Annals of Arid Zone 62(3): 211-217, 2023

Carbon Sequestration Potential of Silvipastoral Systems in Hot Arid Region of India

M. Patidar*, S.P.S. Tanwar, Anil Patidar, B.K. Mathur and M.P. Rajora

ICAR-Central Arid Zone Research Institute, Jodhpur 342 003, India

Received: March 2023

Abstract: Silivipastoral systems having trees and grasses play an important role in providing fodder for sustainable livestock production in arid region, prevent soil erosion, conserve soil moisture and add organic matter to soil. A field experiment was initiated on the silvipastoral system having different trees species i.e., *Hardwickia binata*, *Ailanthus excelsa* and *Colophospermum mopane* in association with *Cenchrus ciliaris* grass at ICAR-CAZRI Jodhpur, India in the year 2003. Observations on growth, biomass production and organic soil carbon content were recorded during kharif season in the year 2015. Maximum plant height was recorded in case of H. *binata* whereas minimum was recorded for *C. mopane*. The highest canopy area was recorded in *C. mopane*, whereas least canopy area was recorded in case of *H. binata*. Highest DBH was recorded for *C. mopane* and least for H. *binata*. Specific gravity of wood of *C. mopane* was maximum whereas it was minimum in *A. excelsa*. The AGB of *C. mopane* (13.5 t ha^{-1}) was maximum among the tree species whereas it was minimum in case of *A. excelsa* (2.6 t ha^{-1}). Root biomass of *C. mopane* (3.51 t ha^{-1}) was maximum whereas least was recorded for *A. excelsa* (0.67 t ha^{-1}) which was at par with that of *H. binata* (0.74 t ha^{-1}). The highest amount of carbon was sequestered by *C. mopane* tree (8.51 t ha^{-1}) and least by *A. excelsa* (1.63 t ha^{-1}) which was comparable with that of *H. binata* (1.80 t ha^{-1}). Total Carbon sequestered by *C. mopane* based silvipature system. (10.19 t ha^{-1}) was higher as compared to *H. binata* (3.69 t ha^{-1}) and *A. excelsa* (4.45 t ha^{-1}) based silvipasture systems. These results would help in selection of suitable silvipasture system for the arid regions of Rajasthan for sustainable land use management and increase carbon sequestration.

Key words: Arid region, carbon sequestration, grass, silvipastoral system.

Edited by

Praveen Kumar
Vipin Chaudhary
K.S. Jadon
S.C. Meena
R.K. Solanki

***Correspondence**

M. Patidar
mavjipatidar@gmail.com

Citation

Patidar, M., Tanwar, S.P.S., Patidar, A., Mathur B.K. and Rajora, M.P. 2023. Carbon sequestration potential of silvipastoral systems in hot arid region of India. Annals of Arid Zone 62(3): 211-217

https://doi.org/10.59512/aaz.2023.62.3.3

https://epubs.icar.org.in/index.php/AAZ/article/view/132537

https://epubs.icar.org.in/index.php/AAZ

Arid and semi-arid regions are associated with less vegetation, high rate of deforestation and land degradation. Approximately 75% of total area of hot arid region is degraded and not suitable for annual crop production (Dhurvanarayan, 1993). Low and erratic rainfall worsens the situation; making most of the seasons unfit for crop growth and intensifies the process of land degradation coupled with high wind speed. Indiscriminate use of the natural resources, high density of human and cattle population, and unscientific land use practices have further accelerated land degradation processes, causing reductions in biodiversity and soil quality (Sidhu *et al.*, 2007). Under such circumstances, silvipasture system can help in reclaiming the degraded land and stabilizing the land use system for sustainable livelihood security. Silvipasture system is an ideal alternative for development of such degraded lands (Rai, 2008). Besides, this particular land use system has the ability to enhance resilience of the system for coping with the adverse impacts of climate change. Land productivity in arid region is very low due to poor fertility and low water holding capacity of soils. In such situations, forage based silivipastoral system could be a promising and sustainable technology as trees and grass in the system prevent soil erosion, conserve soil moisture and add organic matter to soil.

