Journal of Plant Development Sciences
Meerut, India

RESEARCH

HERBAGE CARRYING CAPACITY OF SILVIPASTORAL SYSTEMS IN HIMACHAL PRADESH, NORTH WESTERN HIMALAYA, INDIA

Swaran Lata*, Vivek Chauhan, Tanay Barman and Shiv Paul

Silviculture and Forest Management Division, ICFRE-Himalayan Forest Research Institute, Conifer Campus, Panthaghati, Shimla-171013, Himachal Pradesh, India
Email: swaranswaras86@gmail.com

Received-02.12.2024, Revised-13.12.2024, Accepted-30.12.2024

Abstract: The present study was conducted on herbage carrying capacity of silvipastoral systems in 12 representative villages in all four agro-climatic zones of Himachal Pradesh. The study revealed that there is a great disparity between the carrying capacity and stocking rate of existing silvipastoral systems in Himachal Pradesh. The mean carrying capacity (ACU ha^{1} $year^{1}$) and stocking density (ACU ha^{1} $year^{1}$) in agroclimatic zone I, II, III and IV of Himachal Pradesh were 0.40 and 1.52, 0.57 and 2.17, 0.17 and 6.99, and 0.50 and 1.90 respectively. The higher stocking density of silvipastoral land than carrying capacity in long-term will significantly affect if this pattern continues, it will lead to overgrazing and land degradation. Thus, the study suggested introduction or integration of fast-growing multipurpose leguminous trees and high-yielding nutritive grasses, along with the development of climatically suitable silvicultural models.

Keywords: Agroforestry system, Carrying capacity, Himachal Pradesh, Productivity, Silvipastoral system

INTRODUCTION

Rearing and nurturing livestock is major occupation of individuals residing in rural and tribal areas of India. Despite the availability of grazing resources, there is not enough biomass to meet the demand for fodder. The carrying capacity of grazing pastures has alarmingly decreased as a result of uncontrolled grazing purposes, which has also seriously degraded the surrounding ecosystem. Farmers rely on trees for fodder widely and most heavily during the time of year that is lean to fix the feed deficit (Dev *et al*., 2012; Katoch, 2019).

Himachal Pradesh is one of the north-western Himalayan states of India covering 55,673 km^2, or 1.69% of India's geography and 10.5% area of the Indian Himalayan Region. The majority of the state is drained by five major streams: Chenab, Beas, Satluj, Ravi and Yamuna. With agriculture and horticulture serving as the main economic drivers, the state is predominantly an agrarian one. With 5.5 million cattle and 7.7 million people living there, the state has a population of around 7.7 million people. At the moment, environmental issues are also a concern, in addition to a lack of food, fuel, fiber, and other resources. Plant foliage is a major source of protein and energy for ruminants (Katoch, 2009) and during winter's tree foliage provide almost 80% of the fodder to local communities. Although at present the state is surplus in green (43.9%) and dry fodder (55.9%) availability, these extra fodders are not adequately utilized due to challenging topography, resulting in a practical shortfall (Roy *et al*., 2019). As a result of invasions of *Pinus roxburghii*, *Lantana camera*, and other obnoxious weeds onto Common Property Resources (CPR), fodder production continuously declined (Pathania & Dev, 2011).

As per India State of Forest Report (ISFR) 2021, 5738.25 km^2 area of the state fall under Above Ground Biomass (AGB) class >150 tonnes/ha, indicates healthy and very dense forest. The ages of the perennial woody component, the nature and distribution of different system components, and other abiotic factors primarily influence the production of biomass (above ground, below ground, and total biomass). In Himachal Pradesh, silvi-pasture system reported the highest above-ground (118.8 tonnes/ha) and total biomass output (143.29 tonnes/ha) among all agroforestry systems. In majority of agroforestry systems, Zone IV (High hills dry temperate/Alpine zone) generated the maximum biomass. Because, the predominant component of a grassland is herbage, while trees and shrubs are scattered and contribute very little to the production of biomass (above, below, and total biomass) (Gupta *et al*., 2017). There were three main livestock rearing systems in the state: sedentary, semi-migratory, and migratory. In zones I and II, animals were raised using a sedentary approach. In zones III and IV, livestock rearing was semi-migratory. The Gaddi and Gujjar tribes of the state adopted the migratory system. The sheep and goats leave the plain in March and travel upward, arriving in the sub-alpine and alpine pasture in May or June. They graze there until

