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Research Paper

Effect of pruning and grasses on forage productivity, carbon storage, soil health and economics of Anjan tree (*Hardwickia binata*) based silvopasture systems

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ABSTRACT

A field experiment was conducted during 2018 to 2023 on ten years old *Hardwickia binata* Roxb. based silvopasture system at Indian Grassland and Fodder Research Institute, Jhansi. The treatment consisted of three pruning intensities of *H. binata*, viz. 30%, 45% and 60% and establishment of three grasses, viz. *Cenchrus ciliaris, Chrysopogon fulvus* and *Panicum maximum* in association with *H. binata*. Pruning of branches of *H. binata* at 60% intensity recorded significantly higher top feed (TF 1.48, 1.77, 2.23, 2.68 and 3.27 t/ha) and fire wood yields (FW 2.74, 3.17, 3.49, 3.79 and 4.65 t/ha) as compared to 30% pruning intensity (TF 0.93, 1.01, 1.19, 1.55 and 2.08 t/ha and FW 1.76, 1.90, 1.98, 2.26 and 2.84 t/ha) and 45% pruning intensity (TF 1.21, 1.41, 1.75, 2.15 and 2.59 t/ha and FW 2.33, 2.59, 2.82, 3.08 and 3.63 t/ha) during 1st, 2nd, 3rd, 4th and 5th years of study, respectively. Among grasses, establishment of *C. fulvus* in association with *H. binata* recorded significantly higher dry pasture yields (7.91, 8.33, 8.66, 8.93 and 9.18 t/ha) as compared to *P. maximum* (6.19, 6.37, 6.54, 7.08 and 7.41 t/ha) and it was found at par with *C. ciliaris* (7.62, 8.15, 8.44, 8.70 and 8.86 t/ha) during 1st, 2nd, 3rd, 4th and 5th years of study. Establishment of *H. binata* based silvopasture systems on poor shallow soil and degraded land recorded 9.11-15.50% improvement in available nutrients (N : 12.73%, P : 15.50% and K : 9.11%) and organic carbon (OC 9.47%) in 5th year of experiment than initial year (N 229.39, P 8.32 and K 214.73 kg/ha and OC 0.584%. Similarly, *H. binata* recorded 111.31% higher carbon stock in 5th year of study (23.04 t/ha) as compared to initial year (10.90 t/ha). In term of monetary return, maximum net return and benefit-cost ratio was obtained from 60% pruning intensity (₹ 63459/ha and 2.08) followed by 45% pruning intensity (₹ 50263/ha and 1.91) from *H. binata* based silvopasture system.

Key words: Carbon storage, *Cenchrus ciliaris, Chrysopogon fulvus,* Forage productivity *Hardwickia binata, Panicum maximum,* Pruning intensities, Silvopasture systems

Establishment of silvopasture systems on degraded lands in hot arid and semiarid regions where erratic rainfall and recurrent drought is the common phenomenon can play an important role of bridging the gap in fodder supply during lean period of the year, enhancing fodder availability, boost carbon and nutrient in soil and checking soil erosion (Soni *et. al.,* 2013; Sharma, 2014 and Verma *et al*., 2023). In silvopasture systems grasses provide green forage during monsoon season and trees provide top feed during winter and summer seasons (Kumar *et al*., 2017). In silvopasture systems, canopy management of tree components is essential to obtain a sustained yield of under-storey pasture, top feed and quality wood. Without proper pruning management, trees develop greater taper and larger side branches which provide more shade to under-storey pasture and decrease their productivity and also taper development of trees and larger side branches produce larger knots on the stems and reduce the wood quality (Rosso and Ninin 1998). Canopy management in silvopasture systems also alleviate shade and facilitate penetration of light to under-storey pasture which improve the growth of pasture components than unpruned trees (Thakur and Sehgal, 2000; Dar and Newaj 2007). Light availability is the most important limiting factor for the performance of under-storey pasture in silvopasture systems particularly where upper storey perennial forms a dense cover storey canopy (Miah *et al*., 1995).