Silvipasture systems provides a unique opportunity to combine the twin objectives of climate change adaptation and mitigation as well as ensuring the availability of fodder throughout the year even during the lean period which helps livestock rearing activities. There are many recent studies that substantiate the evidence that silvipasture systems can play a major role in storing carbon in above ground biomass, soil and below ground biomass. Some of the earliest assessments of national and global terrestrial carbon dioxide sinks reveal two beneficial attributes of silvipasture systems (a) direct near term storage (decades to centuries) in trees and soils and (b) the potential to offset immediate GHG (Greenhouse gas) emissions associated with deforestation and subsequent shifting cultivation. The United Nations Framework Convention on Climate Change (UNFCCC) defines carbon sequestration as the process of removing C from the atmosphere and depositing it in a reservoir. It entails the transfer of atmospheric CO_2 and its secure storage in long-lived pools. From the agroforestry point of view, C sequestration primarily involves the uptake of atmospheric CO_2 during photosynthesis and the transfer of fixed C into vegetation, detritus and soil pools for secure (i.e. long-term) storage (Nair *et al.*, 2010). The role of silvipastoral systems, as a means of sequestering atmospheric carbon to mitigate the effects of the greenhouse gas has been increasing (Albrecht and Kandji, 2003; Montagnini and Nair, 2004; Oelbermann *et al.*, 2004). Keeping these things in view silivipastoral system with different trees viz., *Hardwickia binata*, *Ailanthus excelsa* and *Colophospermum mopane* in association with *Cenchrus ciliaris* grass was established to evaluate the biomass and carbon sequestration production potential in arid region.

Materials and Methods

Experimental site and climatic conditions

The experimental site is located at ICAR-Central Arid Zone Research Institute in the Jodhpur district (26°14′53″N and 72°59′34″E) of Rajasthan, India. The area was undulating, and soils were loamy sand textured. Soil pH was 8.29 and organic carbon in the 0-15 cm soil layer was 0.12%. Summer temperatures often exceed 46-47°C in May and June, minimum temperatures in December and January range from 3 to 9°C and there are occasional periods of sub-freezing surface temperatures and frost. In May-July, winds average 6-20 km h^{-1} with occasional dust storms (winds velocities as strong as 120 km h^{-1}). The average rainfall is <350 mm. There was 373.2 mm rainfall received in 24 rainy days during the year 2015. A large variation has been observed in the annual rainfall pattern. The trial was laid out in a randomized block design with three replications in 2003. The total area of the trial was 1.5 ha. There were 92 trees of *C. Mopane*, 54 of *H. binata* and 50 of *A. excelsa* in the experimental field. *C. ciliaris* grass was grown in the tree alleys.

Soil sampling and estimation

Soil was sampled manually at a depth of (0-15 cm) in alley between tree and grasses in 2015. These samples were taken at distance of 1.5, 3.0 and 4.5 m under *C. mopane, H. binata* and *A. excelsa* in different silvipasture systems. Samples were air-dried, grounded in a ceramic pestle and mortar and sieved. Soil pH and electrical conductivity (EC) was determined in a 1:2 soil: water solution, soil available P (Olsen *et al.*, 1954), soil available K and organic carbon was determined using the Walkley-Black method (Jackson, 1958).

Estimation of growth and biomass yield

Growth parameters viz. tree height, crown diameter (average of two diameters at right angle), tree basal diameter at ground level and number of stems per tree were measured in 2015. In accordance with MacDicken *et al*. (1991), tree height measurements were carried out for total stem length to the highest growing point on the longest stem only. All shoots over 1 cm in diameter and originating between 0 and 30 cm from the soil were considered to be stems. Tree basal diameters were measured according to MacDicken *et al.* (1991) formula:

$$D\ combined = \sqrt{d^2 1 + d^2 2 + d^2 3 + ... + dn^2}$$

Crown diameter was measured using a non-elastic tape. Since crowns were irregularly shaped, the longest and shortest axes were measured making sure to pass through the geometric centre of crown (MacDicken *et al*., 1991). The above ground biomass (AGB) includes all living biomass above the soil including stem, stump, branches, bark, seeds and foliage. Grasses were harvested at different stages using 1 m^2 quadrant for estimating the fresh forage yield and oven dried at (65°C) for biomass production. Grass yield was measured at distance of 1.5, 3.0 and 4.5 m from *C. mopane, H. binata* and *A. excelsa* trees to evaluate the effect of trees on growth of grasses.