*Corresponding Author

August or September (Dev *et al.*, 2013). Approximately 30 to 50 percent of all animal feeds and fodder comes from grasslands and forests. Grass, bushes, tree leaves, and other herbaceous plants provide green biomass, which is fed to animals. The energy that the animal absorbs from the feed is redirected into milk, ghee, meat, hides, wool, manure, and traction power. However, grazing, trampling, cutting ground herbage, and lopping of trees and bushes for fodder are major human pressures and threats to this essential interaction today (Islam *et al.*, 2022). Grazing pasture without proper soil conservation and animal management often results in poor soil quality and decreases production due to trampling-induced compaction.

Currently 43.11% (2.4 million ha) of the total geographical area of the state is facing desertification/land degradation problem and vegetation degradation is mainly responsible for it. Therefore, taking into account all of these factors, agroforestry is the only practical choice to lessen the burden on already-existing forests and to improve land productivity, which would make up for a lack of cultivable land resources and strengthen the economy of the natives of Himachal Pradesh. The review of literature revealed that, in general, few studies are available on the silvipastoral land use system of different parts of world (Jansen *et al.*, 1997; Peri *et al.*, 2001; Auad *et al.*, 2010; Souza *et al.*, 2010; Varella *et al.*, 2016., Silva *et al.*, 2017; Rodrigues *et al.*, 2023) and in India mainly in arid and semi-arid ecosystem (Yadav *et al.*, 1997; Keshwa & Mahindra, 2004; Patidhar, 2008; Rai *et al.*, 2008; Rai, 2012; Yadav *et al.*, 2014; Roy, 2016; Topoo *et al.*, 2021). In Himachal Pradesh few studies on silvipastoral systems have been carried out by (Dev *et al.*, 2014; Dev *et al.*, 2016; Rao et al., 2015; Lata *et al.*, 2023; Lata *et al.*, 2024) but studies on carrying capacity of silvipastoral systems of Himachal Pradesh have not been carried out so far. So, we did a study to find out carrying capacity of silvipastoral systems of Himachal Pradesh.

MATERIALS AND METHODS

Study area

The study was conducted in Himachal Pradesh. State shares borders with Ladakh UT and Jammu & Kashmir UT in the north, Uttarakhand in the southwest, Haryana in the south and Punjab in the west. It is located between latitudes 30º22'44"N to 33º12'20"N and longitudes 75º45'55"E to 79º04'20"E. Climatically, Himachal Pradesh is different from most plain states of India. Topographically, the territory of the state can be divided into three prominent zones, namely the Shiwaliks (Outer Himalaya), mid-mountain (Inner Himalaya) and the alpine zones (Greater Himalaya). Himachal Pradesh experiences three seasons i.e., winter, summer and rainy. From mid-November to mid-March comes winter. The rainy season begins at the end of June and lasts until mid-September. The summer season lasts from mid-April to the end of June. Alpine, sub-alpine, temperate, tropical, and sub-tropical plant varieties make up the majority of the vegetation. On the basis of physiographic and climate conditions, the state is divided into four agro-climatic zones viz., i) Sub tropical sub montane & low hills ii) Sub humid mid hills iii) Wet temperate high hills iv) Dry temperate high hills (Fig. 1).