Apart from forage production, silvopasture systems have the potential to offer many ecosystem services. Global climate change caused by rising levels of carbon dioxide and other greenhouse gases are recognized as a serious environmental issue of the twenty-first century. Between

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2000 and 2010, the atmospheric carbon dioxide has increased from 369 to 388 ppm, a 5.1% increase over the last 10 years, let alone 280 ppm in 1850 (Tans *et al*., 2010). Removal of carbon from atmosphere and storing it in the terrestrial vegetation is one of climate change mitigation options, which compensate the greenhouse gas emission. Grasses are a major sink of carbon and could absorb large quantities of carbon if trees are included with grasses and judiciously managed together in the form of silvopasture systems. Thus, silvopasture systems plays an important role in sustainable production through nutrient cycling, soil and water conservation, microclimate modification and sequestrating carbon in the form of wood which considered as potent instrument against climate change mitigation. Evidences are now emerging that silvopasture systems are promising land use system to increase above-ground and soil carbon stock to mitigate greenhouse gas emissions. In India, average sequestration potential in agroforestry has been estimated to be 25 t C per ha over 96 million ha (Sathaye and Ravindranath, 1998) but there is considerable variation in different regions depending upon biomass production. The role of land use systems in stabilizing the carbon dioxide levels and increasing the carbon sink potential has attracted considerable scientific attention in the recent past, especially after the Kyoto Protocol (IPCC, 2007). However, in addition to production aspects, there is also a need to quantify the ecosystem services in terms of carbon storage potential, for reducing carbon emissions for climate change mitigation. In view of this the present study was carried out to study the effect of pruning intensities and grasses on forage productivity, carbon storage, soil health and economics of Anjan tree based silvopasture systems in semiarid rainfed conditions.

MATERIALS AND METHODS

A field experiment was conducted during 2018 to 2023 on ten years old *Hardwickia binata* based silvopasture system at Central Research Farm ($25^0 27'$ N latitude, $78^0 37'$ E longitude and 275 m above mean sea level) of Indian Grassland and Fodder Research Institute, Jhansi to study the effect of pruning intensities and grasses on forage productivity, carbon storage, soil health and economics of Anjan tree based silvopasture systems in semiarid rainfed conditions. The soil of the experimental field was sandy loam, low in available nitrogen and phosphorus and medium in available potash and organic carbon (Table 6). The region receives an annual rainfall of 906.5 mm and annual potential evapotranspiration of 1512 mm (Singh *et al*., 2007). The total rainfall received was 1054.6, 714.2, 786.5, 816.8 and 1031.0 mm in 43, 54, 45, 33 and 67 rainy days during 2018, 2019, 2020, 2021 and 2022 respectively.

There were 9 treatment combinations replicated thrice in factorial randomized block design. The treatment consisted of three pruning intensities of *H. binata* viz. 30%, 45% and 60% and establishment of three grasses viz. *Cenchrus ciliaris, Chrysopogon fulvus* and *Panicum maximum* in association with *H. binata*. Green crown length of trees were pruned once every year as per treatments during winter season. *H. binata* trees were uniformly established in all the experimental plots at 6 m x 6 m spacing and grasses were established in association with *H. binata* at 50 cm x 50 cm spacing.

Pruned yields of *H. binata* were recorded every year as per treatments during winter season. Grasses were harvested by tractor operated side reaper at 15 cm above the ground surface in second fortnight of September in each year. Fodder yields of grasses were recorded at the time of harvesting. Dry fodder yields were recorded in each plot on the basis of per square meter area and values were converted into tonne/ha. Dry matter yields were computed by drying 500 g plant sample of each treatment and replication in hot-air oven at 70^0C.

The light transmission by the canopy of the *H. binata* under different pruning regimes and grass combinations was measured by using canopy analyzer. The light intensity above canopy (I_0) and at the ground level (I) was recorded between 12:30 and 1:00 pm. Light transmission ratio was calculated by the following formula. Measurements were conducted consequently in the month of August in each year. The light interception was measured above a canopy and beneath a canopy of different range grasses near solar noon when the light is unobstructed by cloud cover (Board *et al*., 1992).