The AGB of trees has been calculated by multiplying volume of biomass and wood density. Allometric model are used for calculation AGB and below ground biomass (BGB) based on regressing a dependent variable (i.e. AGB), against one or several independent variables. The possible independent variables included here were trunk diameter D (cm), wood specific gravity ρ (g cm^{-3}), total tree height H (m), or a combination there of. We fitted the following log-log model relating AGB to the compound variable $\rho \times D^2 \times H$

According to Chave *et al*. (2014) regression equation for tree AGB (kg) against the product $\rho \times D^2 \times H$, were found to be the best-fit pantropical model:

$$AGB_{est} = 0.0673 \times (\rho D^2 H)^{0.976}$$

where, D is in cm, H is in m, and ρ is in g cm^{-3}. This model performed well across forest types and bioclimatic conditions

$$AGB\ (g) = Volume\ of\ Biomass\ (cm^3) \times Wood\ Density\ (g/cm^3)$$

Wood specific gravity (here defined as the oven-dry wood mass divided by its green volume, and denoted ρ) is an important predictor of stand-level AGB (Baker *et al*., 2004). In the field, green volume was measured from freshly cut wood samples. The samples were subsequently weighed after having been left in a drying oven until constant weight is reached. The BGB has been calculated by multiplying the AGB by 0.26 factors as the root: shoot ratio (Hangarge *et al*., 2012). Since the grass was harvested as fodder for livestock therefore it was not considered in AGB for calculation of carbon stock.

BGB = AGB x 0.26. Root biomass of grasses were also estimated by cutting the above ground portion with sickle and digging the roots of grasses with spade in an area of 1 m^2 quadrant. Total biomass, the sum of the above and below ground biomass from trees and root biomass of grass is considered for carbon stock.

Total Biomass (TB) = Above Ground Biomass (AGB) + Below Ground Biomass (BGB)

Carbon stock and sequestration

Carbon stock refers to the amount of carbon stored in the forest ecosystem, mainly in living biomass and soil. The total biomass obtained is converted to carbon stock using carbon conversion factor of 0.47.

Biomass carbon stock (tons) = TB × 0.47

The total carbon sequestrated was calculated by adding total biomass carbon stock and carbon sequestrated in soil. The amount carbon stock in soil was determined by multiplying soil weight and carbon content. The carbon accumulated in soil under silvipastoral system was determined by subtracting the quantities of soil carbon stock at the end of experiment and initial value.

***Statistical analysis*:** Data were analysed statistically in RBD design with three replications as per standard procedure (Gomez and Gomez, 1984).

Results and Discussion

Growth and yield of grass under silvipastoral system

Plant height of grass was significantly influenced by all the tree species, i.e. *C. mopane*, *H. binata* and *A. excelsa* (Table 1). Maximum height of *C. ciliaris* was recorded under *H.*

Table 1. Growth and yield of grass affected by trees and the distance from tree in silvipasture system

Tree species	Distance from tree (m)	Grass height (cm)	Fresh weight (q ha^{-1})	Dry weight (q ha^{-1})
C. mopane	1.5	82.67	5.2	1.29
	3.0	82.67	14.4	3.60
	4.5	90.00	36.5	9.12
	Mean	85.11 ±3.81	18.7±4.50	4.67±1.13
	SEm±	2.69	3.18	0.80
	CD (P=0.05)	NS	12.8	3.21
H. binata	1.5	100.67	69.19	17.30
	3.0	100.67	72.87	18.22
	4.5	108.33	102.54	25.63
	Mean	103.22±2.84	81.53±5.60	20.38±2.84
	SEm±	2.09	4.10	2.07
	CD (P=0.05)	NS	16.44	8.3
A. excelsa	1.5	96.67	65.76	15.94
	3.0	103.67	83.72	20.93
	4.5	108.67	97.01	24.75
	Mean	103.00±9.621	82.16±6.76	20.54±2.44
	SEm±	6.803	4.82	1.72
	CD (P=0.05)	NS	19.36	6.89

binata (103.2 cm) whereas least was recorded under *C. mopane* (85.1 cm). The difference in plant height of *C. ciliaris* was due to effect of different growth habit of tree species. *C. mopane* exert more competition due to its branching habits than other species. Further, plant height of *C. ciliaris* was also not affected significantly due to distance from trees however a general increasing trend in plant height of grasses as the distance from the tree increases under all the species of tree. Forage yield of grass was significantly influenced by all the tree species. Fresh forage yield of grass was higher under *H. binata* and *A. excelsa* tree (82 q ha^{-1}) as compared to that of *C. mopane* tree (19 q ha^{-1}). Furthermore, result also shows that highest dry matter accumulation was recorded under *A. excelsa* tree (20.54 q ha^{-1}) whereas least dry matter accumulation was recorded under *C. mopane* tree (4.67 q ha^{-1}). Forage yields of *C. ciliaris* was also affected significantly due to distance from trees in all three species. The yield of grass was more as the distance from the tree increases because the growth of grass was found better as the distance increases. Patidar and Mathur (2017) also reported similar findings. Since, there were least competition between grasses and trees for nutrients and other factors such as light, water etc. as the distance increases. Better growth of the grass promoted the increased production of fresh forage yield and higher dry matter accumulation. Rosecrance *et al.* (1992) also reported that grain yield of maize was decreased only by 10% in the row close to the trees. The yield reduction in close rows was due to shade effect of forage trees. Similar report of dismal performance of under storey forage species after three years may be the result of greater radial growth, spreading of crown and the branching habit of the tree species which interrupted the solar radiation reaching the under storey (Shrinivasan and Swaminathan, 1999).

