Vol. 42, No.3, pp 293-297, 2014
Indian Journal of Soil Conservation
Online URL:http://indianjournals.com/ijor.aspx?target=ijor:ijsc&type=home

Carbon stocks and soil properties under nitrogen-fixing trees on degraded site in subtropical Himalayan region

Vipan Guleria[1], Amol Vashisht, Atul Gupta, Thiru Salven, Chaman Thakur and P. Kumar

Regional Horticultural Research Station, Jachh-176201; Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Solan, Himachal Pradesh.
[1]E-mail: vip_an2003@yahoo.com

ARTICLE INFO

Article history :
Received : December, 2013
Revised : June, 2014
Accepted : July, 2014

Key words :
Agroforestery,
Carbon stocks,
Nitrogen fixing trees,
Subtropical

ABSTRACT

Nitrogen fixing trees (NFTs) are integral part of the indigenous agroforestry plantations on farms. The nitrogen fixing species accumulate more C due to their efficient system of fixation of nitrogen and the carbon in their parts. Increased N inputs most likely increase soil C storage by increasing biomass diversity and production. The present stydy was conducted to study the effect of nitrogen fixing trees *viz., Acacia nilotica, Acacia auriculiformis, Acacia albida, Leucena leucocephala, Albizia lebbeck, Acacia catechu, Dalbergia sissoo* and *Bauhinia variegata* on the growth biomass site amelioration and carbon sequestration. The results revealed that the maximum tree height and diameter was recorded in *A. albida* closely followed by *D. sissoo* and *B. variegata*. *A. nilotica* was the poor performer with 20% survival and 6.86 m height tree^{-1}. It was most affected by the diseases among all the species. The mean annual increment was higher in first six years among all the NFT species. The maximum mean annual increment in height was recorded to be 0.57 m yr^{-1} whereas the maximum mean annual increment in DBH was recorded in *L. leucocephala* to the tune of 1.03 cm yr^{-1}. Carbon stocks in *D. sissoo* were 145.2 and 42.12 t ha^{-1} in above and below ground parts, respectively. It was closely followed by *A. albida.* Carbon dioxide mitigation potential of *D. sissoo* was maximum to the tune of 28.42 t ha^{-1}yr^{-1}. The studies concluded that *D. sissoo* is the highest carbon sequestering species with maximum survival and growth in subtropical climate.

1. INTRODUCTION

Increase in greenhouse gases (GHGs) in the atmosphere is considered one of the major factors for global climate change. Finding low-cost methods to sequester carbon (C) is thus emerging as a major international policy goal for mitigating climate change. Cultivation of nitrogen fixing plants and trees is recommended as mitigation strategies by the IPCC (Smith, 2007) except for reduced use of synthetic fertilizers, which is mentioned by the Terrestrial Carbon Group Project (2009). A number of exotic species, especially capable of fixing atmospheric nitrogen are potential species for reforestation of wastelands. These species, due to their rapid growth and ability to fix atmospheric nitrogen, increase the nitrogen content of otherwise impoverished soils. These nitrogen fixing trees also effectively serve as “nutrient pumps”/“soil improvers” and can be exploited for the rejuvenation of wastelands (Raverkar *et al.,* 2012). All comparisons of N fixers and non N fixers have found 20-100% more soil C under N fixers (Johnson 1992; Cole *et al.,* 1995; Rhoades *et al.,* 1998). Sequestering C through tree based system is now considered as an attractive economic opportunity for mitigating global climate change and C trading in addition to providing multiple products (Goswami *et al.,* 2013). Projections of ICRAF that the carbon market may exceed US$1 trillion by 2025 suggest that significant funds could potentially be available to finance sustainable rural development and adaptation to climate change (ICRAF, 2009). Despite the importance of nitrogen fixing trees for C sequestration, the quantification and evaluation of these trees in terms of C sequestration potential is still in neglected state. The present study was therefore conducted with the aim to study the carbon sequestration potential of nitrogen fixing tree species in subtropical climate of western Himalayas.

