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Research Paper

Performance of anjan tree (*Hardwickia binata*)-based silvopasture systems under moisture-conservation practices in semi-arid conditions

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ABSTRACT

A field experiment was conducted during 2013–2018 on 5-year-old anjan (*Hardwickia binata* Roxb.)-based silvopasture system at the ICAR-Indian Grassland and Fodder Research Institute, Jhansi, Uttar Pradesh. The treatment consisted of establishment of 3 grasses in association with *H. binata* with 3 moisture-conservation practices. Establishment of guria grass [*Chrysopogon fulvus* (Spreng.) Chiov.] in association with *H. binata* resulted in significantly higher dry pasture yield (6.40 t/ha) than guinea grass [*Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs; syn. *Panicum maximum* Jacq.] (6.02 t/ha) and found statistically at par with buffel grass (*Cenchrus ciliaris* L.) (6.39 t/ha). Among the moisture-conservation practices, construction of staggered trenches recorded significantly higher green top feed (2.04 t/ha), dry top feed (1.21 t/ha) and firewood (1.40 t/ha) of *H. binata* than without moisture-conservation practices (1.64, 0.83 and 0.89 t/ha) and bund (1.89, 1.04 and 1.31 t/ha) respectively. Construction of bund across the slope recorded significantly higher moisture content at 0–15 cm (8.71%) and 15–30 cm (9.78%) soil depth as compared to without moisture-conservation practices. However, at 30–60 cm soil depth, moisture content was significantly increased (9.63%) in trenches than the control plots. Available nutrients (N 239.5 and 225.1, P 8.53 and 8.22 and K 221.3 and 212.1 kg/ha) and organic carbon (0.60% and 0.57%) increased significantly where bund and trenches were constructed than no moisture-conservation practice respectively. In term of monetary returns, *Chrysopogon fulvus* showed the maximum net returns (₹35,485/ha) and benefit: cost ratio (1.53), followed by *Cenchrus ciliaris* (₹33,853/ha and 1.51 respectively) and *Megathyrsus maximus* (₹32,107/ha and 1.49 respectively) utilized in grazing mode by goats and sheep at the rate of 2 adult cattle unit. Sustainable yield index of staggered trenches and bund were higher (0.79 and 0.76) than without moisture-conservation practice (0.67) which showed that yields obtained under moisture-conservation practices were more stable over the years than no moisture-conservation practices.

Key words: *Cenchrus ciliaris, Chrysopogon fulvus, Hardwickia binata,* Moisture conservation practices, *Megathyrsus maximus,* Silvopasture systems

The productivity of degraded grazing lands in arid and semiarid regions under rainfed conditions is often poor due to dominance of low-yielding annual grasses and lack of proper soil moisture. In this context, introduction of suitable drought-resistant grasses in association with tree and construction of moisture-conservation practices can play a vital role in improving the productivity of degraded grazing lands. Anjan (*Hardwickia binata* Roxb). belongs to the family Leguminosae sub-family Caesalpinioideae and considered to be an important multipurpose tree species in semi-arid regions of India. It provides quality nutritious fodder rich in crude protein and also supplies extremely hard, heavy and durable timber in addition to high quality fuel-wood.

In semi-arid rainfed situation, establishment and productivity of tree and grasses can be enhanced by adopting different moisture-conservation practices to collect runoff water near the root zone. *In-situ* moisture-conservation practices have a great potential in enhancing moisture availability period and productivity of the system on degraded grazing lands. Yadav and Bhushan (1989) reported that, in degraded lands low-cost mechanical practices may be adopted for moisture conservation. The economy of the arid and semiarid farmers depends on the livestock population dominated by grazing-based animals like sheep and goats Kumar *et al.,* (2019). In hot arid and semiarid regions where erratic rainfall and recurrent drought is the common