Growth parameters of different trees under silvipastoral system

All tree species differ in plant height and canopy area. Maximum plant height was recorded for *A. excelsa* (5.20 m) whereas least

Table 2. Growth parameter of different trees under silvipasture system

Tree species	Plant height (m)	Canopy area (m^2)	DBH (cm)	Specific gravity of trees (g cm^{-3})
C. mopane	4.02.2± 0.083	17.2±1.1	19.5±0.80	0.689±0.011
H. binata	4.92.5±0.148	3.8±0.82	10.9±0.61	0.566±0.009
A. excelsa	5.20.6±0.259	11.7±0.93	12.9±0.75	0.365±0.007

Table 3. Biomass production of different silvipasture systems

Silvipasture systems	No. of trees	Area (ha)	AGB of tree (t ha^{-1})	Root biomass of tree (t ha^{-1})	Grass root biomass (t ha^{-1})	Total biomass (t ha^{-1})
C. mopane + *C. ciliaris*	92	0.5	13.51	3.51	0.882	17.90
H. binata + *C. ciliaris*	54	0.5	2.87	0.75	1.30	4.91
A. excelsa + *C. ciliaris*	50	0.5	2.6	0.68	1.18	4.45

were recorded for *C. mopane* (4.02 m) (Table 2). The plants of *A. excelsa* are fast growing as compared *to H. binata* and *C. mopane*. The canopy area and DBH in *C. mopane* was more due to more number of branches. Further, the variation in these growth parameters was higher in *A. excelsa* compared to *H. binata* and *C. mopane*. The specific gravity of *C. mopane* (0.689 g cm^{-3}) was highest whereas it was lowest in *A. excelsa* (0.365 g cm^{-3}). This might be because of the genetic potential of the tree species for its growth habit, branching pattern etc.

Biomass production of an established silvipasture system

Results shows that (Table 3) AGB (Above ground biomass) of *C. mopane* (13.5 t ha^{-1}) was highest among the tree species whereas lowest in *A. excelsa* (2.6 t ha^{-1}). This might be because of the inherent genetic potential of tree species for its growth and development as well as the number of trees in an experimental area have also contributed for the higher AGB production. Results shows that root biomass of *C. mopane* (3.51 t ha^{-1}) was also maximum whereas least were recorded in *A. excelsa* (0.67 t ha^{-1}) which is at par with *H.binata* (0.75 t ha^{-1}). Root biomass of grass grown in association with *H. binata and A. excelsa* was higher as compared to that grown in association with *C. mopane*. The higher root biomass of grass grown in association with *H. binata* and *A. excelsa* was due to better plant growth under these trees as compared to *C. mopane*. However, the total biomass production was higher with the silvipasture system of *C. mopane* due to higher biomass of *C. mopane* plants in the system.

Carbon sequestered in different silvipasture systems

The highest amount of carbon was sequestered by *C. mopane* trees (8.51 t ha^{-1}) and least by *A. excelsa* (1.64 t ha^{-1}) which is quite comparable to *H. binata* (1.81 t ha^{-1}). This might be because more growth and branching of trees of *C. mopane*. Carbon sequestered through the root biomass of grass was higher in *H. binata* (0.65 t ha^{-1}) and *A. excelsa* (0.6 t ha^{-1}) based silvipasture systems as compared to *C. mopane* based system (Fig. 1). It might be because of the better grass growth under *H. binata* and *A. excelsa* system. Soil C sequestration was found highest (2.23 t ha^{-1}) in case of *A. excelsa* based plantation, whereas soil C sequestration was least in *C. mopane*. The variation of SOC in different land use systems could be attributed to differences in quantity and quality of foliage/litter accumulated on the surface, their decomposition pattern and depth of root penetration (Jobbagy and Jackson, 2000; Yadav *et al*., 2008). Total amount of carbon sequestered was maximum with *C. mopane* based system