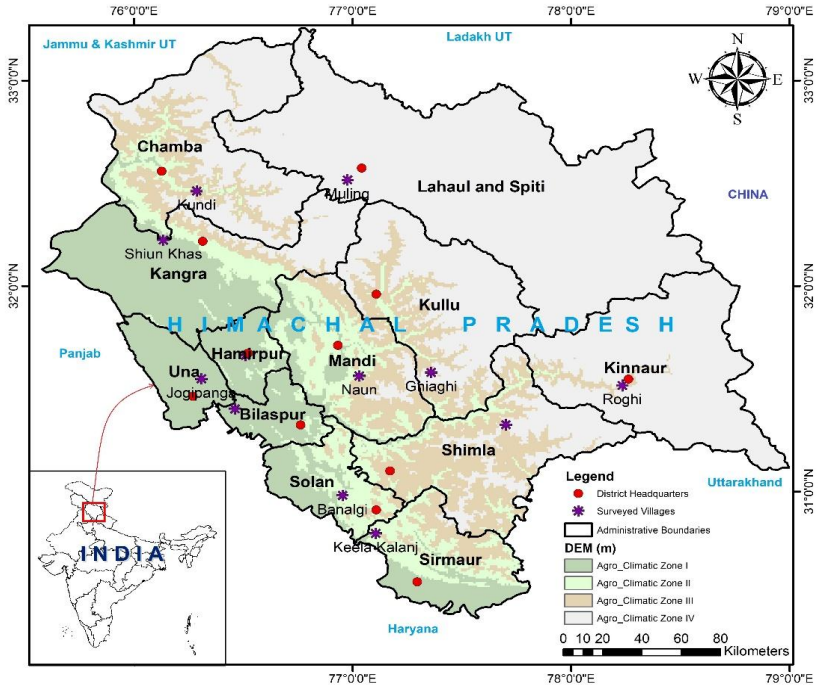

Fig 1. Map of location of study sites

Selection of study sites

Extensive field surveys were conducted in four agroclimatic zones of Himachal Pradesh and multi stage stratified random sampling was used to select sites/representative villages. Twelve villages viz., Jogipanga (Una), Masiyana (Hamirpur), Bhakra (Bilaspur), Shiun Khas (Kangra) of zone I; Naun (Mandi), Banalgi (Solan), Keela Kalanj (Sirmour) of zone II; Ghiaghi (Kullu), Jarashi (Shimla), Kundi (Chamba) of zone III, and Roghi (Kinnaur), Muling (Lahaul-Spiti) of zone IV representing all twelve districts were selected for the present study after the discussion with forest officials of respective districts. To study the carrying capacity, grass samples were collected from three experimental plots of one hectare area selected in each village. Thus, total number of experimental sites (treatments) available from which observation was taken as:

Number of selected villages: 12

Number of experimental plots in each village: 3

Total number of study sites in Himachal Pradesh: 12x3=36

Carrying capacity

Herbage carrying capacities of different silvipastoral systems were worked out on a per-unit-area basis after lying out quadrates of 1x1 m^2 area randomly in CPR and Community land using the formula given by De Leeuw & Tothill (1990) and Hocking & Mattick (1993). The carrying capacity of silvipastoral systems was expressed in ACU and the concept of Adult Cattle Units (ACU) was used to compute silvipastoral system carrying capacity (Kumar and Vinod, 1987). The same area's carrying capacity may differ from year to year and season to season because of variations in fodder production. Additionally, not all plants on silvipastoral land are utilized by livestock since some are preferred by them, others are rejected by them, and extra loss occurs as a result of animal trampling. Therefore, 30% correction factor was used, as recommended by Cossins & Upton (1987) for assessment of actual biomass available to animals. In experimental plots of selected silvipastoral systems of all 12 selected villages of different agro-climatic zones, three quadrates of 1x1 m were laid for harvesting herbage during the period 15th August-30th September. The herbage samples were brought to the lab, cleaned thoroughly under running water, and placed in different paper bags. For 48 hours, these samples were dried at 80 °C in an oven, to a consistent weight. Each sample was weighed on a top-pan balance once it had reached a constant weight, the data tabulated, and the secondary data required for the study, viz., livestock, land holding, and population details, obtained from the Animal Husbandry Department, Revenue Department, and Panchayat Secretariat of the respective villages. The carrying capacity of herbage production systems was calculated using the formula given below, based on the adult cattle body weight (320 kg average body weight):

$$\text{Carrying Capacity} = \frac{\text{Total amount of forage X Correction factor}}{\text{Average yearly feed requirement of ACU}}$$

Where, ACU=Adult Cattle Unit; Correction factor=30%; Daily requirement of dry matter per adult cattle unit=2.5% of body weight

$$\text{Stocking rate for the year (ACU/ha/year)} = \frac{\text{Total Adult Cattle Unit}}{\text{Total grazing area}}$$

RESULTS AND DISCUSSION

The carrying capacity of herbage in silvipastoral system of Himachal Pradesh are represented in the Table 1 and Fig. 2 and described as under.

