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Comparative assessment of *Hardwickia binata* based agroforestry system with sole cropping system under rainfed conditions in arid region of Rajasthan

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ABSTRACT

The study was conducted at research farm of Agricultural Research Station (ARS), Fatehpur-Shekhawati, Sikar (latitude 27°56′10.37″ N, longitude 074°59′04.51″ E) in Rajasthan, India under 16 years old *H. binata* based agroforestry system (systematically planted at 5×5 m spacing) and sole cropping system. The objective of the study was to assess the productivity potential and performance of cereals and pulses crops under *H. binata* based agroforestry system with sole cropping system. The highest yield from pruned tree recorded in sole *H. binata* tree (8120 kg/ha) followed by tree + moth bean (6933 kg/ha) based agroforestry system. The highest grain yield recorded in sole cow pea (716.50 kg/ha) followed by sole pearl millet (696.23 kg/ha). The pearl millet equivalent yield was highest in sole cow pea (2312.43 kg/ha) followed by sole cluster bean (1939.07 kg/ha) and sole green gram (1873.13 kg/ha) based cropping system. The maximum gross return found in sole cluster bean (41151.57 ₹/ha) which was at par for sole cow pea (40643.45 ₹/ha). The net return was found maximum in sole cow pea (28568.45 ₹/ha) which was at par of sole cluster bean (28076.57 ₹/ha). The B:C ratio was also found best for sole cow pea (2.36) based cropping system followed by sole cluster bean (2.13) based cropping system. The land equivalent ration was found highest for tree + green gram and tree + moth bean based agroforestry system (1.42) followed by tree + cow pea based agroforestry system and tree + cluster bean based agroforestry system (1.40). Hence, results shows that *H. binata* based agroforestry system is viable under rainfed arid condition however, the grain yield, straw yield and biological yields significantly reduced in *H. binata* based agroforestry system in comparison to sole cropping based system. Thus it is concluded that *H. binata* based agroforestry system good to compensate the crop productivity and other multipurpose benefit to the environment and livelihood of the people of arid regions.

Keywords: *Hardwickia binata*, Agroforestry system, Sole cropping system, Rainfed, Arid

INTRODUCTION

Livelihood of most of the farmers of arid and semi-arid region of India is highly sensitive to climate change owing to prevalence of drought, erratic rainfall, land degradation, top soil loss. The farmer of the regions mainly depends on rain-fed agriculture and animal husbandry. The production of arable crop is risky and unstable in hot arid regions. In order to minimize the adverse effects of frequent crop failures due to drought, farmers have evolved some combined protective-productive systems by integrating woody perennials and livestock in farming. Historically, the hot arid regions are a land of low-yield and of short-duration crops with high dependence on livestock and traditional agro-forestry (Kar, 2014). Integration of trees with arable crops improved the productivity compared to sole cropping in arid regions (Harsh and Tewari, 2007). In hot arid and semiarid regions where erratic rainfall and recurrent drought is the common phenomenon, development of suitable silvopasture system are recommended to increase system productivity, enhancing fodder availability and checking soil erosion (Soni *et al*., 2013). Under such situation, tree species like *Hardwickia binata* (*H. binata*) are boon owing to its capability to ensure supply of green nutritious fodder to livestock; provide timber, fuel wood and other non-timber forest products; conserve soil and moisture; restore degraded lands and sequester huge amount of atmospheric carbon dioxide. *Hardwickia binata* (*Anjan*) Roxb., is a leguminous tree and was reported to enhance land use efficiency and fulfil multiple demands (timber, fodder and fuel) in arid and semiarid regions. It is a medium to large sized (6-20 m in height; 0.9–3 m in girth) deciduous tree belonging to the family Leguminosae, is well suited for fodder production under semi-arid conditions. The branches of the tree are slender and bear lush green, pendulous foliage. Leaves are small, leathery, grayish-green, reniform shape, compound, bifoliolate, paripinnate, measuring 2-6 cm in length and 2-3 cm in width, and exhibit an actinodromous venation pattern. It is a drought hardy tree which can tolerate prolonged drought and high temperature up to 48°C. The tree thrives well in a dry climate and even withstands for prolonged drought, scanty to moderate rainfall and intense heat during the hot season and is capable of growing on dry shallow soil and rocky ground. There are several studies that indicated that integration of tree with pasture to enhanced fodder yields. *H. binata* based silvipasture system can enhance average carrying capacity of land by 50% and sustain round the year fodder availability (Ram *et al.*, 2017). However, very few on agrisilviculture studies available on crop production potential with tree in comparison to sole cropping system. The objective of the study was to assess the productivity potential and performance of cereals and pulses crops under *H. binata* based agroforestry system with sole cropping system in rainfed condition of arid western Rajasthan. These sustainable systems although resilient to weather aberrations, however have low production levels, which are now inadequate to rainfed. Therefore, the scope of this paper is restricted to purely rainfed situations.