Tree, grass, litter, soil and total carbon stock was estimated under various pruning regimes and grasses. Carbon stock in *H. biñata* trees was calculated based upon dry matter content of the tree which was calculated for various parts of *H. binata* tree using allometric equations given by Newaj *et al.,* (2014). Total dry matter of *H. binata* tree was calculated by adding dry matter of tree bole, branches, leaves and roots. The total carbon stock in tree was determined by multiplying respective dry matter of various parts with their carbon content as given by Newaj *et al*., (2014) and then adding up the carbon stock of all the parts. The carbon stock was then calculated per hectare basis based on the tree density (278 trees/ha). In grasses, above and below ground carbon stock was calculated by multiplying above and below ground dry biomass per hectare basis with conversion factor of 0.50 (IPCC, 2006). Similarly, litter carbon stock was estimated by multiplying litter dry biomass per hectare basis with conversion factor of 0.50 (IPCC, 2006). Total system carbon stock in *H. binata* based silvopasture was determined by adding carbon stock of tree, grasses and soil per hectare basis. Soil organic car-

Table 1. Formula and Allometric equations used during study

Formula & Allometric equations used		Reference
$$LTR\,(\%) = \frac{I}{I_0} \times 100$$		Board *et al*., 1992
Where, I = Light intensity received at the ground level		
I0 = Light intensity received at the top of grass canopy		
Tree components	Allometric equations	Newaj *et al.,* 2014
Bole	$0.232\,(DBH)^{2.046}$	
Branch	$0.002\,(DBH)^{3.142}$	
Leaves	$0.0002\,(DBH)^{3.514}$	
Root	$0.036\,(DBH)^{2.337}$	
Soil Organic Carbon stock = [Soil bulk density (g cm^{-3}) x Soil depth (cm) x Carbon (%)] x 100.		Nelson and Sommers (1996)

bon stock was determined up to 30 cm depth using equation given by Nelson and Sommers (1996). Soil organic carbon percentage was calculated using Walkley and Black (1934) method and soil bulk density was determined using a specific gravity method given by Singh (1980). The data obtained from the experiment were statistically analysed using the F-test.

RESULTS AND DISCUSSION

Growth parameters of H. binata

Pruning of branches of *H. binata* at 60% intensity attained the maximum height (9.16, 9.83, 10.37 and 11.05 m) followed by 45% pruning intensity (8.93, 9.55, 10.02 and 10.65 m) during 2nd, 3rd, 4th and 5th years of study, respectively (Table 2). While, collar diameter (23.92 cm and 25.64 cm) and diameter at breast height (19.05 cm and 20.57 cm) of *H. binata* were higher with 30% pruning intensity as compared to 45% pruning intensity (CD 23.62 cm and 25.26 cm and dbh 18.80 cm and 20.21 cm) and 60% pruning intensity (CD 23.40 cm and 24.96 cm and dbh 18.63 cm and 19.73 cm) during 4th and 5th years of experiment, respectively. Similarly, canopy spread was also significantly higher with 30% pruning intensity (4.57, 4.93 and 5.19 m) as compared to 45% pruning intensity (4.31, 4.63 and 4.81 m) and 60% pruning intensity (4.15, 4.41 and 4.3 m) during 3rd, 4th and 5th years of study respectively. Similar result was also reported by Viquez and Perez (2005). However, establishment of different grasses in association with *H. binata* did not significantly affect the growth parameters of *H. binata* during different years.

