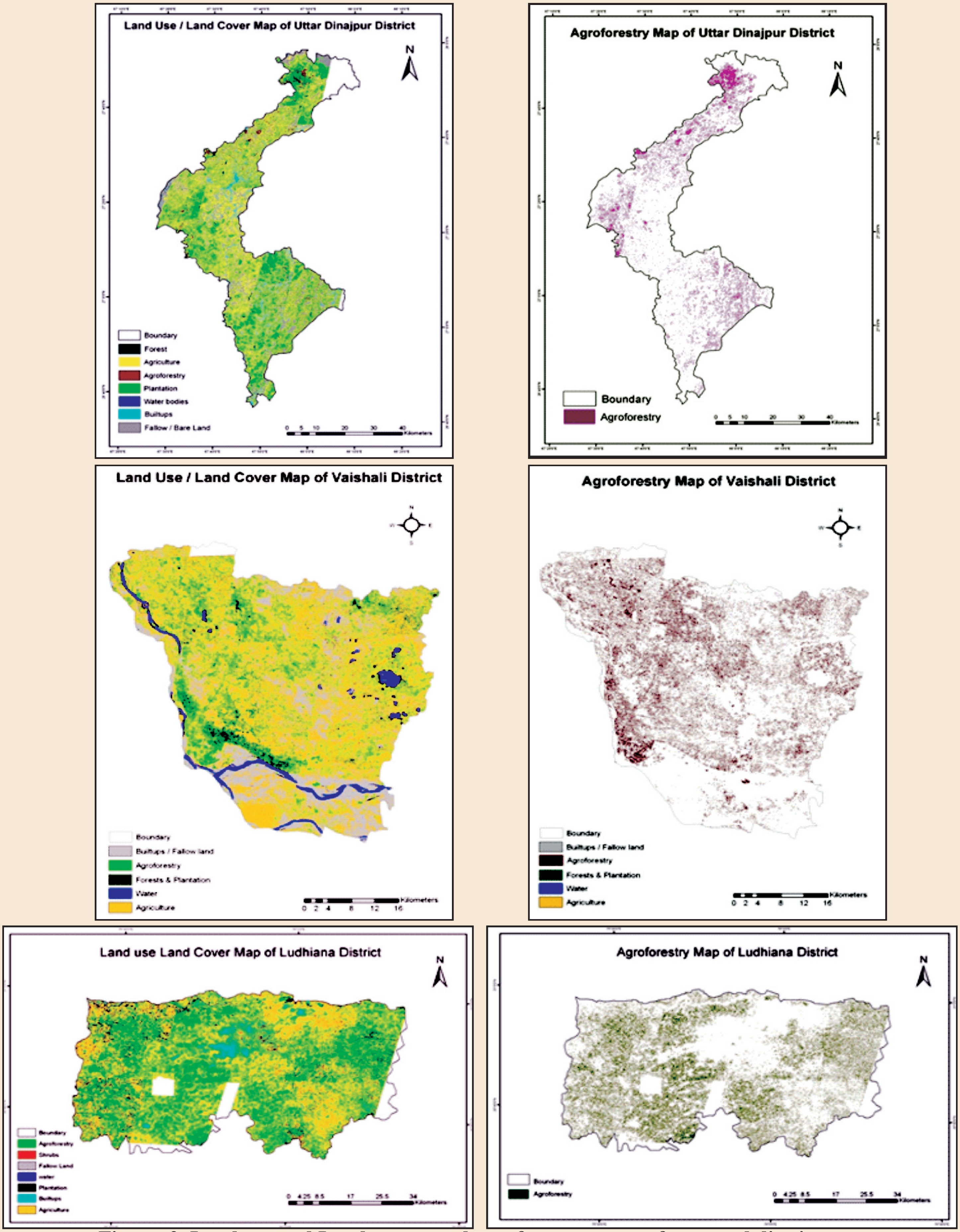


Figure 2. Land use and Land covers and agroforestry maps of surveyed districts

Table 1: Land uses and land covers in study districts using hybrid approach

Land uses/ land covers	Area in different land uses (ha)			
	Sultanpur	Vaishali	Ludhiana	North Dinajpur
Water Bodies	3739.38	6284.01	6007.54	2739.00
Built ups	9159.07	6479.50	33056	9546.00
Fal low / bare land	8038.73	40329.40	6615.48	90672.00
Shrubs	31248.80	-	5540.78	-
Agriculture	39706.70	105762.00	201993.00	109789.90
Agroforestry	7977.58	22926.00	54821.70	13543.07
Forest	15048.50	8144.36	-	551.70
Plantation	102690.00	12136.7 3	34927.80	67507.00
Total Geographical	232400.00	203600.00	368500.00	307059.00

Tree density in different districts of Indo-Gangetic Plains

The tree density varied from 5.67 to 37.5 trees per hectare in different districts (Table 2). The population of medium growing trees is more in Sultanpur and North Dinajpur but the population of fast growing trees is higher in Ludhiana. In sultanpur, the contribution of different tree species exist on farmer's field is in the order of *E. tereticornis* (35.19%) >*Mangifera indica* (23.33)>*Azadirachta indica (5.05%)*>others. These trees are either planted on field bunds or scattered in the field. In Ludhiana, the most common tree species are *Populus deltoides, E. tereticornis* and *Melia azedarch* and their contribution in total tree species is 53.25, 28.25 and 14.98% respectively. In Ludhiana these tree species are planted by the farmers in very systematic manner. Similarly in North Dinajpur, the most popular tree species is *Albizia* species (18.86%) followed by *Laurus nobilis* (14.83%), *Terminalia arjuna* (10.69%), *Mangifera indica* (10.49%) and *E. tereticornis* (7.37%). In Vaishali, *Populus deltoides* is major tree species planted by the farmers on their fields.