MATERIALS AND METHODS

Study site

The study was conducted at research farm of Agricultural Research Station (ARS), Fatehpur-Shekhawati, Sikar (latitude 27°56′10.37″ N, longitude 074°59′04.51″ E) in Rajasthan, India under *H. binata* based agroforestry system (systematically planted at 5×5 m spacing) and sole cropping system during *kharif* seasons in rainfed condition. The climate of the experimental site was arid with average annual rainfall 300-350 mm and was erratic in nature. Due to uneven and insufficient distribution pattern of rain frequent failure of crop is common in the area. The temperature goes as high as 48°C in summer (mid-May) and as low as -5 °C (last week of December to First week of January) in winter. The region experiences high winds velocity (>60 km hrs^{-1}) during summer. The soil of the experimental site was loamy sand with low organic carbon content. The annual rainfall of *kharif* season was <300 mm during the experiment periods. The soil pH was varies 8.10 to 8.14 and have organic carbon (0.14 %), available P (9.05 kg ha^{-1}) and available K (245 kg ha^{-1}).

Experiments detail

The study was conducted in 16 years old *H. binata* plantation maintained in rainfed condition on dunes soil of arid western Rajasthan. The spacing of the tree is 5 m × 5 m and only lifesaving irrigation was provided to the plants during the establishment of plantation. The treatments of different *kharif* crops viz., Pearlmillet (*Pennisetum glaucum*), Clusterbean (*Cyamopsis tetragonoloba*), Green gram (*Vigna radiata*), Moth bean (*Vigna aconitifolia*) and Cow pea (*Vigna unguiculata*) was sown in randomized block design (RBD) in six replications and same treatments were replicated under sole cropping system. The treatments are viz., T_1: Tree + Pearl millet; T_2: Tree + Cluster bean; T_3: Tree + Green gram; T_4: Tree + Moth; T_5: Tree + Cowpea; T_6: Sole Pearl millet; T_7: Sole Cluster bean; T_8: Sole Green gram; T_9: Sole Moth; T_{10}: Sole Cowpea; T_{11}: Sole Tree. The agronomic practices followed during experiments for different treatments are given in Table 1. Tree growth data viz., tree height, diameter at breast height (DBH), and crown diameter measured during the study under rainfed condition of fixed four trees in experimental plot on a yearly basis in each of the treatments as per the standard procedure of forest

Table 1. Agronomic practices of different Kharif crops followed in the experiment

Kharif crops	Seed Rate (kg/ha)	Spacing (cm) row × plant	Fertilizers (kg/ha) N	P	Agronomic operations
Pearl millet (*P. glaucum*)	1.5	45x45	20	10	Hoeing and weeding
Cluster bean (*C. tetragonoloba*)	12	30x10	05	10	Hoeing and weeding
Green gram (*V. radiata*)	12	30x10	05	10	Hoeing and weeding
Moth bean (*V.aconitifolia*)	10	30x10	05	10	Hoeing and weeding
Cow pea (*V. unguiculata*)	15	30x10	05	10	Hoeing and weeding

mensuration using wooden pole, tape and Vernier calliper. For tree biomass pruning operation was carried out in November month and harvested biomass was sun-dried for five days under open sunlight and weight was measured in kg/tree. The crops yield attributes viz., grain yield (kg/ha) and straw yield (kg/ha) were calculated for each treatments. Biological yield (kg/ha) was calculated by adding the total grain yield and straw yield whereas the harvest index (%) was estimated by the following formula:

$$\text{HI (\%)} = \frac{\text{Economic yield (Grain yield)}}{\text{Biological yield (Grain + Straw yield)}} \times 100$$