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phenomenon, development of suitable silvopastoral system is recommended to increase system productivity, enhancing fodder availability and checking soil erosion (Soni *et al*., 2013; Sharma, 2014; Tanwar *et al.,* 2018). Establishment of silvopastoral system on degraded grazing lands can serve the important role of bridging the gap in fodder supply during lean period of the year. In silvopasture system grasses provide green forage during the monsoon season and trees provide top feed during winter and summer seasons (Kumar *et al*., 2017; Ram *et al*., 2019). Silvopastoral systems also stabilize sloping lands from erosion and rehabilitate degraded lands. Soil conditions are improved by contributions from leaf fall and nitrogen fixation by leguminous species. In view of this, the present study was carried out to study the effect of moisture-conservation practices on performance of *Hardwickia binata*-based silvopasture systems in semiarid rainfed conditions.

MATERIALS AND METHODS

A field experiment was conducted during 2013–18 on 5 year-old *Hardwickia binata*-based silvopasture system at Central Research Farm (25^o 27' N, 78^o 37' E and 275 m above mean sea-level) of the ICAR-Indian Grassland and Fodder Research Institute, Jhansi, Uttar Pradesh. The soil of the experimental field was sandy loam, low in available nitrogen (224.1 kg/ha) and phosphorus (8.16 kg/ha) and medium in organic carbon (0.57%) and available potash (210.5 kg/ha). The total rainfall received was 1,510.8, 651.9, 713.3, 827.0 and 486.4 mm in 71, 43, 48, 41 and 35 rainy days during 2013, 2014, 2015, 2016 and 2017 respectively.

There were 9 treatment combinations, replicated thrice in randomized block design. The treatment consisted of establishment of three grasses, viz. buffel grass (*Cenchrus ciliaris* L.)*,* guria grass [*Chrysopogon fulvus* (Spreng.) Chiov.] and guinia grass [*megathyrsus maximus* (Jacq.) B.K. Siomon & S.W.L. Jacobs: syn. *Panicum maximum* Jacq.] in association with *H. binata* and construction of 3 moisture-conservation practices, viz. staggered trenches (2 m × 0.5 m × 0.5 m), bunding and control (without bunding and staggered trenches). Forage produced from *H. binata*-based silvopastoral system was utilized in grazing mode by mixed herd of Bundelkhandi goats and Jalauni sheep at the rate of 2 adult cattle unit. Uniform grazing in all the experimental plots was carried out from August to January. The *H. binata* was established at 6 m × 6 m spacing and grasses were established in association with *H. binata* at 50 cm × 50 cm spacing. Fertilizers to give 40 kg N, 30 kg P_2O_5 and 30 kg K_2O/ha were applied each year after onset of the monsoon. The trees were pruned once every year during the winter season for proper growth, form and yield. Dry-matter content was estimated by drying 500 g plant sample of each plot in hot-air oven at 70^oC for computation of dry-matter yield. Observations on soil-moisture content were taken at 3 depths (0–15 cm, 15–30 cm and 30–60 cm) after monsoon season at 2 months intervals (October–April). Sustainable yield index was calculated as:

Sustainable yield index=(Estimated average yield–estimated standard deviation)/ maximum yield in the experiment during the years of study (Singh *et al.,* 1990).

RESULTS AND DISCUSSION

Growth parameters of grasses

Among grasses, *Megathyrsus maximus* recorded significantly higher height (146.24 cm) as compared to *C. fulvus* (136.75 cm) and *C. ciliaris* (117.06 cm). However, number of tillers/plant (89.36) and tussock diameter (37.89 cm) were maximum in *C. fulvus* followed by *Cenchrus ciliaris* (74.73 and 34.55 cm) respectively (Table 1). In moisture-conservation practices, construction of bund in *H. binata*-based silvopasture system significantly increased the height (140.06 cm), tillers/plant (79.27) and tussock diameter (36.62 cm) of grasses as compared to staggered trenches (134.89 cm, 74.82 and 34.56 cm) and control treatment-without bund and trenches (125.11 cm, 67.84 and 32.48 cm) respectively. This might be due to higher soil moisture content in bund plots at 0–30 cm soil depth during growth period of grasses.