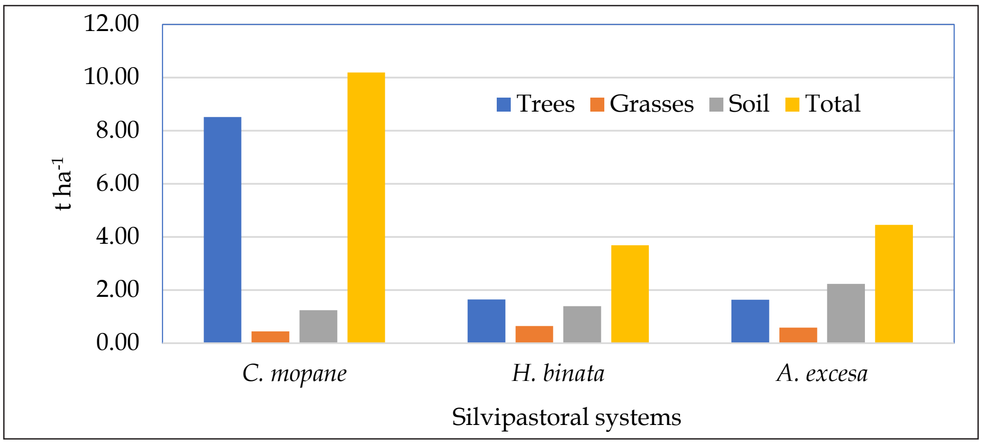

Fig. 1. Carbon sequestered in different silvipasture system.

Table 4. Soil parameters in different silvipasture systems

Treatments	Soil parameters				
	OC %	pH	EC (dS m^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
Tree species					
C. mopane	0.175	8.50	0.068	5.97	195
H. binata	0.182	8.29	0.083	5.60	248
A. excelsa	0.219	8.27	0.086	4.48	240
SEm±	0.007	0.11	0.002	0.09	5.1
CD (P=0.05)	0.024	NS	0.006	0.31	18.0
Distance (m)					
1.5	0.181	8.36	0.069	5.60	210
3.0	0.202	8.48	0.089	5.60	251
4.5	0.192	8.22	0.078	4.85	221
SEm±	0.007	0.09	0.006	0.32	11.8
CD (P=0.05)	NS	NS	NS	NS	NS

(10.19 t ha^{-1}) followed by *A. excelsa* (4.45 t ha^{-1}) and *H. binata* (3.69 t ha^{-1}) based silvipasture systems.

Soil carbon content and other soil properties

Results show that soil carbon content varied significantly in different silvipasture systems (Table 4). The maximum organic carbon content was recorded from *A. excelsa* (0.219%) based silvipasture system followed by *H. binata* (0.182%) and *C. mopane* (0.175%). Low organic carbon content in the soil under *C. mopane* based systems was due to poor grass growth. There might be a chance of allelopathic effect by the roots of these trees which might not have favoured the growth of grass. *A. excelsa* and *H. binata* had less competition for light penetration which favoured better grass growth. This shows that there is direct correlation between growth of grass and improvement in the soil organic carbon. The effect of distance of trees on soil organic carbon content in different silvipasture systems was found non-significant. The other soil properties such as EC, available P and K of soil except pH were significantly affected by tree species under the established silvipasture system. This variation was due to the individual effect of tree, however, distance from tree did not affect these parameters in the soil of different silvipasture systems.

Conclusion

In the arid region of Rajasthan, the adoption of silvipasture appears to be a sustainable land use management practice that preserves and increases soil C pools. We can expect significant gains in SOC in the future resulting from remaining *H. binata*, *C. mopane* and *A. excelsa* stumps and coarse roots decomposition. The above ground below ground C pools ratio showed the preponderance of C pools below ground. Besides the higher stem density in the plantation, the synergistic effect resulting from the combination of trees and pasture led to more C being sequestered in the silvipasture soil. Thus these silvipastoral systems allow the farmer to obtain multiple products from the same area of land, timber, fodder and grazing along with increasing carbon sequestration.

References

Albrecht, A. and Kandji, S.T. 2003. Carbon sequestration in tropical agroforestry systems. *Agriculture, Ecosystems and Environment* 99: 15-27

Baker, T.R., Phillips, O.L and Malhi, Y. 2004. Variation in wood density determines spatial patterns in Amazonian forest biomass. *Global Change Biology* 10: 545-562.