Pearl millet/Cluster bean equivalent yield (kg/ha): the following formula was used to calculate the equivalent yield for pearl millet and cluster bean:

Equivalent yield (Pearl millet/ Cluster bean) =

$$\frac{\text{Yield of crop A} \times \text{Average price of crop A (₹)}}{\text{Average price of pearl millet/ cluster bean}}$$

Cost of cultivation (₹/ha): The cost incurred for inputs, field operation, and management of tree plantation was calculated on a per hectare per year basis.

Gross Return (₹/ha): The prevailing local market prices were used to convert the yield of agricultural crops and pruned tree yield into rupees/ha.

Gross returns = Average yield per hectare × Average market price per kg (₹)

Net Return (₹/ha): Net returns were calculated by subtracting the cost of cultivation from gross returns.

Benefit-Cost ratio: The B:C ratio was calculated by using the following expression:

$$\text{B: C} = \frac{\text{NET Return}}{\text{Cost of Cultivation}}$$

Land Equivalent Ratio (LER): It was calculated as the ratio of the area needed under intercropping to the area under sole cropping using the following formula:

$$\text{LER} = \frac{\text{Yield of crops in agroforestry system}}{\text{Yield of crops in sole cropping system}} + \frac{\text{Yield of tree in } \textit{H. binata} \text{ based agroforestry system}}{\text{Yield of tree in sole } \textit{H. binata} \text{ based system}}$$

The experimental data of various growth, yield attributes and economic parameters were subjected to analysis of variance (ANOVA). The level of significance was tested by (Gomez and Gomez, 1984), and critical differences (CD) at a 5% level of significance were estimated to compare the means of each parameter.

RESULT AND DISCUSSION

Tree growth

The tree growth performance average height, dbh, crown dimeter, dry biomass of pruned branches and dry leaf biomass from pruned branches given in Table 2. The average height of *H. binata* tree ranges between 6.2 to 6.8 m, average dbh ranges between 13.50 to 19.45 cm and average crown diameter ranged between 4.4 to 5.1 m in different treatments. The growth pattern of trees in sole and agri-silviculture system exhibited more or less similar trend. This results with accordance to the studies of (Ajit *et al.,* 2020). The highest pruned branches biomass recorded in sole tree (2546.67 kg/ha) and lowest in Tree + Pearl millet (2080 kg/ha), and same results observed for dry leaf biomass from pruned branches i.e., highest 5573.33 kg/ha and lowest 4613.33 kg/ha for sole tree and Tree + Pearl millet based agroforestry system, respectively.

Yield of tree and intercrops

The yield attributes of different treatments viz., yield from pruned tree, grain yield, straw yield, biological yield and harvest index given in Table 3 and for all the yield parameters significant difference

Table 2. *Hardwickia binata* growths attribute and dry biomass of pruned branches and leaves

Treatments	Average height (m)	Average DBH* (cm)	Average crown dia. (m)	Dry biomass of pruned branches (kg/ha)	Dry leaf biomass from pruned branches (kg/ha)
Tree + Pearl millet	6.2	13.50	4.4	2080.00	4613.33
Tree + Cluster bean	6.4	14.90	4.6	2106.67	4666.67
Tree + Green gram	6.5	17.25	4.8	2106.67	4706.67
Tree + Moth	6.8	19.45	5.1	2133.33	4800.00
Tree + Cowpea	6.2	13.60	4.4	2093.33	4626.67
Sole Pearl millet	-	-	-	0.00	0.00
Sole Cluster bean	-	-	-	0.00	0.00
Sole Green gram	-	-	-	0.00	0.00
Sole Moth	-	-	-	0.00	0.00
Sole Cowpea	-	-	-	0.00	0.00
Sole Tree	6.5	18.25	4.9	2546.67	5573.33

*Diameter at breast height (DBH)