Agroforestry practices adopted by the farmers in different districts of Indo-Gangetic plains

Table 2. Tree density in different districts (trees/ha)

Tree	Sultanpur (U.P.)	Ludhiana (Punjab)	North Dinajpur (West Bengal)
Slow growing tree	0.9	0.17	0.25
Medium growing tree	2.9	0.50	3.22
Fast growing tree	2.4	36.8	2.20
Total	6.2	37.5	5.67

Biomass, soil carbon and carbon sequestered in agroforestry under surveyed districts

The soil organic carbon (SOC) varied from 4.8 to 7.2 g kg^{-1} with mean value of 6.5 g kg^{-1}. Similarly, in Ludhiana (Punjab) SOC varied from 3.9 to 6.1 g kg^{-1}. The SOC pool in exiting agroforestry system in North Dinajpur (West Bengal) varied from 4.0 to 7.8 g kg^{-1} with mean value of 5.6 g kg^{-1}. The tree biomass (above and belowground) varied from 6.67 to 10.23 t ha^{-1} in different districts (Sultanpur, Ludhiana and North Dinajpur) in the beginning of the project.

Simulation of biomass (above and belowground) of tree and crop, soil carbon and carbon sequestered was done for 25-years in each district on per hectare basis. Biomass, which includes above and belowground biomass of trees and crops, was 18.65 and 27.88 t ha^{-1} in Sultanpur and Ludhiana districts, respectively during 2011 and it is predicted that after 25-years, the biomass would be 29.62 and 34.77 t ha^{-1}, respectively in these districts. Similarly, in North Dinajpur biomass in the system is 14.65 t ha^{-1} during 2012 and it is projected that the biomass may increase up to 31.9 t ha^{-1}. The soil carbon in the beginning was 9.18, 8.77 and 8.99 t C ha^{-1} and in end of simulation period the soil carbon would be 17.70, 20.97 and 15.63 t C ha^{-1} in Sultanpur, Ludhiana and NothDinajpur, respectively. The carbon sequestered in the system varied from 15.63 to 20.97 t C ha^{-1} in the beginning of the project and after 25-years and it will increase up to 35.42 to 37.92 t C ha^{-1} in different districts.