2. MATERIALS AND METHODS

The experiment was started in the year 1988 at the Regional Horticultural Research Station, Jachh situated in the subtropical climate of the western Himalayas in Himachal Pradesh. Jachh is situated at 32°16" N and 75°51" E at elevation of having subtropical climate. May-June are the hottest and December-January are the coldest months. On an average, the annual rainfall is 1300-1500 mm annum^{-1}, most of it is received in monsoon season. The study site consisted of sandy soil type with low humus and gravels on the bank of river.

Eight species *viz., Acacia nilotica* L. (Hissar selection), *Acacia auriculiformis* (Hissar selection), *Acacia albida* (NFTA-659), *Leucena leucocephala* (local collection), *Albizia lebbeck* L., *Acacia catechu, Dalbergia sissoo* and *Bauhinia variegata* (all local selections) were planted in 12 x 9 m plots at the spacing of 3 x 3 m each in Randomized Block Design using four replicates in the year 1989. Twelve polybags raised seedlings were planted in pits in each replication. The ground was not ploughed during the study years. Sixth year onward the species were lopped once in a year to get the green fodder.

The data on the plant height (m) and diameter (cm) was recorded at regular intervals on each twelve trees. Above-ground stem, branch and leaf biomass of trees were estimated by non-destructive method. Bole volume was measured with bark using the formula V = f x h x g where, V is the volume, f the form factor, h the total height and g the basal area. Form factor was calculated with a Spiegel Relaskop using the formula $f = 2h_1/3h$, where f is the form factor, h_1 is the heigh at which diameter is half of diameter at breast height and h the total height (Pressler, 1865) Biomass was estimated using the following equation Biomass = specific gravity × volume. Specific gravity was estimated taking the stem cores by maximum moisture method using the formula:

$$G_f = \frac{1}{\dfrac{M_n - M_0}{M_0} + \dfrac{1}{GS_o}},$$

Where, G_f is the specific gravity based on gross volume, M_n is the weight of saturated volume sample, M_o is the weight of oven-dried sample, and Gs_o is the average density of wood substances equal to 1.53. The specific gravity values obtained for the present study were 0.69 for *A. nilotica,* 0.71 for *A. auriculiformis,* 0.70 for *A. albida,* 0.67 for *L. leucocephala,* 0.60 for *A. lebbeck,* 0.87 for *A. catechu,* 0.80 for *D. sissoo* and 0.41 for *B. variegata.* Root biomass in trees was estimated up to 60 cm depth only. Root samples were taken in four directions, *i.e.* east, west, north and south, crossing each other at the stem base. Along each line, four samples were taken at a horizontal distance up to the canopy projection of the tree assuming that root spread does not go beyond the canopy width. All categories of root were hand sorted from the soil cores by means of dry sieving and were visually inspected to remove roots of other species. Fresh weight of all the roots was measured. Total root biomass was calculated by taking into account the area occupied by the tree.

The tree biomass was converted into carbon (C) stock by multiplying the dry weight of the different plant components by a factor of 0.45 (Woomer 1999). The estimated carbon stocks were converted into CO_2 equivalents (quantity of C x 44/12) for calculating CO_2 assimilation by biomass of trees.

Soil organic carbon and bulk density were determined according to Walkley and Black (1934) and Black (1965) by taking composite soil samples from the plantation. Soil carbon stocks were considered up to 30 cm soil depth only as per the guide lines of IPCC. Soil carbon stock was computed by multiplying the soil organic carbon (g kg^{-1}) by bulk density (g cm^{-3}) and depth (cm) and expressed in t ha^{1}. Data recorded for different parameters was analysed according to the methods described by Gomez and Gomez (1984).