Table 3. Yield attributes under *H. binata* based agroforestry system and sole cropping system

Treatments	Total yield from pruned tree (kg/ha)	Grain yield (kg/ha)	Straw yield (kg/ha)	Biological yield (kg/ha)	Harvest index (%)
Tree + Pearl millet	6,693.33	286.73	447.27	734.00	39.06
Tree + Cluster bean	6,773.33	388.33	493.17	881.50	44.05
Tree + Green gram	6,813.33	321.50	353.63	675.13	47.62
Tree + Moth	6,933.33	263.67	276.87	540.54	48.78
Tree + Cowpea	6,720.00	412.70	474.63	887.33	46.51
Sole Pearl millet	-	696.23	1,100.03	1,796.26	38.76
Sole Cluster bean	-	676.83	879.90	1,556.73	43.48
Sole Green gram	-	541.43	622.67	1,164.10	46.51
Sole Moth	-	454.20	499.67	953.87	47.62
Sole Cowpea	-	716.50	823.97	1,540.47	46.51
Sole Tree	8,120.00	-	-	-	-
CD at 5%	1,370.29	65.775	82.677	147.953	0.014

between different treatments was observed. The highest yield from pruned tree recorded in sole *H. binata* tree (8120 kg/ha) followed by tree + moth bean (6933 kg/ha) and lowest tree yield found with tree + pearl millet tree (6693.33 kg/ha). The higher grain yield, straw yield and biological yield recorded in sole cropping system in comparison to *H. binata* based agroforestry system. This is may be due to shade effect of *H. binata* tree on crop and competition for light, nutrients and water for vegetative growth of plants. The highest grain yield recorded in sole cow pea (716.50 kg/ha) followed by sole pearl millet (696.23 kg/ha) and lowest grain yield (286.73 kg/ ha) recorded in tree + pearl millet agroforestry system. The grain yield in sole cropping system was recorded higher for all the crops viz., cow pea, pearl millet, cluster bean, green gram and moth bean (716.50, 696.23, 676.83, 541.43 and 454.20 kg/ha), respectively. Similar findings under *H. binata* based agroforestry system also observed by (Shankar *et al.,* 2005) and (Singh and Rathod, 2007). Reduction in yield of the crops beneath the tree canopy also due to limiting factor of rainfall in the arid regions (Ong *et al.,* 1991). The highest straw yield recorded for sole pearl millet (1100.03 kg/ha) followed by sole cluster bean (879.90 kg/ha) and sole cow pea (823.97 kg/ha) and lowest straw yield observed in tree + moth bean (276.87 kg/ha) based agroforestry system. The same trends of yields were observed for biological yield (highest in sole pearl millet followed by sole cluster bean and cow pea and lowest in tree + moth bean (540.54 kg/ha) based agroforestry system. This is due to pearl millet crop have higher vegetative growth than pulses crops (cluster bean, green gram, moth bean and cow pea) and the foliar spread was higher in cereal crops in comparison to pulses crops. The transpiration rate and stomatal conductance in intercrops decreased due to the presence of the trees

Table 4. Economics analysis of *H. binata* based agroforestry system and sole cropping system

Treatments	Pearl millet equivalent yield (kg/ha)	Cluster bean equivalent yield (kg/ha)	Cost of cultivation (₹/ha)	Gross return (₹/ha)	Net return (₹/ha)	Benefit: Cost ratio	LER
Tree + Pearl millet	286.73	286.73	12845.00	20,721.77	7,876.77	0.6	1.23
Tree + Cluster bean	1,112.53	388.33	15075.00	34,010.66	18,935.67	1.267	1.40
Tree + Green gram	1,112.23	388.20	15075.00	31,576.45	16,501.45	1.067	1.42
Tree + Moth	598.60	208.97	12475.00	21,959.30	9,484.30	0.733	1.42
Tree + Cowpea	1,333.83	506.13	14075.00	33,880.45	19,805.45	1.433	1.40
Sole Pearl millet	696.23	243.03	10845.00	26,080.72	15,235.72	1.400	-
Sole Cluster bean	1,939.07	676.83	13075.00	41,151.57	28,076.57	2.133	-
Sole Green gram	1,873.13	653.83	13075.00	35,585.73	22,510.73	1.733	-
Sole Moth	1,031.17	359.93	10475.00	19,825.90	9,350.90	0.900	-
Sole Cowpea	2,312.43	878.73	12075.00	40,643.45	28,568.45	2.367	-
CD at 5%	173.50	63.68		3,510.95	3,511.09	0.293	-