The carbon sequestration potential of agroforestry in selected districts of Indo-Gangetic plains is about 18.10 t C ha^{-1}. The agroforestry area in each district varied from 3.43 to 14.87% (7977.58 to 54821.70 ha) of total geographical area with mean value of 8.49% (24817.09 ha). Thus the total carbon sequestration potential in each district is about 0.44 million t C. It is also projected that after 25- years the carbon sequestration potential will be 36.25 t C ha^{-1} and total carbon sequestered will be 0.89 million tones carbon in selected districts of Indo-Gangetic plains.

Critical gaps

The importance of agroforestry system acts as effective carbon sink need to be quantified. This will help in ascertaining actual amount of carbon stock available in trees under different agroforestry practices.

In depth studies on partitioning of sequestered carbon in plant parts and soil carbon will be required.

Research and inventorization of life time of the carbon sequestered in agroforestry products.

Consideration of other C stocks often left out in estimates; these include deep soil C (especially when trees are involved) and C in durable wood products, which need to be included.

More information is required on the role of agroforestry in buffering against flood and drought from both the biophysical and financial points of view.

Adequate understanding on issue such as pests and diseases and the emission of other GHGs, especially N_2O and CH_4 in agroforestry systems are researchable issues.

Policy, planning and institutional frameworks particularly for marketing and pricing of agroforestry produce still need to evolve in a way that shall support agroforestry activities. Multidisciplinary and multi-institutional approaches are essential in this process, thus policy convergence and inter-agency coordinatioin/collaboration are becoming increasingly important.

National and international funding schemes have been supporting agroforestry. However, there is still a significant gap in the support of such funding schemes including development of mechanism for partnership and benefit sharing.

Novel ideas

Develop adaptation strategies in response to climate change that maximize food production and security and minimize natural resource degradation.

Reducing abiotic stress provides the linkage between impacts and adaptation research is one of the key issue facing producer is reducing yield loss and improving yield reliability in the face of changing stresses.

Improving resource use efficiency provides the linkage between adaptation and mitigation research within the climate change programme. Improving resource use efficiency will promote natural resource conservation.

Managing carbon provides additional links between adaptation and mitigation research within the climate change programme. The principal means to mitigate climate forcing and at the same time to promote sustainable development are to limit further emission of greenhouse gases to the atmosphere and to actively sequester carbon in biomass and soil.

In addition to an in depth understanding of the benefits from the systems and farmer requirements, mainstreaming of agroforestry requires better market linkages for the goods and services produced. An analysis of consumer needs, local and regional markets including the opportunities for linking carbon sequestration benefits to the CDM, and promotion of market intelligence systems and farmer associations are some of the areas where interventions are required to link smallholder farmers with markets.

Most research, to date, has focused on the impacts of climate change on major annual crops and very little on trees and perennial crop systems. The long duration of the perennials and difficulties in changing varieties over short periods pose special challenges and more research is required to address the same. A thorough understanding of how well the perennial trees overcome the impacts of climate change is an essential requirement before promoting their use.

More proactive interventions must be made to overcome externalities of initiating and promoting biomass energy use. Information exchanges should be promoted particularly on biomass development and use in the context of Clean Development Mechanisms developed under the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC).

There is a vast scope for private sector participation in the agroforestry as well as farm forestry sector. Countries need to evolve sustainable mechanism for enhancing private sector participation for promoting agroforestry in dry and/or degraded lands.

Future thrust

Mapping of agroforestry areas and estimation of carbon stock available in agroforestry systems through predictive models /remote sensing.

Screening and evaluation of plant genetic resources for selected multipurpose trees of agroforestry importance for higher thermotolerance for coping with climate change.

Develop digital library of spectral signatures for major agroforestry systems under different agro-climatic regions.

Studies on socioeconomic aspect and benefits of carbon sequestration reaching to small holder farmers.

