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Critical Analysis of Farmer Managed Natural Regeneration in Agrarian Lands in the Semi-arid Tropics of Peninsular India

Doddabasawa [a++*], Shivanand N. Honnali [b#] and B. M. Chittapur [c†]

[a] College of Agriculture, Bheemarayanagudi, Yadgir District, Karnataka-585 287, India.
[b] AICRP- Irrigation Water Management, ARS, Arabhavi, UAS, Dharwad, Karnataka-591218, India.
[c] University of Agricultural Sciences, Raichur 584 102, Karnataka, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

In nature, forests perpetuate themselves through natural regeneration, largely by self-sown seeds, through the process of secondary succession on degraded or deforested land, and more or less in a similar way, perennial vegetation regeneration occurs on croplands, maybe less vigorously. Traditionally, farmers manage such natural regeneration on their cropland for economic (food,

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++*Associate Professor of Farm Forestry;*
#*Agronomist;*
†*Former Director of Extension;*
**Corresponding author: E-mail: dkpatil2020@gmail.com;*

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fodder, fuelwood, timber) and ecological benefits (shade, protection, and soil conservation). However, the retention of trees on the farmland by the farmer is influenced by heterogenic factors (landholding size, climate and biophysical factors, and utility of the species). The present investigation on farmer-managed natural regeneration (FMNR) under the rainfed agroecosystem of peninsular India revealed a lot of variability. There were as many as 19 tree species belonging to 17 genera and 12 families, and most of them were indigenous (94.74%) to the region. Of these, eight were edible fruit bearers, six were fodder-yielding, and the remaining five were timber tree species. Further, neem (*Azadirachta indica)* was the dominant tree species (7.88 ha^{-1}), followed by babul (*Acacia nilotica*), desert mesquite (*Prosopis juliflora*), ber (*Ziziphus mauritiana),* and morinda (*Morinda pubescens*). Most of these trees were located on the boundary (48.75%), and the remaining mostly occurred on the bunds (38.33%), while a few (12.92%) were found scattered over the farmland. Significantly higher species density (mean number of species) and tree density (trees per ha) were observed with large farmers (holding size > 4 ha) (4.42 and 28.23, respectively), followed by medium farmers (holding size 2–4 ha), while significantly lower species density and tree density were observed with small farmers (holding size < 2.0 ha) (3.39 no. and 9.61ha^{-1}, respectively), productive land being a constraint with smallholders. Similarly, significantly higher species density and tree density occurred on the boundary of the farmland (4.00 no. and 18.9 ha^{-1}, respectively), followed by bund-oriented trees. Similarly, significantly lower species density and tree density were observed among the scattered plantations of the farmland (2.87 no. and 6.48 ha^{-1}, respectively). However, there were no significant differences among the villages with species and tree density. In all, retention of species and density were largely influenced by the size of landholding, mostly in untilled areas, and the retention depended on the utility and characteristics of the species. The tree population on the boundary of the farmland mostly comprised thorny species, probably for protection from stray animals. Further, the predominance of neem trees in the study was attributed to their adaptability to the prevailing environment, multiple utility, and regeneration characteristics, besides their easy dispersal by birds. Finally, it is suggested to conserve a few species such as *Wrightia tinctoria, Acacia ferruginea, Cordia dichotoma, Balanites roxburghii, Bauhinia racemose,* and *Ficus glomerate* for their ecosystem services.

Keywords: Natural regeneration; farmer managed natural regeneration; neem; diversity indices; species density and tree density.

1. INTRODUCTION

It is a well-known fact that forests perpetuate themselves through natural regeneration by self-sown seeds or by coppice or by root suckers largely with native species, and it is a slow process of secondary succession influenced by climate and biophysical factors (Ghazoul and Chazdon, 2017; Robin et al*.,* 2020). Forests are also regenerated manually through sowing or planting, which is rather costlier (Bullock et al*.,* 2011) and which is usually oriented with mono-species of economic value and often consisting of fast-growing non-native species. However, there is one more method, which is by and large overlooked, called assisted natural regeneration, wherein natural regeneration on deforested or degraded lands is assisted, protected, and managed through controlled burning of bushes, regeneration felling, soil working, and fencing from grazing, and it is cheaper and works on the principles of secondary succession and usually with native species (Fischer et al*.,* 2009; Megan et al*.,* 2015) and hence, in recent days this method of regeneration is more emphasized under sustainable forest management (Gilroy et al*.,* 2014).

Similarly, natural regeneration of trees and shrubs is also occurring on cropland, pastureland, and community lands and is mostly assisted, protected, and managed by the farmers for ecological and economic reasons, and such management of vegetation is termed as farmer-assisted natural regeneration (FANR) or farmer-managed natural regeneration (FMNR). In other words, FMNR is described as the practice of managing and protecting non-planted trees and shrubs on farmland by the farmers for economic and ecological benefits (Eric et al*.,* 2011), and these land use systems have significant species diversity and variation in density of useful plants (Schroth et al*.,* 2004; Doddabasawa et al*.,* 2020). This practice of retaining naturally regenerated trees and shrubs on farmland is a traditional method and is also considered an agroforestry system; nevertheless, FMNR is distinct from agroforestry in that it is solely dependent on natural regeneration (Abasse et al*.,* 2009). A good number of studies indicated potential benefits of natural regeneration on farmlands, such as enhanced biodiversity, helping to mitigate and adapt to climate change, and provision of multiple goods and ecosystem services (Jose 2009; Nair et al., 2010 and Chittapur et al., 2017). The FMNR not only benefits the farmer but also helps to increase the forest cover and yields similar to the benefits realized in active reforestation (Abdirizak et al.2013; Kibru et al., 2021). Though a good number of trees and shrubs regenerate naturally on farmland, in most instances farmers retain species of economic value and useful trees and shrubs (Mohammed and Asfaw, 2015). Generally, the structure and composition of tree species on cropland are influenced by heterogenic factors (Pattanayak et al., 2004; Giller et al. 2006), such as the ecological condition of the region, the socio-economic status of the farmer, and the utility and characteristics of the tree species. The critical analysis of FMNR would help in understanding the pattern of retention, species richness, and abundance, which in turn helps for further improvement of the agroecosystem and biodiversity conservation. Therefore, the present investigation on the analysis of FMNR was undertaken under the rainfed agroecosystem of the northeastern region of Karnataka, India.