Top feed and fire wood yields of H. binata

The 60% pruning intensity of branches of *H. binata* recorded significantly higher top feed (TF 1.48, 1.77, 2.23, 2.68 and 3.27 t/ha) and fire wood yields (FW 2.74, 3.17, 3.49, 3.79 and 4.65 t/ha) as compared to 30% pruning intensity (TF 0.93, 1.01, 1.19, 1.55 and 2.08 t/ha and FW 1.76, 1.90, 1.98, 2.26 and 2.84 t/ha) and 45% pruning intensity (TF 1.21, 1.41, 1.75, 2.15 and 2.59 t/ha and FW 2.33, 2.59, 2.82, 3.08 and 3.63 t/ha) during 1st, 2nd, 3rd, 4th and 5th years of study, respectively (Table 3). Biomass production is directly correlated with pruning intensity. Hence, severely pruned trees tended to produce more biomass as compared to lightly pruned trees. The reason is that more foliage was removed in 60% pruning intensity which increased the pruned biomass. Similar results have also been reported by Zeng (2001) and Palsaniya *et al.;* (2012). Pruning results in usage of stored reserve for its growth and production of leaves this happened because of the exposure of pruned portion to sunlight and the dormant buds become active and sprouted into shoots with the available reserves present in the trees (Muhamad and Paudyal, 1992). However, top feed and fire wood yields of *H. binata* also did not affected significantly by establishment of different grasses in association with *H. binata*.

Pasture yield

Pruning of branches of *H. binata* at 60% intensity also recorded significantly higher pasture yields (7.99, 8.40, 8.99 and 9.50 t/ha) as compared to 30% pruning intensity (7.19, 7.27, 7.38 and 7.60 t/ha) and 45% pruning intensity (7.67, 7.95, 8.33 and 8.36 t/ha) during 2nd, 3rd, 4th and 5th years respectively. Rai (2006) also found that pruning of *Acacia nilotica* and *Dalbergia sissoo* up to 50% height gave higher dry forage yield of *C. fulvus* as compared to unpruned trees in silvopasture systems. Higher biomass production under pruned treatments might be due the fact that pruning of trees facilitated more light to under-storey pasture which resulted into higher growth and yield. Light availability is the most important limiting factor for the performance of under storey pasture in silvopasture systems particularly where upper storey perennial forms a dense cover storey canopy (Miah *et al*., 1995). Among grasses, establishment of *C. fulvus* in association with *H. binata* recorded significantly higher dry pasture yields (7.91, 8.33, 8.66, 8.93 and 9.18 t/ha) as compared to

Table 2. Effect of pruning intensity and grasses on growth parameters of *H. binata*

Treatment	Height (m)					Collar diameter (cm)					Diameter at breast height (cm)					Canopy spread (m)				
	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5
Pruning (%)																				
30	8.08	8.59	9.16	9.55	10.08	18.13	20.47	22.21	23.92	25.64	14.61	16.30	17.75	19.05	20.57	3.76	4.10	4.57	4.93	5.19
45	7.90	8.93	9.55	10.02	10.65	17.93	20.29	22.16	23.62	25.26	14.45	16.18	17.60	18.80	20.21	3.69	3.92	4.31	4.63	4.81
60	8.05	9.16	9.83	10.37	11.05	18.16	20.18	21.89	23.40	24.96	14.62	16.10	17.49	18.63	19.73	3.80	3.82	4.15	4.41	4.53
SEm±	0.07	0.09	0.08	0.09	0.11	0.09	0.11	0.13	0.16	0.13	0.06	0.09	0.11	0.11	0.17	0.05	0.06	0.07	0.07	0.08
CD (P=0.05)	NS	0.26	0.25	0.26	0.34	NS	NS	NS	0.47	0.39	NS	NS	NS	0.33	0.52	NS	NS	0.20	0.21	0.24
Grasses																				
C. ciliaris	7.97	8.80	9.49	9.96	10.56	18.01	20.29	22.15	23.63	25.26	14.52	16.18	17.59	18.81	20.16	3.71	3.94	4.33	4.64	4.83
C. fulvus	8.13	9.00	9.66	10.10	10.74	18.21	20.46	22.26	23.81	25.45	14.66	16.30	17.74	18.95	20.33	3.83	4.00	4.41	4.74	4.94
P. maximum	7.94	8.87	9.39	9.88	10.49	17.99	20.18	21.85	23.50	25.14	14.51	16.11	17.50	18.72	20.04	3.70	3.91	4.28	4.59	4.77
SEm±	0.07	0.09	0.08	0.09	0.11	0.09	0.11	0.13	0.16	0.13	0.06	0.09	0.11	0.11	0.17	0.05	0.06	0.07	0.07	0.08
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 3. Effect of pruning intensity and grasses on dry pasture, top feed and fire wood yields of *H. binata* based silvopasture systems