in agroforestry system. Reduction in yields of pulses crops below the tree canopy in comparison to sole crops in traditional agroforestry systems of arid regions registered by (Tewari *et. al.,* 2014). The harvest index percent was highest observed for tree + moth bean (48.78 %) based agroforestry system and lowest for sole pearl millet (38.76%) cropping system. Similar findings in reduction in yield of agroforestry systems observed (Tripathi *et al.,* 2006 and Sarvade *et. al.,* 2014).

Economics analysis and Equivalent yield

The economic analysis of *H. binata* based agroforestry and sole cropping based system given in Table 4. The pearl millet equivalent yield was highest in sole cow pea based cropping system (2312.43 kg/ha) followed by sole cluster bean (1939.07 kg/ha) and sole green gram (1873.13 kg/ha) based cropping system and lowest in tree + moth bean based agroforestry system (598.60 kg/ha). The same trend of cluster bean equivalent yield was observed as highest in sole cow pea based cropping system (878.73 kg/ha) followed by sole cluster bean (676.83 kg/ha) and sole green gram (653.83 kg/ha) based cropping system and lowest in tree + moth bean based agroforestry system (208.97 kg/ha). The maximum gross return found in sole cluster bean (41151.57 ₹/ha) which was at par for sole cow pea (40643.45 ₹/ha) and lowest for sole moth bean (19825.90 ₹/ha) cropping system. The net return was found maximum in sole cow pea (28568.45 ₹/ha) which was at par of sole cluster bean (28076.57 ₹/ha) and lowest for tree + pearl millet (7,876.77 ₹/ha). The B:C ratio was also found best for sole cow pea (2.36) based cropping system followed by sole cluster bean (2.13) based cropping system and lowest in tree + pearl millet (0.60) based agroforestry system. The land equivalent ration was found highest for tree + green gram and tree + moth bean based agroforestry system (1.42) followed by tree + cow pea based agroforestry system and tree + cluster bean based agroforestry system (1.40) and lowest for tree + pearl millet based agroforestry system (1.23). Hence, results shows that *H. binata* based agroforestry system is viable under rainfed arid condition however, the grain yield, straw yield and biological yields significantly reduced in *H. binata* based agroforestry system in comparison to sole cropping based system. The gross return, net return and B:C ration was also found higher in sole crops based system in comparison to *H. binata* based agroforestry system. Same results found under *H. binata* based agroforestry system and sole cropping system with sole sunflower intercrop (Lata *et al.,* 2012) and assessing economic analysis in agroforestry system with sole cropping system (Maurya *et al.,* 2025). *H. binata* based agroforestry system provides yield in term of green leaves fodder for small ruminants and pruned branches also gave wood for fuel and small timber purpose. If we compare total system in term of LER, it is found more than 1 and the system is viable and good to compensate the crop productivity and other multipurpose benefit to the environment and livelihood of the people of arid regions. Similar finding also found while calculating LER for the system (Pent, 2020).

CONCLUSION

It can be concluded that the *H. binata*-based agroforestry system under rainfed conditions in the arid region resulted in lower crop yields than the sole cropping system, primarily due to reduced light availability and soil moisture under the agroforestry system. However, the Land Equivalent Ratio (LER) was greater than 1, indicating that the agroforestry system utilizes land more efficiently than sole cropping. This suggests that the system can enhance farm income stability and promote long-term sustainability by serving as a viable alternative to traditional farming practices in arid regions, while also improving the microclimate. Furthermore, the system provides multiple benefits, including livestock fodder, fuelwood, and small timber, while enhancing the physical and chemical properties of the soil. These advantages make *H. binata*-based agroforestry an effective strategy for sustainable natural resource management in arid ecosystems.

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