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Research article

Assessment of carrying capacity of different silvipastoral system for sustainable sheep production in Western zone of Tamil Nadu, India

V. S. Mynavathi[1*], C. Jayanthi[2], D. Ravisankar[3], V. M. Sankaran[1] and C. Valli[1]

[1]Madras Veterinary College, TANUVAS, Chennai-600007, India
[2]Tamil Nadu Agricultural University, Coimbatore-641003, India
[3]PGP College of Agricultural Sciences, TNAU, Namakkal-637405, India
[*]Corresponding author email: mynagri@gmail.com

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Abstract

A study was conducted to assess the carrying capacity of silvipastoral-based agroforestry systems in dryland regions of Tiruppur district, Tamil Nadu, over a two-year period through on-farm field experiments. The treatments consisted of five silvipastoral systems *viz., Acacia leucophloea + Cenchrus ciliaris (T_1), A. leucophloea + C. ciliaris + Stylosanthes hamata (T_2), A. leucophloea + C. setigerus + S. hamata (T_3), A. leucophloea + Sorghum bicolor + Phaseolus trilobus (T_4)* and *A. leucophloea + C. setigerus + S. hamata* and *S. bicolor + P. trilobus (T_5)*. Six Mecheri sheep (five ewes and one ram) were maintained in each location of silvipastoral system. The results obtained from two years and three locations indicated higher *Cenchrus* equivalent yield, utilization rate and carrying capacity of 11010 kg ha^{-1}, 80.5% and 39 sheep ha^{-1}, respectively in T_5, followed by 9713 kg ha^{-1}, 79.8% and 34 sheep ha^{-1}, respectively in T_4. Thus, the *A. leucophloea + C. setigerus + S. hamata* and *S. bicolor + P. trilobus* (T_5) silvipastoral system was found to be ideal for higher forage yield and carrying capacity of pasture in the western region of the Tamil Nadu.

Keywords: Carrying capacity, Silvipasture system, Small ruminant production

Introduction

Silvipastoral systems could be developed to supply nutritious green foliage to animals throughout the year by growing trees/shrubs in wastelands (Arulnathan *et al.*, 2020). Silvopasture, an agroforestry system that combines trees and forage, has gained appeal in recent years as an environmentally beneficial and economically viable alternative for land-use strategy (Jose and Dollinger, 2019). Similarly, in arid and semi-arid regions, where crop production is risky due to unpredictable rainfall and frequent droughts, horticulture and small ruminant production systems play a critical role in sustaining the lives of the poor in rainfed agro-ecosystems (Pasha, 2000). Feed conversion ratios of the energy and protein in feeds consumed by animals vary depending on species, production systems, feed type and products (Mahanta *et al.*, 2020). In dryland zones, the scarcity of fodder during summer is a serious issue, and supplementary feeding of concentrate, conserved fodder, and tree leaves to animals helps mitigate the negative effects of feed scarcity and improves animal production (Shinde and Mahanta, 2020). In Tamil Nadu, dry land covers 49% of the land area. In dry land, variations in amount and distribution of rainfall affect agricultural productivity as well as the socio-economic status of farmers. In Tamil Nadu, permanent pastures and other grazing land cover 0.11 lakh hectares, whereas fodder crops grown in dry land cover 1.57 lakh hectares. (Velayudham, 2011). Among the 32 districts of Tamil Nadu, Tiruppur, Namakkal and Salem occupy major part of grazing lands under the *Korangadu* pasture. Small ruminants are maintained on grazing lands and their production is limited by the low quality of native grasses and a lack of quality forage, during the dry season (Mynavathi and Jayanthi, 2017).

Silvipasture is a land use system used for grazing livestock. The existing traditional silvipastoral system was unable to provide livestock with nutritious and off-season forage. The paddock is not rotated for grazing on a regular basis, resulting in a loss of soil fertility. Pursuing literature revealed scant information on the carrying capacity of agroforestry models. With this background, an on-farm field experiment was conducted to assess the carrying capacity of a silvipastoral-based agroforestry system in the dryland areas of the western zone of Tamil Nadu.