2. MATERIALS AND METHODS

The present investigation was undertaken under the rainfed agroecosystem of Yadrami taluka in the Kalaburagi district of Karnataka, India. The climate is semi-arid with a short monsoon, a mild winter, and a hot summer. The average rainfall is around 750 mm, and the minimum and maximum average annual temperatures are 18.6^0 C to 32.5^0 C, respectively. The soils are deep and medium black soils in major areas, while red loams, sandy loams, and light-textured soils are also found in a few pockets. The study area comprised 12 villages covering 20 km², and in each village, 20 farmers were selected and later were categorized based on size of landholding into small (<2 ha), medium (2-4 ha), and large (>4 ha) farmers, and in all, the total sample size was 240 farmers (Table 1). The information on the retention pattern of naturally regenerated trees on farmland, species richness, density, and diversity were recorded by visiting the field physically and interviewing farmers with a semi-structured questionnaire prepared for the study.

Trees were retained on the bund and/or boundary or scattered over the entire farmland. The retention pattern of these naturally regenerated trees by farmers was recorded and expressed in percentage out of the total farmers surveyed and were analyzed using Chi-square test at level of 0.05 per cent significance. Species richness, species density, and tree density of > 30 cm gbh (girth at breast height) were recorded with a plot size of one hectare representing the total farmland of each individual farmer. The data on species richness were obtained by aggregating the number of species present and expressed in the total number of species per village, per pattern of retention, and per category of farmers. The species density was calculated by aggregating the total number of species found among patterns, farmers, and per village and expressed as the mean number per hectare. Similarly, the tree density was calculated by counting the total number of trees divided by the number of farmers and expressed as the mean number per hectare.

Table 1. Details of study area selected to assess the FMNR

Sl.No	Name of Village	Categories of farmer (in number)				Latitude	Longitude	MSL (m)
		Small	Medium	Large	Total			
1	Anajagi	09	10	01	20	16°50'32"N	76°38'38"E	501
2	Bilawar	10	03	07	20	16°49'06"N	76°39'21"E	507
3	Jamakhandi	10	07	03	20	16°48'21"N	76°42'59"E	487
4	Kachur	08	07	05	20	16°49'08"N	76°39'02"E	491
5	Konnur	09	10	01	20	16°47'17"N	76°42'07"E	491
6	Mangalore	13	06	01	20	16°49'32"N	76°38'33"E	507
7	Maradagi	12	06	02	20	16°49'00"N	76°42'11"E	527
8	Nandihalli	07	10	03	20	16°50'27"N	76°40'29"E	514
9	Neradagi	10	07	03	20	16°49'55"N	76°42'02"E	515
10	Sathkhed	14	04	02	20	16°51'06"N	76°43'01"E	511
11	Shivapur	14	04	02	20	16°47'47"N	76°38'12"E	491
12	Tippanal	14	05	01	20	16°49'48"N	76°39'20"E	508
	Total	**130**	**79**	**31**	**240**			

The dominance of the tree species on farmland was calculated by taking the relative density of the species, which was calculated by dividing the total number of individual species by the overall total of all the species, and the frequency of the species was calculated based on the frequency of the occurrence of the species in all the sample plots. The data on the species diversity were subjected to Shannon and Simpson's diversity index analyses, which were calculated by using Shannon's index H' $=\sum_{i=1}^{n} \mathrm{Pi} \ln \mathrm{Pi}$ and Simpson index λ== $\sum_{i=1}^{n} Pi^2$ where 'n' is the total number of species and 'p' is the relative abundance of the i^{th} species (Christine andNestor,2008). The data collected were analyzed for descriptive statistics and one-way ANOVA at a significance level of 0.05 by using SPSS (Statistical Package for Social Science, 20).

3. RESULTS AND DISCUSSION

The present investigation on the assessment of FMNR was purposely undertaken under the rainfed agroecosystems, as there is a little interference from the human element in the rainfed agroecosystems compared to the irrigated agroecosystem, and trees form an integral part of the rainfed agroecosystem, contributing greatly to the ecological and economic benefits. In the present investigation, farmers retained naturally regenerated trees on bunds and boundaries and also as scattered vegetation in the farmland.