Treatment	Pasture yield (t/ha)					Top feed (t/ha)					Fire wood (t/ha)				
	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5
Pruning (%)															
30	7.12	7.19	7.27	7.38	7.60	0.93	1.01	1.19	1.55	2.08	1.76	1.90	1.98	2.26	2.84
45	7.37	7.67	7.95	8.33	8.36	1.21	1.41	1.75	2.15	2.59	2.33	2.59	2.82	3.08	3.63
60	7.23	7.99	8.40	8.99	9.50	1.48	1.77	2.23	2.68	3.27	2.74	3.17	3.49	3.79	4.65
SEm±	0.11	0.11	0.13	0.14	0.16	0.05	0.05	0.06	0.08	0.10	0.10	0.10	0.14	0.15	0.17
CD (P=0.05)	NS	0.32	0.39	0.42	0.47	0.16	0.16	0.19	0.24	0.32	0.30	0.29	0.42	0.46	0.52
Grasses															
C. ciliaris	7.62	8.15	8.44	8.70	8.86	1.19	1.39	1.72	2.13	2.62	2.25	2.53	2.74	3.03	3.69
C. fulvus	7.91	8.33	8.66	8.93	9.18	1.25	1.45	1.81	2.20	2.76	2.37	2.67	2.92	3.16	3.83
P. maximum	6.19	6.37	6.54	7.08	7.41	1.17	1.34	1.64	2.06	2.56	2.21	2.46	2.64	2.95	3.60
SEm±	0.11	0.11	0.13	0.14	0.16	0.05	0.05	0.06	0.08	0.10	0.10	0.10	0.14	0.15	0.17
CD (P=0.05)	0.33	0.32	0.39	0.42	0.47	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

P. maximum (6.19, 6.37, 6.54, 7.08 and 7.41 t/ha) and it was found at par with *C. ciliaris* (7.62, 8.15, 8.44, 8.70 and 8.86 t/ha) during 1st, 2nd, 3rd, 4th and 5th years respectively. The higher pasture yields of *C. fulvus* and *C. ciliaris* was due to their adequate plant stands and dense vegetative growth over the years as compared to *P. maximum* under semiarid rainfed condition.

Sustainable yield index

The 60% pruning intensity of branches of *H. binata* also recorded higher sustainability yield index (0.56) than 45% pruning intensity (0.52) and 30% pruning intensity (0.44) which showed that total productivity of the system obtained from 60% pruning intensity of *H. binata* was more stable over the years than 45% and 30% pruning intensity (Table 6). Similarly, sustainable yield index of *C. fulvus* was the maximum (0.54) closely followed by *C. ciliaris* (0.52) which indicated that *C. fulvus* and *C. ciliaris* were produced more stable yields over the years than *Panicum maximum* (0.45) under semiarid rainfed condition.

Light transmission ratio

Pruning of branches of *H. binata* at 60% intensity recorded significantly higher light interception (41.98, 40.01, 40.53 and 39.47%) as compared to 30% pruning intensity (25.59, 23.81, 32.77 and 24.07%) and 45% pruning intensity (33.79, 31.90, 24.78 and 30.32%) during 2nd, 3rd, 4th and 5th years of study, respectively (Table 4). The higher light interception under 60% pruning intensity may be attributed due to lower canopy spreads of the trees which leads to more penetration of the light to the under-storey pastures. However, different grasses did not significantly affect the light transmission in *H. binata* based silvopasture systems.

Carbon stock of H. binata

Carbon stock of *H. binata* was non-significantly affected by different pruning intensities and grasses in 1st year of study (Table 5). However, in 5th year of experiment 30% pruning intensity of branches of *H. binata* recorded significantly higher carbon stock (24.11 t/ha) as compared to 60% pruning intensity (21.88 t/ha). The decrease in carbon stock of *H. binata* with 60% pruning intensity in 5th year was might be due to decrease in diameter at breast height with continuous pruning at severe intensity which resulted in lower biomass production and ultimately carbon stock. *H. binata* recorded 111.31% higher carbon stock in 5th year of study (23.04 t/ha) as compared to initial year (10.90 t/ha). Carbon storage by trees is basically a function of their dry biomass production and tissue carbon concentration (Nair *et al.,* 2009).