Materials and Methods

Study site and experimental design: An on-farm field experiment was conducted at the Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu for a period of two years. Three farmers were also chosen for the field experiment based on the results of a survey. The experiments were conducted in farmer's fields at Kilankattuvalasu, Kangeyam (location I), Pulliampatti, Mulanur (location II) and Kambaliampatti, Mulanur (location III) villages in Tiruppur district of Tamil Nadu. During the experimental period in the location I (Kangeyam), the maximum temperature ranged from 32.0 to 34.0^{o}C and the minimum temperature ranged from 21.0 to 24.0^{o}C. The mean annual rainfall received during the first and second year of the experimental period was 830.8 mm and 875 mm, respectively. In locations II and III (Mulanur), the maximum temperature ranged from 31.0 to 33.0^{o}C and the minimum temperature ranged from 21.0 to 23.0^{o}C. The mean annual rainfall received during the first and second year of the experimental period was 675.5 mm and 705.0 mm, respectively. The soil of the experimental site was calcareous in nature and had a pH of 7.3. The available nitrogen, phosphorus and potassium in the soil were 289.9, 27.8 and 257.1 kg ha^{-1}, respectively and the organic carbon content was 0.54%.

Trees of the *A. leucophloea* species were spaced at 8 × 8 m. The trees were five years old, and each treatment had 30 trees. Fodder crops were grown in the interspaces between tree rows. *A. leucophloea* tree pods were fed to animals and also conserved for feeding during scarcity periods. In each location, five ewes and one ram of Mecheri sheep breed, totalling 18 sheep in 3 locations were maintained. The same group of five ewes and one ram (6 sheep) were shifted to other treatment like T_2, T_3, T_4 and T_5 after seven days of grazing period. Sheep were allowed to graze for eight hours daily in the silvipasture and housed in an open enclosure (*patti*) near farmer's dwelling. During the rainy season, animals prefered to graze lush grass, but during the dry season, when there was no grass, they used to consume *Acacia* tree's leaves and pods. During the off-season, each sheep was fed 2 kg of *Acacia* pods and groundnut haulm every day.

Methodology for estimating carrying capacity: Carrying capacity is the stocking rate for a particular grazing animal unit throughout the grazing period. It was determined by taking into account four factors *viz.*, Annual forage yield, utilization rate, average daily intake and length of the grazing period (Blanchet *et al.*, 2003). Carrying capacity was calculated using the following formula.

$$\text{Carrying capacity} = \frac{\text{Annual forage yield (kg ha-1) x Utilization rate (\%)}}{\text{Average daily intake (kg day-1) x Length of grazing period (days)}}$$

The total amount of forage dry matter produced per unit area in a year is known as annual forage yield. The annual forage yield was calculated by adding the biomass yield of three cuttings together (70 DAS, 115 DAS and 160 DAS). Annual forage yield was estimated by calculating the yield of all fodder crops (*Cenchrus*, *Stylosanthes*, *Sorghum bicolor* and *Phaseolus trilobus*) in the sivipastoral system. Forage yield of *Acacia leucophloea* was estimated by partial lopping of leaves and twigs along with pods during the summer season.

The utilization rate of forage was calculated and expressed as a percentage over a five-day rotation. Forage samples were taken and weighed immediately before and after grazing to evaluate the utilization rate at the start of each grazing period. Forage yield was calculated by harvesting the forage using quadrat (0.5 x 0.5 m) in four places at random.

$$\text{Utilization rate} = \frac{\text{Forage yield before grazing (kg ha-1)} - \text{Forage yield after grazing (kg ha-1)}}{\text{Forage yield before grazing (kg ha-1)}} \times 100$$