The majority of the respondents retained naturally regenerated trees on the boundary (48.75%), followed by bund-grown trees (38.33%), whereas only 12.92 percent of growers retained naturally regenerated trees scattered over the farmland (Table 2). In fact, the retention of trees on farmland is influenced by heterogenic factors such as climate, biophysical factors, landholding, utility of the species, and regeneration ability, besides other characteristics of species. In the present study, farmers preferred to retain trees on bunds and boundary areas of the farmland as it offered the least interference with field crops; moreover, the bund and/or boundary retention permitted efficient/productive use of bund and boundary areas. The majority of the respondents in the study area preferred trees on the boundary to serve the protection issue from stray animals. The results are in line with Dwivedi et al., 2014 in their study on analysis of traditional agroforestry systems of Aligarh district of Uttar Pradesh reported majority of the farmers retained trees on bund and boundary of the farm land and similarly, Kibru et al. (2021), who, in their study on the perception of farmers practicing FMNR

Table 2. Retention pattern of trees on farmland by the farmers through FMNR under rainfed agroecosystem

Particulars	**Retention pattern of trees (%)**		
Land holding size	**Bund (n=92)**	**Boundary (n=117)**	**Scattered (n=31)**
Small (n=130)	65(27.09)	37(15.42)	28(11.66)
Medium (n=79)	23(09.58)	53(22.08)	03(01.25)
Large (n=31)	04(01.66)	27(11.25)	0 (0.00)
Total (N=240)	**92(38.33)**	**117(48.75)**	**31(12.92)**
P -Value	**0.000**	**0.000**	**0.000**
Village			
Anajagi (n=20)	8 (03.33)	9 (03.75)	3(01.25)
Bilawar (n=20)	6 (02.50)	11 (04.58)	3(01.25)
Jamakhandi (n=20)	8 (03.33)	6(02.50)	6(02.50)
Kachur (n=20)	12(05.01)	7(2.92)	1(00.42)
Konnur (n=20)	7(02.92)	10(04.17)	3(01.25)
Mangalore (n=20)	9(03.75)	10(04.17)	1(00.42)
Maradagi (n=20)	7(02.92)	10(04.17)	3(01.25)
Nandihalli (n=20)	6(02.50)	13(05.42)	1(00.42)
Neradagi (n=20)	3(01.25)	16(06.66)	1(00.42)
Sathkhed (n=20)	11(04.57)	8(03.33)	1(00.42)
Shivapur (n=20)	7(02.92)	9(03.75)	4(01.66)
Tippanal (n=20)	8(03.33)	8(03.33)	4(01.66)
Total (N=240)	**92(38.33)**	**117(48.75)**	**31(12.92)**
P -Value	**0.199**	**0.199**	**0.199**

Note: The values in parenthesis indicates percentage in Ethiopia, reported that farmers were more concerned with the shading effect of trees on crops and competition for space, water, and nutrients when trees grow as scattered vegetation in the cropland.

There were 19 tree species, belonging to 17 genera and 12 families, dominated by the Fabaceae family, and 94.74% of them were indigenous to the region (Table 3). Among the trees, there were eight edible fruit trees, six fodder-yielding, and the remaining five were timber species. This reveals farmers preference for edible fruits over fodder, timber, and fuelwood in the study area. The preference matters a lot, and in Ethiopia farmers practiced FMNR to get mainly fuelwood, followed by fodder, fruit, timber, and soil conservation (Kibru et al*.,* 2021). Fuelwood is the last preference in the study area, as the Govt. of India is promoting gas for domestic use to avoid tree felling.

Further, the study on dominance and relative frequency indicated that only five of the tree species were more preferred by the farmers, predominated by neem (*Azadirachta indica),* followed by babul (*Acacia nilotica*), desert mesquite (*Prosopis juliflora*), ber (*Ziziphus mauritiana),* and morinda (*Morinda pubescens*) with relative dominance of 52.88, 11.27, 7.52, 7.21, and 6.96%, respectively. Neem was retained by all the respondents with a cent per cent frequency, followed by babul (46.25%), ber (42.92%), morinda (42.08%), and khejri (*Prosopis cineraria*) (37.08%). Neem was also found to be the predominant species with a higher number of trees (7.88 ha^{-1}), followed by babul (1.68 ha^{-1}), desert mesquite (1.12 ha^{-1}), ber (1.08 ha^{-1}) and morinda (1.04 ha^{-1}) (Table 3). Neem fruits are preferred by birds, and the trees bear heavily during monsoon; the birds helped seed dispersal, and congenial environments favored establishment, thereby accounting for higher natural regeneration compared to other species in the study. That apart, neem trees have multiple utilities, which also contributed to their higher retention by farmers. This is in conformity with the Forest Survey of India (FSI) (2024), which reported the predominance of neem under drier ecosystems in India[21] (IFSR, 2021). Similarly, in Niger, under FMNR, Larwanou and Reij (2011) observed higher dominance of gao (*Faidherbia albida*) and baobab (*Adansonia digitata*) due to their wider utility and regeneration characteristics and also Haglund et al., 2025, in their study on Farmer Managed Natural Regeneration under dry land situation in Niger noticed three dominant species such as *Faidherbia albida, Bauhinia reticulata, and Guiera senegalensis.*

Though neem dominated the study area, the analysis revealed significant variability in retention of tree species on the farmland. Neem and babul were more preferred on bunds with 6.53 and 1.49 trees ha^{-1}, respectively, whereas neem (9.97 trees ha^{-1}), babul (2.14 trees ha^{-1}), desert mesquite (1.60 trees ha^{-1}) and ber (1.44 trees ha^{-1}) in that order, dominated the boundary area (Table 3). Interestingly, though neem is more competitive, it formed the majority among the scattered vegetation. However, farmers preferred thorny species, e.g., ber on the boundary to protect the farmland from stray cattle menace and encroachment. Even in the interior cropland, the predominance of neem is mainly for the reason that its higher crown width allows frequent pruning for fodder and fuelwood, and growers meet their dual needs. Results of this study are also substantiated from an Ethiopian study wherein Legesse and Negash (2021) observed variability in species with home gardens, parkland, and live fences, and there was a preference for thick, thorny trees such as *Vernonia amygdalina, Cupressus lusitanica, Juniperus procera, and Erythrina abyssinica* in live fences.