3. RESULTS AND DISCUSSION

The maximum tree height was recorded to be 12.6 m in *D. sissoo* followed by *A. catechu, A. albida, L. leucocephala* and *B. variegata* (Table 1). The tree diameter showed large variation. The maximum tree diameter of 0.71 m was observed in *A. albida* which was closely followed by *D. sissoo* and *A. catechu*. The crown behaviour also varied with species. The maximum crown width of 7.30 m was observed in *A. lebbeck*. The maximum clean bole after 24 years of plantation was recorded in *B. variegata* (10.01 m). The branching pattern was quite different for each species. *A. albida* and *L. leucocephala* showed the tolerance to the pruning and recorded the maximum number of branches tree^{-1} (10.3 and 10.1, respectively). The mortality of the established plants over the 24 years showed that the maximum survival was recorded in *D.sissoo* to the tune of 76.2% and the minimum survival (20%) was observed in *A. nilotica*. The mean annual increment (MAI) in height and tree diameter was quite variable within the species as well as among the species. MAI in tree height at early age was higher than the MAI at the 24 years of age. The maximum MAI in tree height (0.97 m yr^{-1}) was recorded in *D. sissoo* at

6 years and 0.57 m yr^{-1} in *A. auriculiformis* at 24 years. For tree diameter, *B. variegata* recorded the maximum MAI of 1.86 cm yr^{-1} at the age of 6. However, after 24 years, *L. leucocephala* recorded the maximum MAI of 1.03 cm yr^{-1} at the age of 24 years (Table 2). Among all the species, *A. nilotica* was the poor performer.

Above and below ground biomass in the different tree components is given in Table 3. After 24 years, highest above ground biomass was 322 t ha^{-1} in *D. sissoo* whereas, lowest biomass was observed in *A. nilotica.* The biomass of the different above-ground components *viz.,* stem, branch and leaf depends upon a number of factors, *viz.,* growth

Table: 1
Tree quality parameters of different nitrogen fixing trees after 24 years

Treatment (Species)	Plant height (m)	Tree diameter (cm)	Crown width (m)	Crown length (m)	Clean bole (m)	Number of branches	Survival (%)
A. nilotica	6.8	65	4.2	2.1	5.1	6.3	20.0
A. auriculiformis	9.3	68	5.8	2.3	9.6	9.6	48.7
A. albida	12.6	71	6.2	4.5	9.4	10.1	30.0
L. leucocephala	11.3	62	6.6	3.5	6.7	10.3	33.7
A. lebbek	8.1	67	7.3	4.0	6.5	8.4	40.0
A. catechu	11.7	68	6.0	2.25	8.7	8.6	61.2
D. sissoo	12.6	69	6.2	3.6	8.4	7.3	76.2
B. variegeta	11.0	59	5.2	2.6	10.0	7.2	38.7
CD 0.05	3.6	8.78	1.9	1.7	2.0	3.1	10.9

Table: 2
Mean annual increment in tree height (m) and diameter (cm) of nitrogen fixing trees after 6 and 24 years

Nitrogen fixing tree species	Mean annual increment of plant of plant height (m)		MAI of tree diameter (cm)	
	6 years	24 years	6 years	24 years
A. nilotica	0.50	0.27	1.01	0.74
A. auriculiformis	0.85	0.57	1.50	0.93
A. albida	0.34	0.54	0.83	0.77
L. leucocephala	0.57	0.47	0.91	1.03
A. lebbek	0.81	0.46	1.63	0.87
A. catechu	0.38	0.50	1.08	0.74
D. sissoo	0.97	0.54	1.65	0.81
B. variegata	0.81	0.46	1.86	0.74
CD 0.05	0.23	0.18	0.39	0.1.04

Table: 3
Biomass production, carbon stocks and CO_2 mitigation by NFTs in 24 years

Treatment (Species)	Above ground biomass (t ha^{-1})	Above ground carbon stocks (t ha^{-1})	Below ground biomass (t ha^{-1})	Root Carbon Stocks (t ha^{-1})	Total biomass (t ha^{-1})	Total tree carbon stocks (t ha^{-1})	CO_2 mitigation by trees (t ha^{-1})	CO_2 mitigation rate (t ha^{-1} yr^{-1})
A. nilotica	103.2	46.5	29.9	13.5	133.2	59.9	219.7	9.1
A. auriculiformis	216.0	97.2	62.6	28.2	278.7	125.4	459.8	19.2
A. albida	296.5	133.4	85.9	38.7	382.4	172.1	631.0	26.3
L. leucocephala	156.1	70.2	45.3	20.4	201.4	90.6	332.3	13.9
A. lebbek	183.3	82.5	53.2	23.9	236.5	106.4	390.2	16.3
A. catechu	269.4	121.2	78.1	35.2	347.5	156.4	573.4	23.9
D. sissoo	322.7	145.2	93.6	42.1	416.4	187.4	686.9	28.6
B. variegata	171.6	77.2	49.8	22.4	221.4	99.6	365.3	15.2
CD 0.05	56.3	52.7	21.7	14.9	102.3	45.3	118.0	11.7