Green and dry pasture yield

Establishment of *C. fulvus* in association with *H. binata* recorded significantly higher dry pasture yield (6.40 t/ha) than *Megathyrsus maximus* (6.02 t/ha) and it was found at par with *C. ciliaris* (6.39 t/ha). In moisture-conservation practices, construction of bund in *H. binate*-based silvopasture system also showed significantly increased understorey green pasture yield (19.57 t/ha) and dry pasture yield (6.72 t/ha) than control treatment-without bund and trenches (16.79 and 5.72 t/ha) respectively. This might be owing to increase in the availability of soil moisture in field for longer period by construction of bund in field during the rainy season which acts as barrier against the runoff of water and therefore the maximum water was absorbed in the soil and resulted in higher moisture regime in the root zone of pasture which enhanced the forage yield. Kumar and Shukla (2010) also reported significantly higher pasture yield by construction of bund than without bund in *ber*-based hortipasture system. Patil and Sheelavantar (2000), Meena *et al*. (2002) and Regar *et al.* (2007) also reported higher yield of different crops with the construction of bunds.

Growth parameters of Hardwickia binata

Establishment of different grasses in association with

Table 1. Effect of moisture-conservation practices and grasses on growth parameters of pasture components and *Hardwickia binata* in silvipasture systems (pooled data of 5 years)

Treatment	Grasses			*Hardwickia binata*			
	Height (cm)	Tillers/ plant	Tussock diameter (cm)	Height (m)	Collar diameter (cm)	Diameter at breast height (cm)	Canopy spread (m)
Grasses							
C. ciliaris	117.1	74.7	34.6	7.3	16.2	13.1	3.5
C. fulvus	136.8	89.4	37.9	7.3	16.3	13.3	3.5
Megathyrsus maximus	146.2	57.8	31.2	7.2	16.1	13.0	3.4
SEm±	1.4	1.4	0.6	0.1	0.1	0.1	0.1
CD (P=0.05)	4.3	4.1	1.8	NS	NS	NS	NS
MCP							
Control	125.1	67.8	32.5	7.2	15.9	12.9	3.4
Trenches	134.9	74.8	34.6	7.5	16.5	13.4	3.6
Bund	140.1	79.3	36.6	7.3	16.2	13.2	3.5
SEm±	1.4	1.4	0.6	0.1	0.1	0.1	0.1
CD (P=0.05)	4.3	4.1	1.8	0.2	0.2	0.2	0.1

MCP, Moisture-conservation practices

H. binata did not significantly affect the growth parameters of *H. binata* (Table 1). However, construction of staggered trenches recorded significantly higher height (7.47 m), collar diameter (16.45 cm), diameter at breast height (13.36 cm) and canopy spread (3.55 m) of *H. binata* as compared to the control treatment-without trenches and bund (7.16 m, 15.91 cm, 12.88 cm and 3.39 m) respectively. The higher growth parameters of *H. binata* in staggered trenches may be attributed to sufficient moisture regime in the root zone of tree during growth period in this treatment. Shukla *et al.,* also reported (2014) enhanced tree growth under staggered trenches in bael.

Green and dry top feed and firewood

Green and dry top feed and fire wood yield of *H. binata* were also not affected significantly by establishment of different grasses (Table 2). However, construction of staggered trenches resulted in significantly higher green top feed (2.04 t/ha) and dry top feed (1.21 t/ha) and fire wood (1.40 t/ha) of *H. binata* than the control treatment (1.65, 0.83 and 0.89 t/ha respectively). The higher top feed and fire wood yield of *H. binata* in staggered trenches may be attributed to sufficient moisture regime in the root zone of tree in these plots for longer period. Kumar *et al.,* (2012) also reported higher growth and productivity of guava in hortipastoral system by construction of staggered trenches.