Table 4. Effect of pruning intensity and grasses on transmitted radiation and light transmission ratio (LTR) in *H. binata* based silvopasture system

Treatment	Year 1			Year 2			Year 3			Year 4			Year 5		
	Transmitted radiation (Lux)		LTR (%)	Transmitted radiation (Lux)		LTR (%)	Transmitted radiation (Lux)		LTR (%)	Transmitted radiation (Lux)		LTR (%)	Transmitted radiation (Lux)		LTR (%)
	Upper	Lower		Upper	Lower		Upper	Lower		Upper	Lower		Upper	Lower	
Pruning (%)															
30	1282.04	320.90	25.15	1397.42	356.77	25.59	1339.73	318.83	23.81	1370.57	337.79	24.78	1380.56	332.79	24.07
45	1297.72	409.31	31.49	1414.51	477.32	33.79	1356.12	433.32	31.90	1387.08	451.93	32.77	1404.08	425.93	30.32
60	1305.67	416.25	31.86	1423.18	596.34	41.98	1364.43	546.36	40.01	1395.45	564.62	40.53	1430.45	564.62	39.47
SEm±	24.94	13.84	2.28	27.18	9.41	1.51	26.06	8.94	1.31	28.36	8.92	1.15	22.50	8.98	0.42
CD (P=0.05)	NS	NS	NS	NS	27.75	4.49	NS	26.64	3.89	NS	26.97	3.46	NS	27.17	1.26
Grasses															
C. ciliaris	1306.40	421.75	32.27	1423.98	467.79	32.95	1365.19	424.27	31.01	1396.22	442.90	31.58	1404.95	439.57	31.16
C. fulvus	1337.91	444.05	33.17	1458.32	495.93	34.05	1398.12	450.99	32.29	1429.38	469.54	32.97	1413.91	453.21	31.94
P. maximum	1241.12	417.68	3.59	1352.82	466.72	34.29	1296.97	423.25	32.59	1327.50	441.89	33.54	1396.23	430.56	30.76
SEm±	24.94	13.84	2.28	27.18	9.41	1.51	26.06	8.94	1.31	28.36	8.92	1.15	22.50	8.98	0.42
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Carbon stock of grasses

Pruning of branches of *H. binata* at 60% intensity significantly increased carbon stock of grasses (6.22 t/ha) as compared to 30% pruning intensity (4.98 t/ha) and 45% pruning intensity (5.49 t/ha) in 5th year of study (Table 5). The higher carbon stock under 60% pruning intensity was due to higher biomass yields of grasses with 60% pruning intensity as compared to 30% and 45% pruning intensity. Among grasses, *C. ciliaris* recorded significantly higher carbon stock (5.57 and 6.28 t/ha) as compared to *C. fulvus* (5.03 and 5.93 t/ha) and *P. maximum* (3.68 and 4.49 t/ha) in both initial and 5th years of experiment. The higher carbon stock of *C. ciliaris* was due to higher root-shoot ratio of *C. ciliaris* as compared to *C. fulvus* and *P. maximum*.

Litter carbon stock

30% pruning intensity of branches of *H. binata* also significantly increased litter carbon stock (0.88 and 2.10 t/ha) as compared to 45% pruning intensity (0.77 and 1.90 t/ha) and 60% pruning intensity (0.66 and 1.62 t/ha) during 1st and 5th years respectively. This may be also due higher litter biomass recorded under 30% pruning intensity of *H. binata* as compared to 45% and 60% pruning intensity. Litter carbon stock was not significantly affected by different grasses in 1st year of study (Table 5). However, in 5th year of experiment *C. fulvus* recorded significantly higher litter carbon stock (1.99 t/ha) as compared to *P. maximum* (1.74 t/ha) and it was found at par with *C. ciliaris* in association with *H. binata* (1.89 t/ha) during 5th year. This was might be due to higher litter biomass addition in soil under *C. fulvus* as compared to *P. maximum* which also resulted in higher litter carbon stock.