Agro-climatic zone-I

A perusal of data on carrying capacity of herbage in table 1 revealed that in agro-climatic zone I value of silvipastoral land varied from 16 to 275 ha; adult cattle unit varied from 26.0 to 176.5; dry matter varied significantly from 3353.3 to 3833.3 kg/ha/year; carrying capacity varied significantly from 0.10 to 0.79 ACU/ha/year, whereas stocking rate varied from 0.44 to 3.26 ACU/ha/year. However, the average value of drymatter, carrying capacity and stocking rate were 3549.7 kg/ha/year, 0.40 ACU/ha/year and 1.52 ACU/ha/year respectively. In the agroclimatic zone I, maximum value of carrying capacity 0.79 ACU/ha/year recorded from Jogipanga (Una) with stocking rate 0.44 ACU/ha/year whereas in minimum value of carrying capacity 0.10 ACU/ha/year recorded from Bhakhra (Bilaspur) with stocking rate 3.26 ACU/ha/year.

Agro-climatic zone-II

In agro-climatic zone II, silvipastoral land varied from 54 to 396 ha; adult cattle unit varied from 100.0 to 240.0; dry matter varied significantly from 3264.4 to 3482.2 kg/ha/year; carrying capacity varied significantly from 0.08 to 1.36 ACU/ha/year, whereas stocking rate varied from 0.92 to 4.44 ACU/ha/year. However, the average value of dry matter, carrying capacity and stocking rate were 3391.83 kg/ha/year, 0.57 ACU/ha/year and 2.17 ACU/ha/year respectively. In zone-II maximum value of carrying capacity 1.36 ACU/ha/year recorded from Banalgi (Solan) with stocking rate 0.92 ACU/ha/year whereas minimum carrying capacity of 0.08 ACU/ha/year recorded from Naun (Mandi) with stocking rate 4.44 ACU/ha/year.

Agro-climatic zone-III

In agro-climatic zone III, silvipastoral land varied from 38 to 86 ha; adult cattle unit varied from 82.0 to 636.0; dry matter varied significantly from 3383.3 to 3794.4 kg/ha/year, carrying capacity varied significantly from 0.02 to 0.40 ACU/ha/year,

whereas stocking rate varied from 0.95 to 15.9 ACU/ha/year. However, the average value of dry matter, carrying capacity and stocking rate were 3569.23 kg/ha/year, 0.16 ACU/ha/year and 6.98 ACU/ha/year respectively. In zone-III, maximum value of carrying capacity 0.40 ACU/ha/year was recorded from Ghiaghi (Kullu) with stocking rate 0.95 ACU/ha/year whereas in minimum value of carrying capacity of 0.02 ACU/ha/year was recorded from Kundi (Chamba) with stocking rate 15.9 ACU/ha/year.

Agro-climatic zone-IV

In agro-climatic zone IV, silvipastoral land varied from 27 to 736 ha; adult cattle unit varied from 92.5 to 276.0; dry matter varied significantly from 3292.2 to 3327.8 kg/ha/year, carrying capacity varied significantly from 0.09 to 0.90 ACU/ha/year, whereas stocking rate varied from 0.37 to 3.42 ACU/ha/year. However, the average value of dry matter, carrying capacity and stocking rate were 3310.0 kg/ha/year, 0.49 ACU/ha/year and 1.89 ACU/ha/year respectively. In zone-IV, maximum value of carrying capacity of 0.90 ACU/ha/year was recorded from Roghi (Kinnaur) with stocking rate of 0.37 ACU/ha/year whereas minimum value of carrying capacity of 0.09 ACU/ha/year was recorded from Muling (Lahaul & Spiti) with stocking rate 3.42 ACU/ha/year.