Moisture content

Pooled data of 5 years showed that, establishment of different grasses in association with *H. binata* did not influence significantly the soil-moisture content (Table 3). However, construction of bund resulted significantly higher moisture content (8.71%) at 0–15 cm and (9.78%) at 15–30 cm soil depth than the control (7.50% and 8.39% re-

Table 2. Effect of moisture-conservation practices and grasses on green and dry pasture yield, top feed, and firewood yield of *Hardwickia binata*-based silvipasture systems (pooled data of 5 years)

Treatment	Green pasture yield (t/ha)	Dry pasture yield (t/ha)	Green top feed (t/ha)	Dry top feed (t/ha)	Fire wood (t/ha)
Grasses					
C. ciliaris	18.03	6.39	1.86	1.02	1.19
C. fulvus	17.94	6.40	1.92	1.06	1.24
Megathyrsus maximus	18.99	6.02	1.80	1.00	1.16
SEm±	0.44	0.07	0.06	0.05	0.05
CD (P=0.05)	NS	0.23	NS	NS	NS
MCP					
Control	16.79	5.72	1.65	0.83	0.89
Trenches	18.61	6.37	2.04	1.21	1.40
Bund	19.57	6.72	1.89	1.04	1.31
SEm±	0.44	0.07	0.06	0.05	0.05
CD (P=0.05)	1.32	0.23	0.19	0.14	0.16

MCP, Moisture-conservation practices

Table 3. Effect of grasses and moisture-conservation practices on moisture content of *Hardwickia binata*-based silvipasture system

Treatment	Moisture content (%)																	
	2013–14			2014–15			2015–16			2016–17			2017–18			Pooled (5 years)		
	0–15 cm	15–30 cm	30–60 cm	0–15 cm	15–30 cm	30–60 cm	0–15 cm	15–30 cm	30–60 cm	0–15 cm	15–30 cm	30–60 cm	0–15 cm	15–30 cm	30–60 cm	0–15 cm	15–30 cm	30–60 cm
Grasses																		
C. ciliaris	9.14	11.65	10.84	8.10	7.61	7.80	7.00	8.04	7.51	9.95	10.41	10.96	6.70	8.25	8.95	8.18	9.20	9.18
C. fulvus	8.67	11.10	10.46	7.87	7.32	7.53	7.23	8.28	7.78	10.16	10.63	11.13	6.92	8.50	9.17	8.17	9.16	9.15
Megathyrsus maximus	9.62	12.01	10.87	8.47	7.96	7.83	6.76	7.84	7.37	9.72	10.16	10.78	6.51	8.01	8.72	8.22	9.20	9.22
SEm±	0.13	0.18	0.16	0.10	0.12	0.12	0.08	0.10	0.11	0.09	0.12	0.13	0.12	0.14	0.16	0.10	0.15	0.15
CD (P=0.05)	0.39	0.54	NS	0.31	0.37	NS	0.23	0.31	NS	0.28	0.37	NS	0.36	0.43	NS	NS	NS	NS
MCP																		
Control	8.15	10.34	9.92	7.38	6.83	7.22	6.54	7.50	7.16	9.30	9.78	10.49	6.10	7.50	8.44	7.50	8.39	8.65
Trenches	9.37	11.89	11.39	8.30	7.80	8.18	7.13	8.21	7.87	10.11	10.56	11.32	6.86	8.45	9.36	8.35	9.39	9.63
Bund	9.91	12.54	10.85	8.75	8.27	7.76	7.33	8.45	7.62	10.41	10.85	11.06	7.17	8.82	9.04	8.71	9.78	9.27
SEm±	0.13	0.18	0.16	0.10	0.12	0.12	0.08	0.10	0.11	0.09	0.12	0.13	0.12	0.15	0.16	0.10	0.15	0.15
CD (P=0.05)	0.39	0.54	0.48	0.31	0.37	0.35	0.23	0.31	0.33	0.28	0.37	0.39	0.36	0.43	0.48	0.31	0.45	0.46