Soil carbon stock

Soil carbon stock was also significantly increased with 30% pruning intensity of branches of *H. binata* (26.88 t/ha) as compared to 45% pruning intensity (25.31 t/ha) and 60% pruning intensity (22.90 t/ha) in 5th year of experiment. This may be also due higher litter biomass addition in soil with 30% pruning intensity of branches of *H. binata* as compared to 45% and 60% pruning intensity. *C. fulvus* resulted in significantly higher soil carbon stock (22.99 and 25.80 t/ha) as compared to *P. maximum* (21.92 and 24.41 t/ha) and it was found at par with *C. ciliaris* (22.11 and 24.88 t/ha) during 1st and 5th years respectively. This was might be due to higher litter biomass addition in soil under *C. fulvus* as compared to *P. maximum* which also resulted in higher soil carbon stock.

Total carbon stock

Pruning intensities of branches of *H. binata* did not significantly affect the carbon stock of *H. binata* based silvopasture system in 1st year of experiment (Table 5). However, during 5th year 30% pruning intensity of branches of *H. binata* recorded significantly higher total carbon stock of the system (55.97 t/ha) as compared to 60% pruning intensity (51.00 t/ha). This may be also due higher litter biomass addition in soil under 30% pruning intensity of branches of *H. binata* as compared to 45% and 60% pruning intensity. Total carbon stock of the systems was also maximum under *C. fulvus* in association with *H. binata* (39.29 and 55.18 t/ha) followed by *C. ciliaris* (38.51 and 54.16 t/ha) and *P. maximum* (36.20 and 51.56 t/ha) during 1st and 5th years respectively. This was might be due to higher biomass production and higher litter addition in soil under *C. fulvus* as compared to *P. maximum* which resulted in higher total carbon stock of the systems.

Soil health

Pruning of branches of *H. binata* found non-significant

Table 5. Carbon stock (t/ha) in *H. binata* based silvopasture systems as influenced by pruning intensity and grasses

Treatment	Year 1					Year 5				
	HBCS	GCS	LCS	SCS	TCS	HBCS	GCS	LCS	SCS	TCS
Pruning (%)										
30	10.98	4.68	0.88	21.85	37.51	24.11	4.98	2.10	26.88	55.97
45	10.72	4.84	0.77	22.93	38.49	23.13	5.49	1.90	25.31	53.94
60	11.01	4.75	0.66	22.24	38.00	21.88	6.22	1.62	22.90	51.00
SEm±	0.11	0.07	0.03	0.38	0.48	0.46	0.10	004	0.49	0.62
CD (P=0.05)	NS	NS	0.08	NS	NS	1.39	0.31	0.13	1.48	1.88
Grasses										
C. ciliaris	10.83	5.57	0.78	22.11	38.51	22.99	6.28	1.89	24.88	54.16
C. fulvus	11.06	5.03	0.80	22.99	39.29	23.46	5.93	1.99	25.80	55.18
P. maximum	10.81	3.68	0.74	21.92	36.20	22.67	4.49	1.74	24.41	51.56
SEm±	0.11	0.07	0.03	0.38	0.48	0.46	0.10	004	0.49	0.62
CD (P=0.05)	NS	0.22	NS	1.14	1.44	NS	0.31	0.13	NS	1.88

HBCS- *H. binata* carbon stock, GCS-Grasses carbon stock, LCS- Litter carbon stock, SCS-Soil carbon stock, TCS-Total carbon stock

Table 6. Effect of pruning intensities and grasses on soil health, net return, benefit-cost ratio and sustainability yield index of *H. binata* based silvopasture systems