habit of the species, site quality, age, soil on which trees are growing, stand age, management practices and their interactions with below-ground components (Graham *et al.,* 1992; Niu and Duiker 2006; Terakunpisut *et al.,* 2007; Jana *et al.,* 2009; Kanime *et al.,* 2013; Arora *et al.,* 2014; Goswami *et al.,* 2014). Below ground biomass followed the similar trend as that of above ground biomass and it ranged from 29.9 - 93.6 t ha^{-1}. It was highest in *D. sissoo* and lowest in *A. nilotica*. Distribution of root systems in space and time is usually influenced by both the genetic characters of the plant and the localized soil conditions (Huck, 1983). Further, variation in root biomass in the present study may also be attributed to the sampling difficulties in estimating the root biomass.

Many studies have estimated high potential of carbon storage in Indian forests, especially through raising plantations (Lal and Singh, 2000; Hooda *et al.*, 2007; Kaul *et al.,* 2010). In the present study, total biomass carbon stocks varied from 59.9 t ha^{-1} in *A. nilotica* to 187.4 t ha^{-1} in *D. sissoo.* The carbon stock values obtained in the present study are comparable to the estimates of Kaul *et al.* (2010) for fast growing short rotation forests (101-134 t C ha^{-1}). CO_2 mitigation also showed the similar trend.

Soil properties *viz.*, organic carbon, available N, P and K showed improvement under the trees after 24 years (Table 4). Soil pH decreased from 7.5 to 6.03 during the study. The reduction in pH may be attributed to greater accumulation of organic matter leading to production of organic acids (Killham, 1994; Pal and Panwar, 2013). Low soil pH under forest plantation may also be attributed to leaching of bases and enhancement of weathering process giving rise to high Al levels (Chavan *et al.*, 1995; Contractor and Badnur, 1996; Chakravarty and Barthakur, 1997). Soil organic carbon was doubled after 24 years. The enrichment of organic carbon content under tree could be due to litter fall and root biomass accumulation (Madhumitha *et al.,* 1997; Naitham and Bhattacharyya 2004; Negi *et al.,* 2006).

Table: 4
Changes in pH, OC and available NPK in the soils under nitrogen fixing trees

Soil Property	Year		Change
	1989	2012	After 24 years
OC (%)	0.6±0.10	1.2±0.12	0.6 (100)
Soil carbon stocks (t ha^{-1})	9.2±1.3	18.4±1.0	9.2 (100)
Nitrogen (kg ha^{-1})	300.0±20	437.4±23	137.4 (45.8)
Phosphorus (kg ha^{-1})	20.1±1.9	55.4±4.0	35.4 (175.6)
Poatssium (kg ha^{-1})	240.0±12	339.8±18	99.8 (41.6)
pH	7.5	6.03	-1.47 (19.6)

Values in parenthesis indicate % change in values (2012) over initial values (1989) ± indicates standard deviation

The soil nitrogen increased from 300 to 437 kg ha^{-1}. Similarly potassium increased from 240 kg ha^{-1} to 339 kg ha^{-1} during 24 years of study. Improvement in available NPK may be attributed to more accumulation of biomass through litter fall and root biomass (Juo and Lal, 1977; Srinivasan and Caulfield, 1989; Pal and Panwar, 2013). Sigrid *et al.* (2002) also reported soils beneath Nfixing trees showed greater retention of older soil than non N fixers.