Again, it was assumed that sheep can consume, on average, 2.5 kg of fodder per day, and this was used to calculate the carrying capacity. The number of days available for grazing determined the length of the grazing period. Sheep were allowed to graze until there was enough fodder to feed them. The grazing period began 70 days after the last rain. The carrying capacity was calculated using the actual number of days that the sheep were allowed to graze in the silvipasture. The productivity of each crop component was also converted into *Cenchrus* equivalent yield (CEY) for better comparison

Table 1. Treatment details (silvipastoral systems of 1 ha area)

T_1	-	*Acacia leucophloea + Cenchrus ciliaris*	:	0.20 ha
T_2	-	*A.leucophloea + C. ciliaris + Stylosanthes hamata*	:	0.20 ha
T_3	-	*A. leucophloea + C. setigerus + S. hamata*	:	0.20 ha
T_4	-	*A. leucophloea + Sorghum bicolor + Phaseolus trilobus*	:	0.20 ha
T_5	-	*A. leucophloea + C. setigerus + S. hamata & S. bicolor + P. trilobus*	:	0.20 ha

and expressed as tons. Thus CEY= [Production of fodder crop (t) x Cost of fodder crop (Rs.t^{-1})]/ [Cost of *Cenchrus grass* (Rs.t^{-1})].

Statistical analysis: The data were subjected to analysis of variance using the general linear model procedure of SPSS and means were compared for statistical significance by Duncan's multiple range tests (Snedecor and Cochran, 1994). The silvipasture production data were analyzed by means of Microsoft Excel program to generate descriptive statistics.

Results and Discussion

Annual Cenchrus equivalent yield: Higher annual *Cenchrus* equivalent yield of 12090, 9000 and 9820 kg ha^{-1} was recorded in T_5 followed by T_4 (10530, 7530 and 8260 kg ha^{-1}) in location I, II and III, respectively. In contrast, T_1 recorded lower annual *Cenchrus* equivalent yield of 4020, 2970 and 3270 kg ha^{-1} in location I, II and III, respectively. During the second year, T_5 recorded higher annual *Cenchrus* equivalent yield of 14050, 9980 and 11120 kg ha^{-1} in locations I, II and III, respectively. However, this was comparable with T_4 with an annual *Cenchrus* equivalent yield of 12220, 8690 and 11050 kg ha^{-1} in location I, II and III, respectively followed by T_2 with an annual *Cenchrus* equivalent yield of 7490, 5320 and 5770 kg ha^{-1} in location I, II and III, respectively. T_1 recorded lower annual *Cenchrus* equivalent yield of 4730, 3360 and 4390 kg ha^{-1} in locations I, II and III, respectively (Table 2).

In this study, due to variation in rainfall, the annual *Cenchrus* equivalent yield varied throughout the year and between locations. In location I, the high and well distributed rainfall resulted in higher forage production. These findings were consistent with Mulindwa *et al.* (2009), who reported that carrying capacity is dynamic and its variability is more pronounced within the year than between the years, which could be attributed to climatic circumstances. Climate factors, particularly rainfall in semiarid locations, have an impact on carrying capacity of pastures. Annual *Cenchrus* equivalent yield was higher in T_5. The combined cultivation of grasses and legumes improved forage output by 60% compared to grasses alone. This was in line with the findings of Ibrahim *et al.* (2001).

Utilization rate: During first year, higher utilization rate (UR) of 75% was recorded in T_2 followed by T_4 and T_5 with a utilization rate of 73% in location I, whereas in location II and III, T_2 recorded higher utilization rate of 84 and 83%, respectively followed by T_4 and T_5 (Table 3). During the second year, higher utilization rate of 88% was recorded in T_5 followed by T_4 with a utilization rate of 87% in location I. A lower utilization rate of 79 percent was recorded in T_1. In locations II and III, a higher utilization rate of 83% was recorded in T2, followed by T5 with a utilization rate of 81% and 79%, respectively. This was comparable to T4, which had utilization rates of 80% and 77%, respectively (Table 4). T_2 had a higher utilization rate of 83%. This might be due to higher palatability and preference of legume fodder by the sheep. This was also dependent on the length of the grazing season and the rotational frequency. The research of Massimiliano *et al.* (2014) also concluded that appropriate stocking levels and rotational grazing system of livestock in small paddocks improved grazing distribution and thus maximized grazing efficiency on rough sub-alpine and alpine pastures in the south-western Alps.