The analysis of retention of tree species under FMNR also revealed significant variability with the size of landholding. A significantly higher number of neem and babul trees per ha were observed with large farmers (15.19 and 4.77, respectively), followed by medium farmers (9.84 and 1.78, respectively), while next to neem it was desert mesquite in small farmers fields (4.95 and 1.15/ha, respectively) (Table 4). This suggests that large and medium farmers preferred timber-yielding species, whereas small farmers' preferred fuelwood and fodder species, as neem and desert mesquite are important sources of fuel wood and fodder. The results are in concurrence with the study on traditional agroforestry systems carried out in the Benin region of West Africa (Vodouhe et al*.,* 2011). There also the number of trees was directly proportional to the size of landholding; higher landholding and net income, large farmers preferred timber species; whereas, the smaller landholding and lesser income, farmers preferred more of fuel wood and fodder species. Similarly, wide scale adoption of Farmer Managed Natural Regeneration of trees were reported in West African Sahel by Reij and Garrity (2016).

Table 3. Total number of trees, number of individual trees per ha, relative dominance, relative frequency and utilization of each tree species of FMNR under rainfed agroecosystem

Sl.No.	Scientific name of tree species	Family	Nativity	Total trees	Trees ha^{-1}	Relative Dominance	Relative Frequency	Uses as expressed by the farmers
1	*Azadirachta indica*	Meliaceae	I	1891	7.88 (±5.01)	52.88	100.00	Ti, Fo, Fu, Se, Sh
2	*Acacia nilotica*	Fabaceae	I	403	1.68 (±2.60)	11.27	46.25	Ti, Fo, Fu, Sh, Pr
3	*Prosopis juliflora*	Fabaceae	E	269	1.12 (±1.89)	07.52	34.17	Fu, Fo, Pro
4	*Ziziphus mauritiana*	Rhamnaceae	I	258	1.08 (±1.64)	07.21	42.92	Ef, Fu, Fo, Pr, Sh
5	*Morinda pubescens*	Rubiacea	I	249	1.04 (±1.51)	06.96	42.08	Ti, Fu, Sh
6	*Tamarindus indica*	Fabaceae	I	146	0.61 (±1.17)	04.08	31.25	Ef, Sh
7	*Prosopis cineraria*	Fabaceae	I	133	0.55 (±0.86)	03.72	37.08	Fo, Sh, Fu
8	*Annona squamosa*	Annonaceae	I	116	0.48 (±1.40)	03.24	12.92	Ef
9	*Mangifera indica*	Anacardiaceae	I	53	0.22 (±0.84)	01.48	10.42	Ef, Sh
10	*Pithecellobium dulce*	Fabaceae	I	17	0.07 (±0.65)	00.48	01.25	Ef, Fo,Ti, Fu, Po
11	*Ailanthus excelsa*	Simarubaceae	I	11	0.05 (±0.28)	00.31	02.50	Fo, Me
12	*Balanites roxburghii*	Zygophyllaceae	I	07	0.03 (±0.21)	00.20	01.67	Fu, Me, Pr
13	*Bauhinia racemose*	Fabaceae	I	07	0.03 (±0.19)	00.20	02.92	Fo, Ti
14	*Ficus glomerata*	Moraceae	I	07	0.03 (±0.19)	00.20	02.50	Ef, Sh
15	*Cordia dichotoma*	Boraginaceae	I	03	0.01 (±0.11)	00.08	01.25	Ef, Sh
16	*Cassia fistula*	Fabaceae	I	02	0.01 (±0.09)	00.06	01.25	Ti, Sh
17	*Syzygium cumini*	Myrtaceae	I	02	0.01 (±0.09)	00.06	00.83	Ef Sh
18	*Acacia ferruginea*	Fabaceae	I	01	0.00 (±0.06)	00.03	00.83	Fo, Fu, Po
19	*Wrightia tinctoria*	Apocynaceae	I	01	0.00 (±0.06)	00.03	00.42	Ti, Sh
	Total (N=240)			**3576**				

Note: The values in parenthesis indicate standard deviation; Nativity: I= Indigenous, E=Exotic; Ti=Timber; Fo=Fodder; Fu=Fuelwood; Se=Seeds; Sh=Shade; Pr=Protection; Ef=Edible fruits Me=Medicine

Table 4. Total number of trees and mean no. of trees per ha with different retention pattern in FMNR under rainfed agroecosystem