MCP, Moisture-conservation practices

spectively). However, at 30–60 cm soil depth the moisture content was significantly increased (9.63%) in trenches than control treatment (8.65%). The higher moisture contents in bund and staggered trenches might be owing to minimum runoff and higher infiltration of water in these plots. Ahmed *et al.* (2014) also reported higher moisture-content in soil by *in-situ* moisture-conservation practices in aonla-based hortipasture system. In the year 2013, moisture content was the maximum (10.48%) when rainfall was also maximum (1511 mm) closely followed by 2016 (moisture content 10.43% and rainfall 827 mm) as compared to 2014, 2015 and 2017 when moisture contents varied from 7.53 to 7.97% with rainfall 486–713 mm. Results showed that variation in moisture contents was not in exactly in same pattern as in amount of rainfall in different years. As in the year 2017 when rainfall was minimum 486 mm but moisture content was higher 7.97% as compared to year 2015 when rainfall was higher 713 mm but moisture content was minimum 7.53%. So, in addition to rainfall amount, moisture contents was varied with various other factors like number of rainy days, rainfall intensity, soil type, slope of the land, vegetative cover of land etc.

Soil-fertility status

Soil-fertility status of *H. binata*-based silvopasture system was not affected significantly by establishment of different grasses (Table 4). However, *C. fulvus* recorded maximum available nitrogen, phosphorus and potash and organic carbon (229.6, 8.35 and 216.7 kg/ha and 0.58%), followed by *C. ciliaris* (222.9, 8.12 and 209.4 kg/ha and 0.57%) and *P. maximum* (219.65, 8.01 and 205.44 kg/ha and 0.556%) respectively. However, available nutrients (N 239.5 and 225.1, P 8.53 and 8.22 and K 221.3 and 212.1 kg/ha) and organic carbon (0.60% and 0.57%) were significantly improved where bund and trenches were constructed than the control plots in 5th year of study respectively (Table 4). Soil nutrients like organic carbon, nitrogen, phosphorus and potash were improved in the soil might be owing to decomposition of leaf litter of tree and grasses in different moisture-conservation treatments. Impact of moisture conservation on the mineralization of the elements such as nitrogen and phosphorus was reported by Forge *et al*., (2003). Jha and Rattan (2007) also reported that, moisture regime for longer period facilitates the decomposition of crop residue and mineralization of nutrients.

Economic returns

In term of monetary returns, *C. fulvus* recorded the maximum net returns (₹35,485/ha) and benefit: cost ratio (1.53) in association with *H. binata,* followed by *Cenchrus ciliaris* (₹33,853/ha and 1.51) and *Megathyrsus maximus*

Table 4. Effect of moisture-conservation practices and grasses on soil fertility status, cost of cultivation, net return, benefit: cost ratio (2017–18) and sustainability yield index of *Hardwickia binata*-based silvopasture systems

Treatment	Available nutrients (kg/ha)			Organic carbon (%)	Cost (₹/ha)	Net returns (₹/ha)	Benefit: cost ratio	Sustainability yield index
	N	P	K					
Grasses								
C. ciliaris	222.92	8.12	209.42	0.567	66,208	33,853	1.51	0.744
C. fulvus	229.63	8.35	216.70	0.577	66,921	35,485	1.53	0.750
Megathyrsus maximus	219.65	8.01	205.44	0.556	65,258	32,107	1.49	0.727
SEm±	3.64	0.15	3.65	0.012	–	172	0.01	0.012
CD (P=0.05)	NS	NS	NS	NS	–	520	0.02	NS
MCP								
Control	207.60	7.73	198.17	0.530	65,337	32,663	1.50	0.669
Trenches	225.06	8.22	212.06	0.565	66,287	34,271	1.52	0.791
Bund	239.54	8.53	221.32	0.604	66,763	34,512	1.52	0.761
SEm±	3.64	0.15	3.65	0.012	–	172	0.01	0.012
CD (P=0.05)	10.99	0.46	11.03	0.036	–	520	0.02	0.037