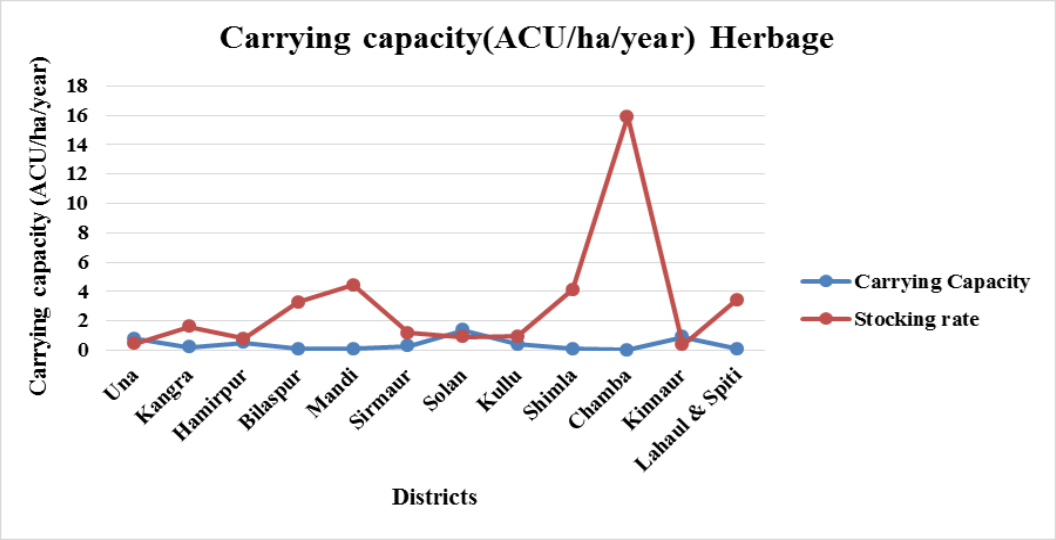

Fig 2. Carrying capacity of biomass and stocking rate in silvipastoral system in different agro-climatic zones (ACU=adult cattle unit.)

In the present study the herbage forage yield data showed considerable variation in forage yield varying from 3264.4 to 3833.3 kg/ha/year. Among all agro-climatic zones maximum herbage carrying capacity 1.36 ACU/ha/year recorded in Banalgi (Solan) with stocking rate 0.92 ACU/ha/year in agro-climatic zone-II followed by Roghi (Kinnaur) 0.90 ACU/ha/year with stocking rate 0.37 ACU/ha/year in zone-IV, Jogipanga (Una) 79 ACU/ha/year with stocking rate 0.44 ACU/ha/year, Masiyana (Hamirpur) 0.50 ACU/ha/year stocking rate 0.77 ACU/ha/year in zone I, Ghiaghi (Kullu) 0.40 ACU/ha/year with stocking rate 0.95 ACU/ha/year in zone-III, Keela Kalanj (Sirmaur) 0.28 ACU/ha/year with stocking rate 1.16 ACU/ha/year in zone-II and Shiun Khas (Kangra) 0.22 ACU/ha/year with stocking rate 1.62 ACU/ha/year in zone-I. Minimum carrying capacity 0.02 ACU/ha/year recorded from Kundi (Chamba) with stocking rate 15.9 ACU/ha/year followed by Naun (Mandi) 0.08 ACU/ha/year with stocking rate 4.44 ACU/ha/year, Jarashi (Shimla) 0.08 ACU/ha/year with stocking rate 4.11 ACU/ha/year, Muling (Lahaul & Spiti) 0.09 ACU/ha/year with stocking rate 3.42 ACU/ha/year and Bhakhra (Bilaspur) 0.10 ACU/ha/year with stocking rate 3.26 ACU/ha/year.