Executive summary

Carbon sequestration potential was studied in *Albizia procera* and *Dalbergia sissoo* based agroforestry system under irrigated and *Hardwickia binata* and *Emblica officinalis* based system under rainfed conditions at NRCAF, Jhansi and in agroforestry practices adopted by the farmers in Bundelkhand regions and in Indo-Gangetic plains. For which, 10 districts (Jhansi, Lalitpur, Banda, Hamirpur, Chitrakoot, Mahoba, Jalaun, Datia, Tikamgarh and Chhatarpur) from Bundelkhand regions, five districts of U.P. (Jaunpur, Pratapgarh, Azamgarh, Sultanpur and Basti) and one district from Bihar (Vaishali), Punjab (Ludhiana) and West Bengal (North Dinajpur) were selected and surveyed to generate required data for predictive model. GIS and remote sensing technique was also used for mapping agroforestry area in Sultanpur, Ludhiana, Vaishali and North Dinajpur. The results of study indicates that carbon sequestration potential of agroforestry system was higher under irrigated condition than rainfed condition. However, carbon sequestration potential of the system depends on nature of tree species, tree density, crop grown and agronomic inputs given to the intercrops. *Albizia procera* based agroforestry had sequestered 173.21 t C ha^{-1} at age of 30-years but other systems like *Dalbergia sissoo* and *Hardwickia binata* based system could sequester 79.43 and 73.28 t C ha^{-1}. Simalarly aonla based system had sequestered only 18.41 t C ha^{-1} at 25-year age.

In Bundelkhand region, mixed tree species occurs on farmer's field. *Acacia nilotica, Zizyphus mauritiana, Azadirchta indicam, Butea monosperma, Madhuca latifolia, Acacia leucophloea and Leucaena leucocephala* are major tree species exist in the region. Carbon sequestration potential in agroforestry practices varied in each district and during 2010, the region having 22.42 to 23.84 t C ha^{-1} carbon sequestration potential in different districts. It is predicted that the carbon sequestration potential in the region after 21-years would be 35.65 to 40.03 t C ha^{-1} in different districts.

In Northern Eastern Plains and Eastern Plains of U.P. (Middle Gangetic Plains), tree density also varied in each district but in districts Pratapgarh aonla based agroforestry system is most popular and farmers having systematic plantation of aonla under agroforestry. But in other districts, trees mostly occurs on field bunds and most common tree species in this Plains are *Emblica officinalis, Mangifera indica, Madhuca latifolia, Azadirchta indica, Acacia* *nilotica, Eucalyptus tereticornis, Tectona grandis.* The carbon sequestration potential in different districts during 2011 was 14.94 to 21.80 t C ha^{-1} and it is projected that after 24-years carbon sequestration potential may be up to 28.66 to 37.99 t C ha^{-1}.

The carbon sequestration potential of agroforestry in selected districts (Sultanpur, Ludhian ,Vaishali and North Dinajpur) Indo-Gangetic was about 18.10 t C ha^{-1} during 2011. The agroforestry area in each district varied from 3.43 to 14.87% (7977.58 to 54821.70 ha) of total geographical area with mean value of 8.49% (24817.09 ha). Thus the total carbon sequestration potential in each district is about 0.44 million t C. It is also projected that after 25-years the carbon sequestration potential will be 36.25 t C ha^{-1} and total carbon sequestered will be 0.89 million tones carbon in selected districts of Indo-Gangetic plains.

Acknowledgement

We are highly thankful to DDG (NRM), and ADG (Agronomy & Agroforestry), NRM Division, ICAR, New Delhi for providing financial help, guidance and encouragement to implement ICAR, Ad-hoc scheme, NPCC and NICRA project at NRCAF, Jhansi. We are also thankful to Director, CRIDA, Hyderabad for their guidance, encouragement and help for conducting research under NPCC and NICRA project. Our team express sincere thanks to Coordinator, Network Project and Principal Investigator Lead Centre (CRIDA, Hyderabad) for their guidance and help in conducting the prestigious project. We are also thankful to Department of Science and Technology, Govt. of India, New Delhi for providing financial help, guidance and encouragement for conducting research on carbon dioxide sequestration in agroforestry. We are also thankful to Director, IASRI, New Delhi and , CCPI and CC-Co-PI of NICRA project from IASRI for their guidance and significant contribution in the project. In last but not least we are highly thankful to Director, NRCAF, Jhansi for their guidance, help and support for conducting the research.

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