Sl. No.	Name of the tree species	Bund (n=92)		Boundary (n=117)		Scattered (n=32)		F Test
		Total number of trees	Mean no. of trees ha^{-1}	Total number of trees	Mean no. of trees ha^{-1}	Total number of trees	Mean no. of trees ha^{-1}	
1	*Azadirachta indica*	601	6.53 (±4.05)	1166	9.97 (±5.22)	124	4.00 (±2.58)	0.000
2	*Acacia nilotica*	137	1.49 (±2.28)	250	2.14 (±3.00)	16	0.52 (±0.96)	0.005
3	*Morinda pubescens*	80	0.87 (±1.34)	162	1.38 (±1.70)	07	0.23 (±0.56)	0.000
4	*Ziziphus mauritiana*	68	0.74 (±1.15)	168	1.44 (±2.03)	22	0.71 (±0.82)	0.004
5	*Annona squamosa*	37	0.40 (±1.12)	79	0.68 (±1.66)	00	00	0.045
6	*Prosopis cineraria*	48	0.52 (±0.83)	69	0.59 (±0.95)	16	0.52 (±0.57)	0.824^{NS}
7	*Prosopis juliflora*	82	0.89 (±1.67)	187	1.60 (±2.13)	00	00	0.000
8	*Tamarindus indica*	64	0.70 (±1.31)	69	0.59 (±1.16)	13	0.42 (±0.62)	0.509^{NS}
9	*Mangifera indica*	24	0.26 (±0.74)	26	0.22 (±1.00)	03	0.10 (±0.30)	0.645^{NS}
10	*Cassia fistula*	02	0.02 (±0.15)	00	00	00	00	0.199^{NS}
11	*Balanites roxburghii*	03	0.03 (±0.23)	04	0.03 (±0.23)	00	00	0.716^{NS}
12	*Bauhinia racemose*	00	00	07	0.06 (±0.27)	00	00	0.054^{NS}
13	*Ailanthus excelsa*	03	0.03 (±0.23)	08	0.07 (±0.34)	00	00	0.405^{NS}
14	*Cordia dichotoma*	02	0.02 (±0.15)	01	0.01 (±0.09)	00	00	0.559^{NS}
15	*Pithecellobium dulce*	06	0.07 (±0.63)	11	0.09 (±0.74)	00	00	0.769^{NS}
16	*Ficus glomerata*	05	0.05 (±0.27)	02	0.02 (±0.13)	00	00	0.252^{NS}
17	*Acacia ferruginea*	01	0.01 (±0.10)	00	00	00	00	0.449^{NS}
18	*Syzygium cumini*	00	00	02	0.02 (±0.13)	00	00	0.349^{NS}
19	*Wrightia tinctoria*	00	00	01	0.01 (±0.09)	00	00	0.593^{NS}

*Note: * Indicates planted trees; The values in parenthesis indicate standard deviation*

3.1 Species Richness and Density Analysis under FMNR

In the present investigation, 19 tree species were recorded with a species density of 3.73 ha^{-1} (mean number of species per ha), and the mean number of trees per ha was 14.90 (Table 5). The high number of tree species was observed with medium farmers (17), followed by small farmers (16), and a relatively lesser number of species were observed with large farmers (12). However, significantly higher species density was recorded with large farmers (4.42 species ha^{-1}) followed by small farmers (4.00 species ha^{-1}) and the least was recorded with small farmers (3.39 species ha^{-1}) (Table 5). Similarly, a significantly higher number of trees was observed with large farmers (28.23 ha^{-1}) followed by medium farmers (18.38 ha^{-1}), whereas a significantly lower number of trees were recorded with small farmers (9.61 ha^{-1}) (Fig. 1). Further, a significantly higher Shannon index was obtained with large farmers (0.50) followed by medium farmers (0.48) and a significantly lower Shannon index was recorded with small farmers (0.43).

With regard to the Simpson index, there existed non-significant differences among the categories of farmers; however, a numerically higher Simpson index was observed with small farmers (0.44), followed by medium and large farmers (41 and 0.40, respectively). This envisages that larger farmers had a higher number of trees per hectare compared to medium and small farmers, which might be due to larger land areas allowing large farmers to accommodate a greater number of trees compared to other farmers, and thus land size becomes a deciding factor in accommodating trees. Though a lower number of species was observed with large farmers, a significantly higher Shannon index suggested that species were proportionally distributed. In contrast, a numerically higher Simpson index with small farmers indicated that the species were not proportionally distributed; in other words, small farmers retained a higher density of one or two tree species (Fig. 3). The results are in conformity with (Abebe et al. 2013; Bucagu et al. 2013 and Doddabasawa et al., 2019), who reported an increase in species richness and tree density with an increase in the farm size holding.

The high number of tree species was recorded on the boundary of the farmland (17), followed by the bund area (16), whereas only seven trees were retained under scattered vegetation. Significantly, higher species density (mean number of species per ha) and mean number