MCP, Moisture-conservation practices

(₹32,107/ha and 1.49) utilized in grazing mode by goats and sheep at the rate of 2 ACU. The higher net returns and benefit: cost ratio from establishment of *C. fulvus* in association with *H. binata* was owing to higher forage yield obtained from this treatment. Construction of bund also recorded significantly higher net returns (₹34,512/ha) and benefit: cost ratio (1.52) from *H. binata*-based silvopasture system utilized in grazing mode by goats and sheep at the rate of 2 ACU as compared to control treatment (₹32,663/ha and 1.50). The higher net returns and benefit: cost ratio from construction of bund was also owing to higher forage yield obtained from this treatment. Cost of cultivation incurred on *C. fulvus* was maximum (₹66,921/ha) followed by *Cenchrus ciliaris* (₹66,208/ha). Similarly, bund recorded higher cost of cultivation (₹66,763/ha) than the control treatment-without moisture conservation practices (₹65,337/ha). The reason for less difference in cost of cultivation, net returns and benefit: cost ratio among moisture-conservation practices was due to construction of bund and trenches at the time of planting only, 5 years before start of this study. In present study, as only repairing of the bund and the trenches was carried out, so only repairing cost of bund and trenches were considered in calculating cost of cultivation. Similarly, reason for less difference in cost of cultivation, net returns and benefit: cost ratio among different grasses was owing to higher forage yield of *Megathyrsus maximus* in initial 2 years of experiment, while in last 3 years of experiment higher forage yield was obtained from *C. fulvus* because of their adequate plant stand and dense vegetative growth. In present study, *H. binata* trees were in very growing phase, their maturity stage (harvesting stage) was more than 30–35 years, so the differences among treatments may increase as trees will reach towards maturity stage and contribute more in term top feed and wood in total productivity of the system over the years and then it would be more profitable to farmers.

Sustainability yield index

Sustainable yield index of the system was not affected significantly by different grasses (Table 4). This was due to higher forage yield of *Megathyrsus maximus* in initial 2 years of experiment, while in last 3 years of experiment higher forage yield was obtained from *C. fulvus* because of their adequate plant stand and dense vegetative growth. However, sustainability yield index of staggered trenches and bund was higher (0.79 and 0.76) than without moisture-conservation practices (0.67) which showed that yields obtained under moisture-conservation practices were more stable over the years than control treatment. Differences in sustainable yield index of bund and control treatment was more than 0.12 which will further increase over the years as the yield differences will increase, this system is perennial it remains in the field for longer period. In present study, *H. binata* trees were in very growing phase, their maturity stage (harvesting stage) is more than 30–35 years, so the differences among treatments may increase as trees will reach towards maturity stage and contribute more in term of top feed and wood in total productivity of the system over the years and then it would be more sustainable.

On the basis of results obtained, it could be concluded that establishment of perennial grasses (*C. fulvus, C. ciliaris* and *Megathyrsus maximus*) in association with *H. binata* in silvipasture system along with moisture-conservation practices (bunds and staggered trenches) and utilization of forages in grazing mode by goats and sheep at the rate of 2 adult cattle unit resulted in higher productivity (pasture, top feed and fire wood), better soil-moisture content, improved nutrients status in soil and gave higher monetary returns under semi-arid rainfed conditions. *Hardwickia binata* being hardy and deep rooted proved to be a potential tree suitable for silvopastoral systems on degraded grazing lands in rainfed areas of semiarid regions.

REFERENCES

Ahmed, A., Kumar, S. and Shukla, A.K. 2014. Effect of different soil moisture conservation techniques for establishment of Aonla based hortipasture systems in Bundelkhand region. In: *Proceedings of National Symposium on Climate Resilient Forage Production and its Utilization,* held during 13–14 November 2014 at Bidhan Chandra Krishi Viswavidyalaya, Kalyani, West Bengal, India; Organized by the Indian Society of Range Management, Indian Grassland and Fodder Research Institute, Jhansi, Uttar Pradesh, pp. 21.

Forge, T.A., Hugue, E., Neilsen, G. and Neilsen, D. 2003. Effects of organic mulches on soil microfauna in the root zone of apple: Implications for nutrient fluxes and functional diversity of soil food web. *Applied Soil Ecology* **22**: 39–54.