Herbage carrying capacity in zones I and II of the Himalaya ranges from 0.1 to 1.4 ACU/ha/year, according to Palsaniya *et al.* (2011). The herbage carrying capacity in the current study, which ranges from 0.08 to 1.36 ACU/ha/year, is in line with the previously reported values. In Himachal Pradesh, grasslands and pastures have a carrying capacity of only 1.31 ACU for subtropical regions, 1.21 ACU for temperate regions, and 0.64 ACU for alpine regions, according to Katoch & Dogra (1999). These values are marginally greater than those found in the current research. According to Sharma & Minhas (1993), stocking rate in different tehsils of Kinnaur district varied between 0.2 -0.77 ha^{-1}. In the current study stocking rate in the studied village of Kinnaur district was 0.3 ACU $ha^{-1}year^{-1}$ and falling with in the previously reported value. The results of herbage carrying capacity varied significantly in all agro-climatic zones. This result is consistent with Singh, 1975; Singh, 1988; Singh *et al.*, 1980; Singh *et al.*, 1985; Ahuja *et al.*, 1985; Singh, 1987; Das, 1995; Guleria, 1996; Katoch and Dogra, 1999; Dev *et al.*, 2006, 2012; Rao *et al.*, 2015; Meshesha *et al.*, 2019; Sewade *et al.*, 2017).The study also revealed that the

among all studied sites Kundi (Chamba), Naun (Mandi), Jarsahi (Shimla), Muling (Lahaul & Spiti) and Bhakra (Bilaspur) has high stocking rate in comparison to existing carrying capacity. If the current pattern continues, these areas will face overgrazing and land degradation pressures in the future due to which not only livelihood of the locals will be affected but also led environmental problems. Therefore, optimization of tree density and spacing by more plantations, introduction/ integration of fast growing multipurpose leguminous trees and high yielding nutritive grasses is suggested along with development and introduction of climatically suitable Silvipastoral models.

Table 1. Carrying capacity of herbage biomass in Silvipastoral system in different agro-climatic zones

Agro-climatic Zones	Villages/Districts	Silvipastoral Land (ha)	Total ACU	Dry Matter (g m^{-2})	Dry Matter (kg/ha/year)	Total Dry Matter (kg $year^{-1}$)	Dry matter requirement ACU/Year	Carrying Capacity (ACU ha^{-1} $year^{-1}$)	Stocking Rate (ACU ha^{-1} $year^{-1}$)
Zone 1	Jogipanga (Una)	275	121.5	339.89 ± 5.23	3398.9 ± 52.39	280409.25	354780	0.79 ± 0.22	0.44
	Shiun Khas(Kangra)	16	26.0	361.33± 5.23	3613.3± 52.39	17343.84	75920	0.22 ± 0.22	1.62
	Masiyana (Hamirpur)	88	68.0	383.33± 5.23	3833.3± 52.39	101199.12	198560	0.50± 0.22	0.77
	Bhakra (Bilaspur)	54	176.5	335.33± 5.23	3353.3± 52.39	54323.46	515380	0.10± 0.22	3.26
Zone 2	Naun (Mandi)	54	240.0	348.22± 5.23	3482.2± 52.39	56411.64	700800	0.08± 0.22	4.44
	Keela Kalanj(Sirmaur)	86	100.0	326.44± 5.23	3264.4± 52.39	84221.52	292000	0.28± 0.22	1.16
	Banalgi (Solan)	396	102.0	342.89± 5.23	3428.9± 52.39	407353.32	297840	1.36± 0.22	0.92
Zone 3	Ghiaghi (Kullu)	86	82.0	379.44± 5.23	3794.4± 52.39	97895.52	239440	0.40± 0.22	0.95
	Jarashi (Shimla)	38	156.5	338.33± 5.23	3383.3± 52.39	38569.62	456980	0.08± 0.22	4.11
	Kundi (Chamba)	40	636.0	353.00± 5.23	3530± 52.39	42360.00	1857120	0.02± 0.22	15.9
Zone 4	Roghi (Kinnaur)	736	276.0	329.22± 5.23	3292.2± 52.39	726917.76	805920	0.90± 0.22	0.37
	Muling (Lahaul & Spiti)	27	92.5	332.78± 5.23	3327.8± 52.39	26955.18	270100	0.09± 0.22	3.42

ACKNOWLEDGMENTS

The authors are thankful to the Director and Head, Silviculture and Forest Management Division, ICFRE-Himalayan Forest Research Institute, Conifer Campus, Panthaghati, Shimla, Himachal Pradesh for their encouragement and support. Fund received from Indian Council of Forestry Research and Education (ICFRE), Dehradun is highly acknowledged.