Length of grazing period: In the location I, the actual length of a grazing period (LGP) was 95 and 120 days during first and second year, respectively (Table 5). In locations II and III, the actual length of grazing period was 75 and 95 days during first and second year, respectively (Table 6-7). The reason attributed to the variation in length

Table 2. Annual *Cenchrus* equivalent yield (kg ha^{-1}) of different silvipastoral systems

Treatment	First year			Second year		
	Location I	**Location II**	**Location III**	**Location I**	**Location II**	**Location III**
T_1	4020	2970	3270	4730	3360	4390
T_2	6040	4460	4150	7490	5320	5770
T_3	5530	4060	4430	6380	4530	5120
T_4	10530	7530	8260	12220	8690	11050
T_5	12090	9000	9820	14050	9980	11120
Mean	7642	5604	5986	8974	6376	7490
SE	3.47	2.54	2.87	3.98	2.83	3.32
CD (p <0.05)	45.5	45.4	48.0	44.3	44.3	44.3

1000 kg = 1 ton

Table 3. *Cenchrus* equivalent yield and utilization rate of different silvipastoral systems (first year)

Treatments	Location I			Location II			Location III		
	CEY (kg ha^{-1})		UR (%)	*CEY* (kg ha^{-1})		UR (%)	*CEY* (kg ha^{-1})		UR (%)
	Before grazing	After grazing		Before grazing	After grazing		Before grazing	After grazing	
T_1	1290	370	71	950	284	70	1050	324	69
T_2	2110	518	75	1560	245	84	1450	252	83
T_3	1500	414	72	1100	278	75	1200	338	72
T_4	8940	2400	73	6390	1196	81	7010	1311	81
T_5	7550	2007	73	5620	1075	81	6130	1173	81
Mean	4278	1142	73	3124	616	78	3368	680	77

CEY: *Cenchrus* equivalent yield; UR: Utilization rate

Table 4. *Cenchrus* equivalent yield and utilization rate of different silvipastoral systems (second year)

Treatments	Location I			Location II			Location III		
	CEY (kg ha^{-1})		UR (%)	*CEY* (kg ha^{-1})		UR (%)	*CEY* (kg ha^{-1})		UR (%)
	Before grazing	After grazing		Before grazing	After grazing		Before grazing	After grazing	
T_1	1530	315	79	1090	326	70	1420	379	73
T_2	2560	417	84	1820	302	83	1970	344	83
T_3	1790	357	80	1270	321	75	1440	408	72
T_4	10320	1319	87	7340	1476	80	9330	2116	77
T_5	9940	1198	88	7060	1350	81	7870	1627	79
Mean	5228	721	84	3716	755	78	4406	975	77

CEY: *Cenchrus* equivalent yield; UR: Utilization rate

Table 5. Carrying capacity of different silvipastoral systems (Location I)

Treatments	Annual CEY (kg ha^{-1})		Utilization rate (%)		ADI (kg day^{-1})	LGP (days)		CC (No. of sheep ha^{-1})		CC of sheep (in ACU)	
	Ist year	IInd year	Ist year	IInd year		Ist year	IInd year	Ist year	IInd year	Ist year	IInd year
T_1	4020	4730	71	79	2.5	95	120	12	13	2.4	2.6
T_2	6040	7490	75	84	2.5	95	120	19	21	3.8	4.2
T_3	5530	6380	72	80	2.5	95	120	17	17	3.4	3.4
T_4	10530	12220	73	87	2.5	95	120	32	35	6.4	7.0
T_5	12090	14050	73	88	2.5	95	120	37	41	7.4	8.2
Mean	7642	8974	73	84	2.5	95	120	23	25	4.6	5.0

CC: Carrying capacity; ADI: Average daily intake; LGP: Length of grazing period; ACU: Adult cattle unit

of grazing period over location was due to variation and distribution of annual rainfall of 830.8 mm and 875.0 mm in location I and 675.5 mm and 705.0 mm in location II and III during first and second year, respectively.