Jha, Pramod and Rattan, R.K. 2007. Mineralization of carbon and phosphorus in soil as affected by soil moisture regimes and incorporation of crop residues. *Journal of Indian Society of Soil Science* **55**(2): 218–221.

Kumar, R.V., Singh, H.V., Kumar, S., Roy, A.K. and Singh, K.A. 2017. Growth and biomass production of fodder trees and grasses in a silvipasture system on non-arable land of semi-arid India. *Range Management and Agroforestry* **38**(1): 43–47.

Kumar, S. and Shukla A.K. 2010. Improvement of old ber cv. Gola orchard through bunding and micronutrients (Boron and Zinc) management. *Indian Journal of Horticulture* **67**(3): 322–327.

Kumar, S., Patel, A.G., Jat, J.R., Shakhela, R.R. and Joshi, R.V. 2019. Nitrogen management in forage oat (*Avena sativa*) under North Gujrat Agro-climatic conditions. *Indian Journal of Agronomy* **64**(3): 397–400.

Kumar, S., Shukla, A.K. and Rai, A.K. 2012. Development of guava based hortipastoral system with natural resource conservation. *Annual Report*, Indian Grassland and Fodder Research Institute, Jhansi, Uttar Pradesh, pp. 40.

Meena, L.R., Singh, R.K. and Gautam, R.C. 2002. Effect of moisture conservation practices, phosphorus levels and bacterial inoculation on chickpea (*Cicer arietinum*) under rainfed condition. *Indian Journal of Agronomy* **47**(3): 398–404.

Patil, S.L. and Sheelavantar, M.N. 2000. Yield and yield components of *Rabi* sorghum (*Sorghum bicolor*) as influenced by *in-situ* moisture-conservation practices and integrated nutrient management in vertisols of semi-arid tropics in India. *Indian Journal of Agronomy* **45**(1): 132–137.

Ram, S.N., Kumar, R.V. and Shukla, A.K. 2019. Influence of shrubs and tree densities on three-tier silvopasture components in semiarid rainfed conditions. *Range Management and Agroforestry* **40**(1): 104–108.

Regar, P.L., Rao, S.S. and Joshi, N.L. 2007. Effect of *in-situ* moisture-conservation practices on productivity of rainfed Indian mustard (*Brassica juncea*). *Indian Journal of Agronomy* 52(2): 148–150.

Singh, R.P., Das, S.K., Bhaskara Rao, U.M. and Narayana Reddy, M. 1990. Sustainability index under different management. (In) *Annual Report*. Central Research Institute for Dryland Agriculture, Hyderabad, India.

Sharma, K.C. 2014. Production potential of fodder crops sequences in association with ber (*Ziziphus mauritiana* Lamk.) under agri-horticulture system in hot arid ecosystem of western India. *Range Management and Agroforestry* **35**(2): 188–192.

Shukla, A.K., Kumar, S., Ram, S.N., Singh, H.V., Watpade, S.G. and Pramanick, K.K. 2014. Bael (*Aegle marmelos*) based hortipastoral system with moisture conservation in semiarid condition. *Journal of Tree Science* **33**(1): 7–11.

Soni, M.L., Yadav, N.D., Beniwal, R.K., Singh, J.P., Kumar, S. and Birbal. 2013. Grass based strip cropping systems for controlling soil erosion and enhancing system productivity under drought situations of hot arid western Rajasthan. *International Journal of Agricultural Statistics Science* **9**: 685–692.

Tanwar, S.P.S., Bhati, T.K., Singh, A., Patidar, M., Mathur, B.K., Kumar, P. and Yadav, O.P. 2018. Rainfed integrated farming systems in arid zone of India: Resilience unmatched. *Indian Journal of Agronomy* **63**(4): 403–414.

Yadav, R.C. and Bhushan, L.S. 1989. Soil and water conservation practices for range lands. *Indian Journal of Range Management* **10**(1): 59–65.