4. CONCLUSIONS

Nitrogen fixing trees can be a good option for ameliorating the degraded sites. There is increase in soil nitrogen, phosphorus and potassium under nitrogen fixing tree species due to their efficiency to capture the atmospheric nitrogen and higher biomass production. Among different nitrogen fixing tree species the maximum tree height was recorded in *D. sissoo* followed by *A. catechu, A. albida, L. leucocephala* and *B. variegata. D. sissoo* and *A. catechu* can be the best carbon sequestering NFT's under subtropical climate. *A. niltotica* although grows well in dry sites but its poor performance in the experiment has clearly depicted that it is not suitable for the subtropical climate which experience severe cold.

REFRENCES

Arora, G., Chaturvedi, S., Kaushal, R., Nain, A., Tewari, S., Alam, N.M. and Chaturvedi, O.P. 2014. Growth, biomass, carbon stocks and sequestration in age series of *Populus deltoides* plantations in Tarai region of central Himalaya. *Turkish J. Agri. For.,* 38 : 550-560.

Black, C.A. 1965. *Methods of soil analysis.* American Society of Agronomy, Part I. Madison WI.

Chakravarty, D.N. and Barthakur, B.C. 1997. Acid Soils of Assam Area and Extent of Acidity. *In:* Mahapatra, I.C., Mandal, S.C., Misra, C., Mitra, G.N., Panda, N., (eds), Acid Soils of India, ICAR, New Delhi.

Chavan, K.N., Kenjale, R.Y. and Chavan, A.S. 1995. Effect of Forest Tree Species on Properties of Lateritic *J. Indian Soc. Soil Sci*., 43(1): 43-46.

Cole, D.W., Compton, J.E., Edmonds, R.L., Homann, P.S. and Van Miegroet, J. 1995. Comparison of carbon accumulation in Douglas fir and red alder forests. *In:* McFee W.W., Kelly, J.M., (editors). Carbon forms and functions in forest soils. Madison (WI): *Soil Sci. Soc. Am.,* pp. 527-546.

Contractor, R.M. and Badnur, V.P. 1996. Effect of Forest Vegetation on Properties of a Vertisols. *J. Indian Soc. Soil Sci.,* 44(3): 510-511.

Gomez, K.A. and Gomez, A.A. 1984. *Statistical procedure for Agricultural Research*. 2nd ed. John Wiley and Sons, New York, 680 p.

Goswami, S., Verma, K.S. and Kaushal, R. 2014. Biomass and carbon sequestration in different agroforestry systems of a Western Himalayan watershed. *Bio. Agri. Hort.,* 30(2): 88-96.

Graham, R.L., Wright, L.L. and Turhollow, A.F. 1992. The potential for short rotation woody crops to reduce U.S. CO_2 emissions. *Climate Change*, 22: 223-238.

Hooda, N., Gera, M., Andrasko, K, Sathaya, J., Gupta, M.K., Vasistha, H.B., Chandran, M. and Rassaily, S.S. 2007. Community and farm forestry climate mitigation projects: case studies from Uttaranchal, India. *Mitig. Adapt. Strategies Glob. Change*, 12: 1099-1130.

Huck, M.G. 1983. *Root distribution, growth and activity with references to agroforestry*. In: Huxley P.A. editor. Plant research and agroforestry, ICRAF, Nairobi, Kenya, pp. 527-542.

Jana, B.K., Biswas, S., Majumder, M., Roy, P.K. and Mazumdar, A. 2009. Carbon sequestration rate and aboveground biomass carbon potential of four young species. *J. Ecol. Nat. Environ.,* 1(2):15-24.

Johnson, D.W. 1992. Effects of forest management on soil carbonstorage. *Water Air Soil Poll.,* 64: 83-120.

Juo, A.S.R. and Lal, R. 1977. The effects of fallow l and continuous cultivation on t he chemical and physical properties of Alfisols in western Nigeria. *Plant Soil*, 47: 517-589.

Kaul, M., Mohren, G.M.J. and Dadhwal, V.K. 2010. Carbon storage and sequestration potential of selected tree species in India. *Mitig. Adapt. Strategies Glob. Change,* 15: 489-510.