Chave Jerome, Maxime Rejou Mechain, Alberto burquez, Emmanuel chidumayo, Matthew, S. C., Welington, B.C., Delitti Alvaro duque, Tron Eid, Philip M. Fearnside, Rosa C. Goodman, Matieu Henry, Angelina Martinez-Yrizar, Wilson, A. Mugasha, Helene, C. Mullerlandau, Maurizio Mencuccini1, Bruce, W. Nelson, Alfred Ngomanda, Euler M. Nogueira, Edgar Ortiz-Malavassi, Rapha€el P Elissier, Pierre Ploton, Casey M. Ryan, Juan G. Saldarriaga and Ghislain Vieilledent 2014. Improved allometric models to estimate the aboveground biomass of tropical trees. *Global Change Biology* doi: 10.1111/gcb.12629

Dhurvanarayan, V.V. 1993. Land capability classification. In: Soil and Water Conservation

Research in India. Indian Council of Agricultural Research, New Delhi. pp. 57-61.

Gomez, K.A. and Gomez, A.A. 1984. *Statistical procedures for agricultural research* (2nd Ed.). John Wiley and Sons, New York. p. 680.

Hangarge, L.M.D.K., Kulkarni, V.B., Gaikwad, D.M., Mahajan and Chaudhari, N. 2012. Carbon Sequestration potential of tree species in Somjaichi Rai (Sacred grove) at Nandghur village, in Bhor region of Pune District, Maharashtra State, *India Annals of Biological Research* 3(7): 3426-3429.

Jackson, M.L. 1958. *Soil Chemical Analysis*. Prentice-Hall, Englewood Cliffs, New Jersey.

Jobbagy, E.G. and Jackson, R.B. 2000. The vertical distribution of soil organic carbon in relation to climate and vegetation. *Ecological Applications* 10: 423-436.

MacDicken, K.G., Wolf, G.V. and Briscoe, C.B. 1991. *Standard Research Methods for Multi-purpose Trees and Shrubs*. Multi-purpose Tree Species Network Research Series. Winrock International Institute for Agricultural Development and ICRAF.

Montagnini, F., Nair, P.K.R. 2004. Carbon sequestration: an underexploited environmental benefit of agroforestry systems. *Agroforestry Systems* 61-62(1-3): 281-295.

Nair, P.K.R., Nair, V.D., Kumar, B.M., Showalter, J.M. 2010. Carbon sequestration in agroforestry systems. *Advances in Agronomy* 108: 237-307.

Oelbermann, M., Voroney, R.P., Gordon, A.M. 2004. Carbon sequestration in tropical and temperate agroforestry systems: A review with examples from Costa Rica and Southern Canada. *Agriculture, Ecosystems and Environment* 104: 359-377.

Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L.A. 1954. Estimation of available phosphorus in soils by extraction with $NaHCO_3$, USDA Cir. 939. Washington, U.S.

Patidar, M. and Mathur, B.K. 2017. Enhancing forage production through a silvi-pastoral system in an arid environment. *Agroforestry Systems* 91(4): 713-727.

Rai, P. 2008. Management of arid rangelands. In: *Diversification of Arid Farming Systems* (Eds. P. Narain, M.P. Singh, Amal Kar, S. Khatju and Parveen-Kumar), pp. 79-102. AZRAI and Scientific Publishers (India), Jodhpur.

Rosecrance, R.C., Brewabaker, J.I. and Fowens, J.H. 1992. Alley cropping of maize with nine leguminous trees. *Agroforestry Systems* 17:159-168.

Shrinivasan, K. and Swaminathana, C. 1999. Comparative performance of *Cenchrus* legumes mixtures as under storey in *Acacia leucophloea* for silivipasture. *Tropical Agriculture* 76 (14): 232-35.

Sidhu, G.S., Rana, K.P.C., Lal, T., Mahapatra, S.K., Verma, T.P. and Rao, R.V.S. 2007. Soils of Himachal Pradesh: land capability classification and assessment of soil degradation status for suggested land use. *Journal of the Indian Society of Soil Science* 55(3): 335-339.

Yadav, B.S., Yadav, B.L. and Chhipa, B.R. 2008. Litter dynamics and soil properties under different tree species in a semi-arid region of Rajasthan, India. *Agroforestry Systems* 73: 1-12.

Printed in September 2023