Treatment	Year 1				Year 5				Year 5		Sustainability yield index
	Available nutrients (kg/ha)			OC (%)	Available nutrients (kg/ha)			OC (%)	Net return (₹/ha)	Benefit-cost ratio	
	N	P	K		N	P	K				
Pruning (%)											
30	225.19	8.21	211.03	0.571	271.56	9.96	245.61	0.688	39005	1.76	0.44
45	235.81	8.46	219.39	0.601	260.31	9.66	235.65	0.647	50263	1.91	0.52
60	227.17	8.29	213.78	0.581	243.89	9.21	221.61	0.584	63459	2.08	0.56
SEm±	4.31	0.14	4.08	0.008	4.71	0.17	4.40	0.013	1643	0.03	0.01
CD (P=0.05)	NS	NS	NS	NS	14.24	0.52	13.31	0.038	4968	0.09	0.02
Grasses											
C. ciliaris	226.77	8.26	212.57	0.581	257.19	9.57	233.37	0.637	49869	1.89	0.52
C. fulvus	238.55	8.54	221.78	0.601	266.71	9.78	240.39	0.660	53226	1.93	0.54
P. maximum	222.84	8.16	209.85	0.571	251.85	9.48	229.11	0.621	49633	1.92	0.45
SEm±	4.31	0.14	4.08	0.008	4.71	0.17	4.40	0.013	1643	0.03	0.01
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.02

for available nutrients and organic carbon in *H. binata* based silvopasture system in 1st year of experiment (Table 6). However, in 5th year of study available nitrogen (271.56 kg/ha), phosphorus (9.96 kg/ha), potash (245.61 kg/ha) and organic carbon (0.688%) were significantly increased with 30% pruning intensity of branches of *H. binata* as compared to 60% pruning intensity (N 243.89 kg/ha, P 9.21 kg/ha, K 221.61 kg/ha and OC 0.584%). This may be due higher litter biomass addition in soil under 30% pruning intensity of branches of *H. binata* as compared to 60% pruning intensity. Establishment of *H. binata* based silvopasture systems on poor shallow soil and degraded land recorded 9.11–15.50% improvement in available nutrients and organic carbon (N 12.73%, P 15.50% and K 9.11% and OC 9.47%) in 5th year of experiment than initial year (N 229.39, P 8.32 and K 214.73 kg/ha and OC 0.584%.). Meena *at al*. (2023) also reported increase in organic carbon with diversified food and fodder based cropping systems over initial year. However, establishment of different grasses did not significantly affect available nutrients and organic carbon content in *H. binata* based silvopasture systems in initial and 5th years of the study.

Economics of treatments

In term of monetary return, *H. binata* based silvopasture system gave net returns ₹50,909/ha and benefit: cost ratio 1.92. Pruning of branches of *H. binata* at 60% pruning intensity recorded the maximum net return (₹63,459/ha) and benefit: cost ratio (2.08) followed by 45% pruning intensity (₹50,263/ha and 1.91) and 30% pruning intensity (₹39,005/ha and 1.76) from *H. binata* based silvopasture system (Table 6). The higher net return and benefit-cost ratio obtained from 60% pruning intensity was mainly due to higher under-storey pasture, top feed and fire wood yields recorded under 60% pruning intensity. However, net return and benefit-cost ratio was not significantly affected by establishment of different grasses in association with *H. binata*.

Based on the results it can be concluded that 60% pruning intensity of branches of *H. binata* recorded higher light interception, production from under-storey pasture and top feed components, economic return and sustainability yield index as compared to 30% and 45% pruning intensity in silvopasture systems. However, carbon stock and nutrients and organic carbon build up in soil were higher under 30% pruning intensity in *H. binata* based silvopasture systems. Among grasses, *C. fulvus* recorded the maximum forage production, economic return, sustainability yield index, carbon stock, available nutrients and organic carbon in soil followed by *C. ciliaris* and *P. maximum* under semi-arid rainfed conditions. *H. binata* being straight growing, hardy and deep rooted, proved to be a potential tree suitable for silvopasture system on degraded lands in rainfed areas of semiarid region. Thus, *H. binata* based silvopasture system is an ideal alternate land-use option for degraded lands for higher forage production, economic return, sustainability yield index, carbon stock and nutrients and organic carbon build up in soil under semi-arid rainfed situation.

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