Carrying capacity: In the location I (Table 5), higher carrying capacity (CC) of 37 sheep ha^{-1} for 95 days of grazing period was obtained in T_5 followed by T_4 with a carrying capacity of 32 sheep ha^{-1} and the lower carrying capacity of 12 sheep ha^{-1} was obtained in T_1 during first year. During the second year, higher carrying capacity of 41 sheep ha^{-1} for 120 days of grazing length was obtained in T_5 followed by carrying capacity of 35 sheep ha^{-1} with T_4. It was followed by T_2 with a carrying capacity of 21 sheep ha^{-1} in location I.

In location II (Table 6), higher carrying capacity of 39

Table 6. Carrying capacity of different silvipastoral systems (Location II)

Treatments	Annual CEY (kg ha^{-1})		Utilization rate (%)		ADI (kg day^{-1})	LGP (days)		CC (No. of sheep ha^{-1})		CC of sheep (in ACU)	
	Ist year	IInd year	Ist year	IInd year		Ist year	IInd year	Ist year	IInd year	Ist year	IInd year
T_1	2970	3360	70	70	2.5	75	95	11	10	2.2	2.0
T_2	4460	5320	84	83	2.5	75	95	20	19	4.0	3.8
T_3	4060	4530	75	75	2.5	75	95	16	14	3.2	2.8
T_4	7530	8690	81	80	2.5	75	95	33	29	6.6	5.8
T_5	9000	9980	81	81	2.5	75	95	39	34	7.8	6.8
Mean	5604	6376	78	78	2.5	75	95	24	21	4.8	4.2

CC: Carrying capacity; ADI: Average daily intake; LGP: Length of grazing period; ACU: Adult cattle unit

Table 7. Carrying capacity of grazing lands (Location III)

Treatments	Annual CEY (kg ha-1)		Utilization rate (%)		ADI (kg day^{-1})	LGP (days)		CC (No. of sheep ha-1)		CC of sheep (in ACU)	
	Ist year	IInd year	Ist year	IInd year		Ist year	IInd year	Ist year	IInd year	Ist year	IInd year
T_1	3270	4390	69	73	2.5	75	95	12	14	2.4	2.8
T_2	4150	5770	83	83	2.5	75	95	18	20	3.6	4.0
T_3	4430	5120	72	72	2.5	75	95	17	16	3.4	3.2
T_4	8260	11050	81	77	2.5	75	95	36	36	7.2	7.2
T_5	9820	11120	81	79	2.5	75	95	42	37	8.4	7.4
Mean	5986	7490	77	77	2.5	75	95	25	25	5.0	5.0

CC: Carrying capacity; ADI: Average daily intake; LGP: Length of grazing period; ACU: Adult cattle unit

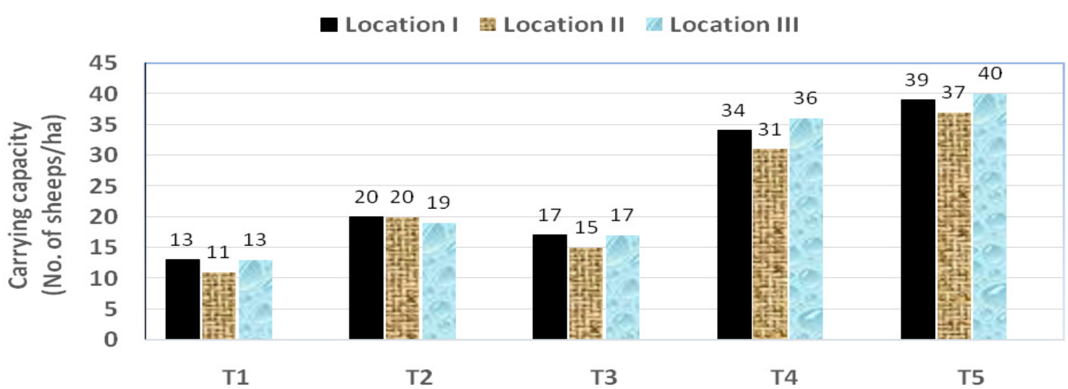

Fig 1. Carrying capacity of silvipastoral system (mean of two years)