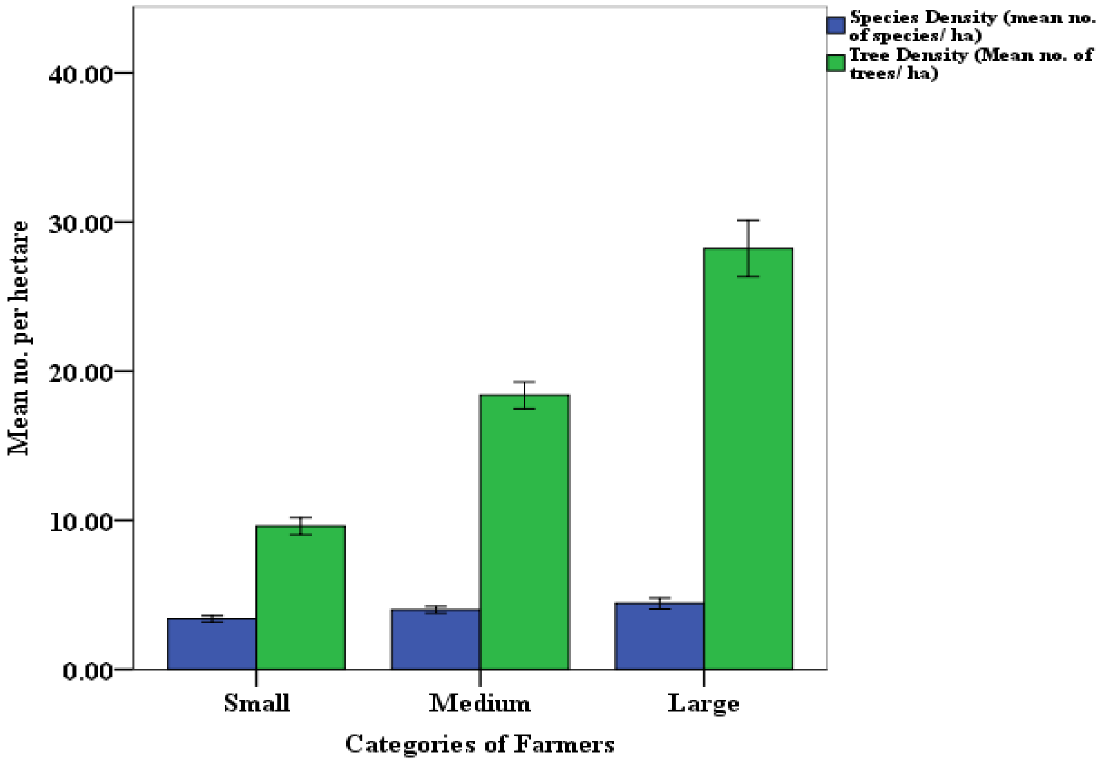

Fig. 1. Species and tree density of FMNR with categories of farmers under rainfed ecosystem

Table 5. Species richness, species density and no. of trees per ha with different land holding size, retention pattern and villages in FMNR under rainfed agroecosystem

Particulars	Species Richness	Species Density	Number of Trees	Shannon' Diversity Indices	Simpson Diversity Indices
Land holding size		**(ha^{-1})**	**(ha^{-1})**	**H**	**ƛ**
Small (n=130)	16	3.39 (±1.19)	9.61 (±3.28)	0.43 (±0.15)	0.44 (±0.15)
Medium (n=79)	17	4.00 (±1.06)	18.38 (±4.03)	0.48 (±0.13)	0.41(±0.13)
Large (n=31)	12	4.42 (±0.99)	28.23 (±5.16)	0.50 (±0.11)	0.40 (±0.11)
F Test(P< 0.05)		0.000	0.000	0.011	0.148^{NS}
Retention Pattern					
Bund	16	3.66 (±1.07)	12.64 (±4.95)	0.46 (±0.13)	0.42 (±0.14)
Boundary	17	4.00 (±1.23)	18.91 (±7.49)	0.48 (±0.14)	0.41 (±0.12)
Scattered	07	2.87 (±0.88)	06.48 (±3.02)	0.37 (±0.16)	0.50 (±0.19)
F Test(P< 0.05)		0.000	0.000	0.001	0.003
Village					
Anajagi (n=20)	13	3.70 (±1.38)	14.30 (±7.41)	0.46 (±0.16)	0.43 (±0.17)
Bilawar (n=20)	14	4.55 (±1.28)	18.95 (±9.96)	0.52 (±0.15)	0.39 (±0.14)
Jamakhandi (n=20)	13	3.65 (±0.75)	14.20 (±6.83)	0.46 (±0.10)	0.41 (±0.10)
Kachur (n=20)	12	3.80 (±1.00)	16.80 (±8.39)	0.45 (±0.13)	0.43 (±0.14)
Konnur (n=20)	10	3.70 (±1.17)	14.45 (±6.55)	0.44 (±0.17)	0.46 (±0.19)
Mangalore (n=20)	12	4.10 (±1.33)	13.20 (±7.10)	0.50 (±0.15)	0.39 (±0.13)
Maradagi (n=20)	11	3.40 (±1.43)	13.15 (±6.70)	0.44 (±0.15)	0.42 (±0.13)
Nandihalli (n=20)	09	3.65 (±1.09)	16.90 (±8.04)	0.44 (±0.13)	0.44 (±0.12)
Neradagi(n=20)	11	3.70 (±1.49)	16.20 (±7.65)	0.46 (±0.16)	0.42 (±0.13)
Sathkhed (n=20)	10	3.90 (±1.07)	15.10 (±5.96)	0.48 (±0.14)	0.40 (±0.15)
Shivapur (n=20)	08	3.25 (±0.64)	13.30 (±7.53)	0.42 (±0.08)	0.43 (±0.09)
Tippanal(n=20)	09	3.30 (±0.98)	12.25 (±6.64)	0.40 (±0.16)	0.48 (±0.18)
F Test (P< 0.05)		0.056^{NS}	NS 0.183^{NS}	0.465^{NS}	0.703^{NS}
Average (N=240)		**3.73(±1.18)**	**14.90 (±7.53)**	**0.46 (±0.14)**	**0.42 (±0.14)**