Kanime, N, Kaushal, R., Tewari, S.K., Raverkar, K.P., Chaturvedi, S. and Chaturvedi, O.P. 2013. Biomass production and carbon sequestration in different tree-based systems of Central Himalayan Tarai region. *For. Trees Livelihoods,* 22:38-50.

Killham, K. 1994. *Soil ecology.* Cambridge: Cambridge University Press.

Koul, D.N. and Panwar, P. 2012. Soil carbon buildup and bioeconomics of different lanuduses in humid subtropics of West Bengal, India. *Ann. For. Res*., 55(2): 253-264.

Lal, M. and Singh, R. 2000. Carbon sequestration potential of Indian forests. *Environ Monit. Assess*., 60: 315-327.

Madhumitha, D., Singh, B.P. and Khan, S.K. 1997. Effect of major land uses on soil characteristics of Alfisols in Meghalaya. *J. Indian Soc. Soil Sci*., 45: 547-553.

Naitham, R. and Bhattacharyya, T. 2004. Quasi-equilibrium of organic carbon in shrinkswell soils of the subhumid tropics in India under forest, horticultural and agricultural systems. *Aus. J . Soil Res*., 42:181-188.

Negi, S.S., Singh, S.B. and Gupta, M.K. 2006. Agroforestry: A sustainable land use for carbon sequestration. Proceedings of the Workshop on Status and Potential of Agroforestry in Northwestern Himalayas, ed. J. Singh, V.P. Panwar, K.D. Singh and J. Singh, 1015. Himalayan Forest Research Institute (HFRI), Shimla, India.

Niu, X. and Duiker, S.W. 2006. Carbon sequestration potential by afforestation of marginal agricultural land in the Midwestern U.S. *Elsevier B.V. Forest Ecol Manage*., 223: 415-427.

Pal, S. and Panwar, P. 2013. Interrelationship of Carbon Sequestration, Soil Fertility and Microbial Indices as Influenced by Long-Term Land Uses in Lower Himalayan Region, India. Communications in Soil Science and Plant Analysis, 869-882.

Pressler, M. 1965. Das gessetz der stambilodung Leipzig. 153 p.

Raverkar, K.P., Tripathi, D. and Kaushal, R. 2012. Capability of wasteland soils of north western Himalayas to support nodulation and growth of *Robinia pseudoacacia. Ind. J. Soil Cons.,* 40(1): 78-83.

Rhoades, C.C., Eckert, G.E. and Coleman, D.C. 1998. Effect of pasture trees on soil nitrogen and organic matter: implications for tropical montane forest restoration. *Restor. Ecol.* 6: 262-70.

Sigrid, C.R., Dan Binkley and Parrotta, John A. 2002. Greater Soil Carbon Sequestration under nitrogen-fixing Trees Compared with *Eucalyptus* Species. *Ecosyst.,* 5: 217-231.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., Mc Carl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B. and Sirotenko, O. 2007. *Agriculture in Climate Change Mitigation*. Contribution of Working Group III to the Fourth Assessment Report of the Inter-governmental Panel on Climate Change [BMetz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Srinivasan, U.M. and Caulfield, I. 1989. Agroforestry land management system in developing countries: An overview. *Indian For.,* 115:57-68.

Terakunpisut, J., Gajaseni, N. and Ruankawe, N. 2007. Carbon sequestration potential in aboveground biomass of Thong Pha Phun National Forest, Thailand. *Appl. Ecol. Environ. Res.,* 5: 93-102.

Terrestrial Carbon Group Project. 2009. A Roadmap for Terrestrial Carbon: Research Needs for Implementation of Carbon Management in Agriculture, Forestry and Other Land Uses. Rapid Assessment-Revised Draft. September 2009. Published by UN-REDD, The World Bank, CGIAR and The Heinz Center.

Walkley, A.J. and Black, I.A. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.,* 37: 29-38.

Woomer, W.L. 1999. Impact of cultivation of carbon fluxes in woody savans of Southern Africa. *Water Air Soil Poll.,* 70(1-4): 403-412.