sheep ha^{-1} was noticed in T_5 followed by T_4 with a carrying capacity of 33 sheep ha^{-1} and it was comparable with T_2 with a carrying capacity of 20 sheep ha^{-1} during the first year. During the second year, higher carrying capacity of 34 sheep ha^{-1} was obtained in T_5 followed by carrying capacity of 29 sheep ha^{-1} with T_4. However, it was followed by T_2 with a carrying capacity of 19 sheep ha^{-1} in location II.

In location III (Table 7), a higher carrying capacity of 42 sheep ha^{-1} was observed in T_5 followed by T_4 with a carrying capacity of 36 sheep ha^{-1} during the first year. During the second year, higher carrying capacity of 37 sheep ha^{-1} was obtained in T_5 and it was followed by T_4 with a carrying capacity of 36 sheep ha^{-1}. T_2 registered a carrying capacity of 20 sheep ha^{-1}.

The mean of two years (Fig 1) indicated that higher carrying capacity of 39, 37 and 40 sheep ha^{-1} for 108, 85 and 85 days of grazing period was obtained in T_5 in location I, II and III, respectively. It was numerically comparable with T_4 with a carrying capacity of 34, 31 and 36 sheep ha^{-1} in location I, II and III, respectively However, it was followed by T_2 with a carrying capacity of 20, 20 and 19 sheep ha^{-1} in location I, II and III, respectively. The results of this experiment corroborate with the findings of Muthuramalaingam *et al.*(2024).

Annual *Cenchrus* equivalent yield was higher in T_5. Forage production increased by 60 to 70% in silvipastoral systems compared to grasses alone, which may be due to the combined production of grasses, legumes, and tree foliage. This was in line with the findings of Devi (2005). Generally, grass is the main feed source in traditional livestock production systems, and livestock production is constrained by poor nutrition, especially during the dry season when there is a severe shortage of grass on pastures. Inclusion of annual fodder crops like sorghum and *Phaseolus trilobus,* are excellent addition to the system, since they extend the grazing season several weeks or even months. The legumes, besides being rich in protein content, are more palatable and digestible, drought-tolerant, enrich the soil through nitrogen fixation, and help in checking soil erosion. Forage legumes were most preferred by the agro-pastorals followed by fodder trees and grasses. (Ahmad *et al*., 2021).

Overgrazing occurs when the grazing pressure exceeds the carrying capacity of the land, modifying the physical properties of the soil and ecosystem. Due to the overuse of grazing land, vegetation cover declines, which in turn reduces the soil organic matter content and soil infiltration capacity. This corroborates with the findings of Padmakumar **(**2007), who noted that high stocking rates in small paddocks can force animals to consume forage fully, thereby reducing their forage regeneration ability. Plants might not be able to compensate sufficiently for the biomass removed by grazing animals under excessive grazing pressure. According to the findings by Mohit et al. (2021), a decreasing trend in biomass and soil organic carbon was observed at the grazed site compared to the protected site, indicating that overgrazing reduced species diversity and affected grassland productivity.

Conclusion

Among the different silvipastoral systems, *Acacia leucophloea* + *Cenchrus setigerus* + *Stylosanthes hamata* + *Sorghum bicolor* + *Phaseolus trilobus* (T_5) recorded higher annual *Cenchrus* equivalent yield and utilization rate with carrying capacity of 39 sheep per ha per year.

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