Note: The values in parenthesis indicate standard deviation

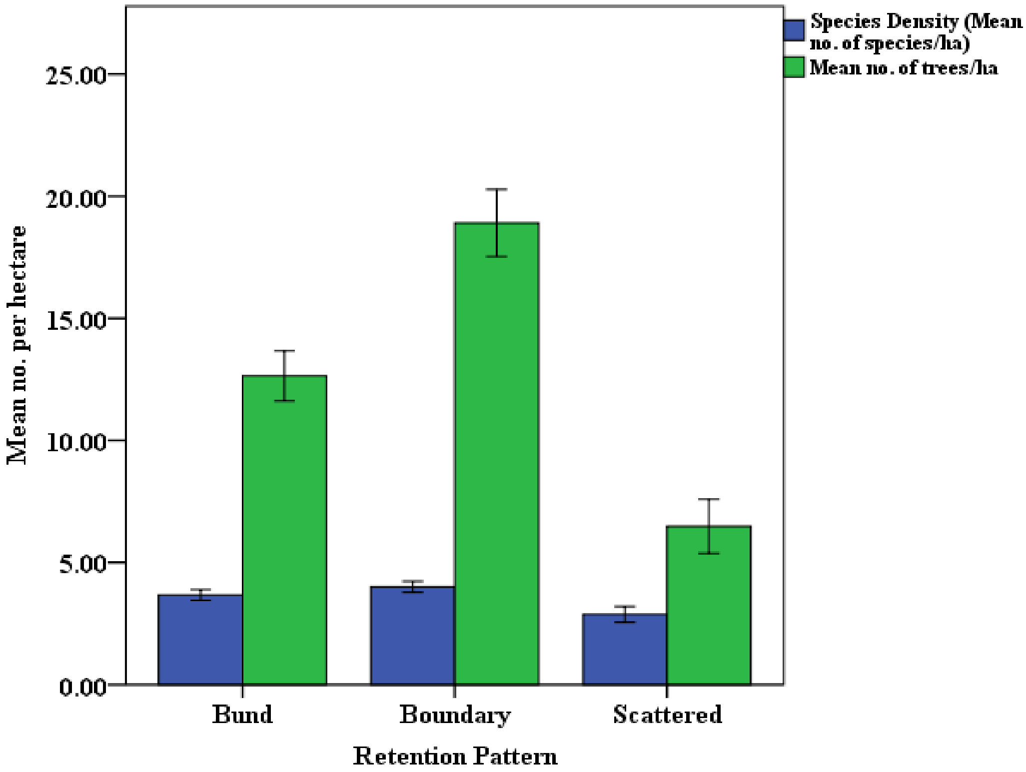

Fig. 2. Species and tree density of FMNR with retention pattern under rainfed ecosystem

of trees per ha were observed on the boundary (4.00 and 18.91, respectively), followed by the bund area (3.66 and 12.64, respectively) of the farmland, while significantly lower species density and mean number of trees per ha were observed in scattered vegetation retained (2.87 and 06.48, respectively) (Table 5 and Fig. 2). Similarly, a significantly higher Shannon index was recorded with boundary-oriented trees (0.48), followed by bund area (0.46), and a significantly lower Shannon index was with scattered retention (0.37) (Table 5). In contrast, a significantly higher Simpson index was observed in scattered retention (0.50), followed by the bunds (0.42), and a significantly lower Simpson index was recorded with the boundary area (0.41). The reason for the high species number and tree density on the boundary of the farmland could be due to the fact that farmers preferred thick populations mainly for protection and also for the reason of the least interference of the trees with field crops. Whereas, lower species and tree density under scattered situations could be to avoid interference of trees with field crops and with cultural operation. Further, scattered retention was observed more with small farmers. This is expected as small farmers have relatively less area under bund or boundary compared to medium or large farmers. Increased tree-crop interference from the trees scattered over the field with crops forced farmers to retain lesser trees in side fields compared to the bund and boundary regions of the farmland. Similarly, diversity indices analysis indicated that bund and boundary retained trees had higher species diversity and density, which means species were proportionally distributed in the bund and the boundary regions of the farmland compared to the interior region. The higher Simpson index with scattered retention indicated the dominance of one or two species (Fig. 4). The results are in line with Legesse and Negash (2021). However, the investigation revealed non-significant differences among the villages under the study with regard to species density and tree density and also with diversity indices. This suggests that climate and biophysical factors almost remained the same in the agroecological region; hence the FMNR was not much influenced, and the decisions of the farmers across their categories more or less remained the same under similar environments across villages. This is also affirmed by the fact that the villages selected for the study were within 20 km apart laterally, and the elevation of the villages also did not vary much (ranged between 487 to 527 m MSL) (Table 1).

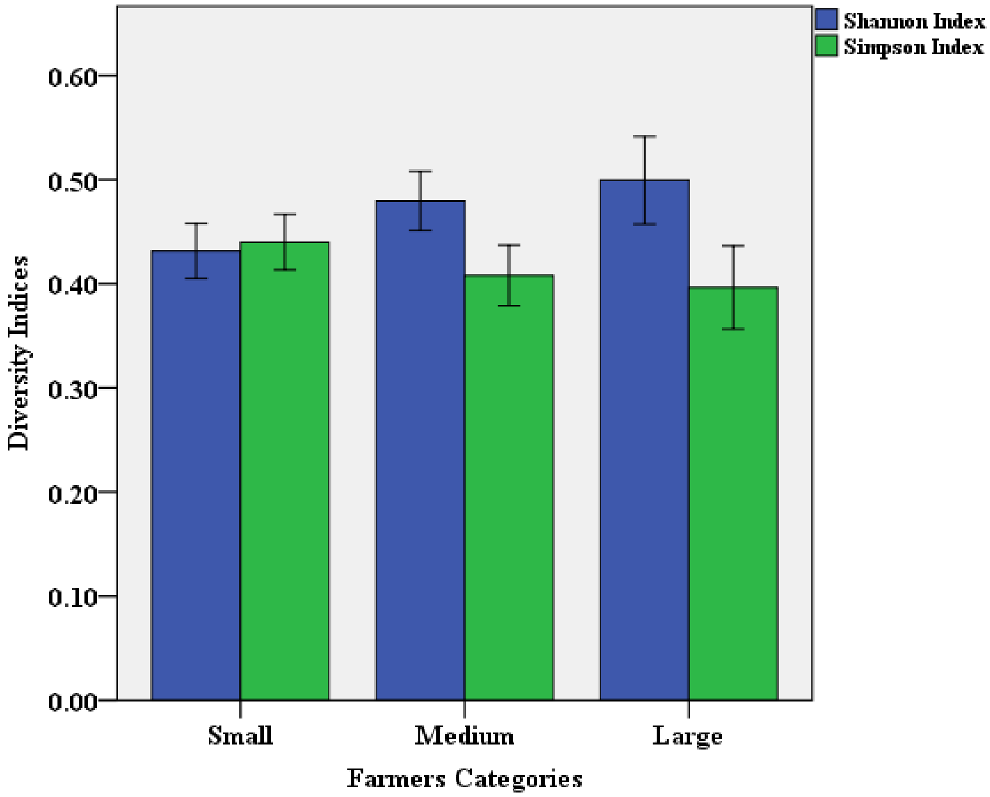

Fig 3. Diversity Indices of FMNR with categories of farmers under rainfed ecosystem

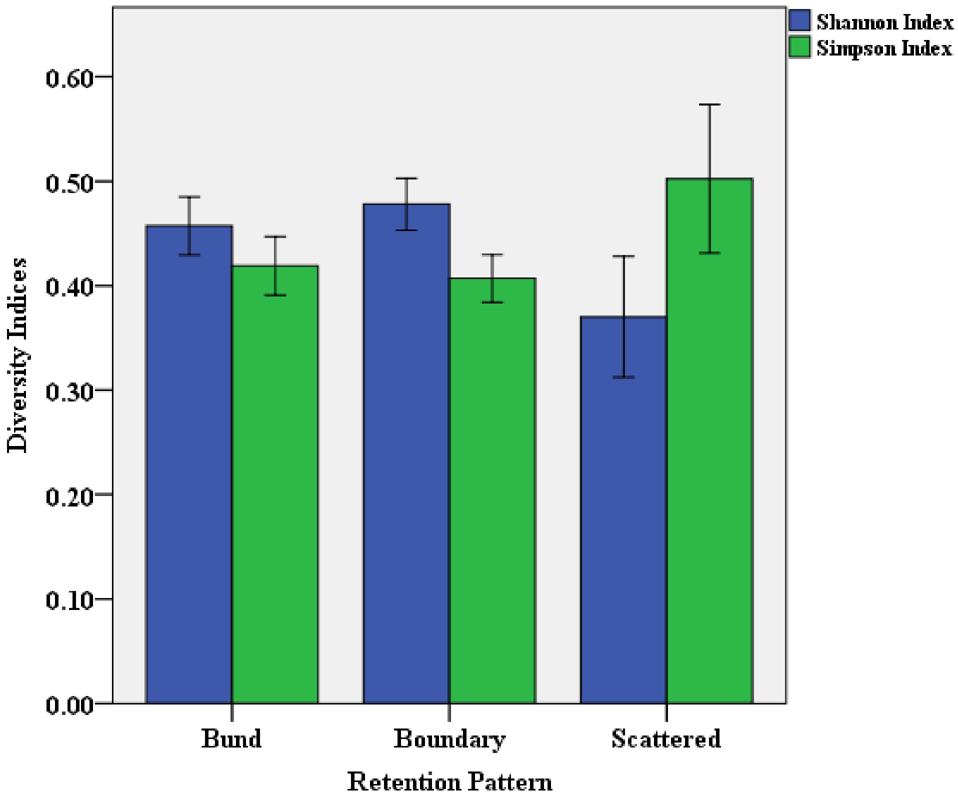

Fig. 4. Diversity Indices of FMNR with retention pattern under rainfed ecosystem

4. CONCLUSION

The present investigation on critical analysis of FMNR under the rainfed ecosystems recorded 19 tree species; most of them were indigenous to the region, except desert mesquite, which was considered a weed in the recent past due to its prolific regeneration and vigorous growth. However, in the present study, it was retained by the farmer more preferably on the boundary areas of the farmland for protection, fuel wood, and fodder purposes. Thus, it indicates that farmers have accepted this species in spite of its gregarious nature; of course, of late it is becoming an important biochar source. Further, neem was found to be predominant with 7.88 trees per ha, followed by babul, ber, and morinda, whereas a few trees need conservation attention, such *Wrightia tinctoria (dyer's oleander), Acacia ferruginea (safaid kahir), Cordia dichotoma* (Indian cherry)*, Balanites roxburghii (desert date), Bauhinia racemose,* and *Ficus glomerate (*cluster fig). As these species have significant medicinal value and are being used as ethnomedicines. However, in the present study, these species were less used by the farmers and lesser natural regeneration had compound effect on the lower population (Table 3). Hence, in the interest of their utility these species need to be conserved. Predominance of neem was attributed to its multiple utilities and its characteristics, such as higher crown width, fruiting season, and dispersal mainly through birds. The study revealed that retention of naturally regenerated perennial vegetation was influenced by the size of landholding. Significantly higher species density and tree density per ha were observed with large farmers (4.42 and 28.23, respectively), followed by medium farmers. However, significantly lower species density and tree density per ha were observed with small farmers (3.39 and 9.61, respectively). Thus, it suggests that larger landholding helps greater retention of trees. Further, the diversity indices indicated higher and proportional distribution of trees with larger farmers, whereas small farmers, though they retained more species, had one or two species with higher density with special preference to neem and khejri (Fig. 1). Similarly, significantly higher species density and tree density per hectare were noticed with retention on the boundary of the farmland (4.00 and 18.91, respectively), followed by bund vegetation. However, significantly lower species density and tree density per ha were noticed with scattered vegetation over the farmland (2.87 and 06.48, respectively). More tree species were retained thickly on the boundary of the farm mainly to get protection. However, species density and tree density per ha were not influenced among the villages, as the villages for the study were adjacent and enjoyed almost similar climate (20 sq km range).

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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