REFERENCES

Ahuja, L. D., Verma, C. D., Sharma, S. K. and Lamba, T. R. (1985). Contribution of grass component (ground story) in afforested areas in arid regions. *Indian Forester*, **111**(7): 542-548.
Google Scholar

Auad, M. A., Carvalho, C. A., Clemente, M. A. and Prezoto, F. (2010). Diversity of Social Wasps (Hymenoptera) in a Silvipastoral System. *Socio-biology*, **55**(2): 627-636.
Google Scholar

Chaturvedi, O. P., Handa, A. K., Kaushal, R., Uthappa, A. R., Sarvade, S. and Panwar, P. (2016). Biomass production and carbon sequestration through agroforestry. *Range Management and Agroforestry*, **37**(2): 116-127.
Google Scholar

Cossins, N. J. and Upton, M. (1987). The Borana pastoral systems of South Ethiopia, *Agricultural Systems*, **25**: 199-218.
Google Scholar

Das, B. (1995). *System behaviour under Pinus roxburghii sergeant in Solan district* (H.P.). M.Sc Thesis, Dr Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh.
Google Scholar

De Leeuw, P. N. and Tothill, J. C. (1990). *The concept of rangeland carrying capacity in sub – Saharan Africa: Myth or reality*? ODI, pastoral Development Network Paper 29 b. London, UK. 20 PP.
Google Scholar

Dev, I., Misri, B. and Pathania, M. S. (2006). Forage demand and supply in western Himalaya: A balance sheet for Himachal Pradesh, *Indian Journal of Animal Sciences*, **76**(9): 720-726.
Google Scholar

Dev, I., Radotra, S., Khosla, O. P. S., Mishra, B., Sareen, S., Singh, J. P., Srivastava, A. K., Singh, B., Sharma, S. K., Chamoli, K. P. and Kumar, D. (2012). Impact of participatory silvipastoral intervention and soil conservation measures for forage resource enhancement in western Himalaya. *Indian Journal of Agriculture Science*, **84**(3): 365-370.
Google Scholar

Dev, I., Radotra, S., Misri, B., Sareen, S., Pathania, M. S. and Singh, J. P. (2013). Participatory appraisal of grazing resources and socio-economic profile of livestock keepers of Himachal Pradesh. *Indian Journal of Agroforestry*, **15**(1): 64-70.

Google Scholar

Dev, I., Radotra, S., Khola, P.S.O., Misri, B., Sareen, S., Srivastava, A.K., Singh, B., Sharma, S.K., Chamoli, K.P. and Kumari, D. (2016). Natural resource enhancement through silvipastoral establishment in western Himalayan region, *Indian Journal of Animal Science*, **86** (11): 1296-1301.

Google Scholar

Dev, I., Radotra, S., Khola, O.P.S., Misri, B., Sareen, S., Singh J.P., Srivastava, A.K., Singh B., Sharma, S.K., Chamoli, K.P. and Kumar, D. (2014). Impact of participatory silvipastoral intervention and soil conservation measures for forage resource enhancement in western Himalaya, *The Indian Journal of Agricultural Sciences*, **84** (3): 365–70.

Google Scholar

Guleria, V. (1996). *Structure, productivity and quality of grasses under Chirpine in Mid hills of Himachal Pradesh*. M.Sc. Thesis, Dr. Y.S. Parmar, University of Horticulture and Forestry, Solan, Himachal Pradesh.

Google Scholar

Gupta, B., Sarvade, S. and Singh, M. (2017). Species composition, biomass production, and carbon storage potential of agroforestry systems in Himachal Pradesh. *Agroforestry for Increased Production and Livelihood Security*. Ed (s) S. K. Gupta, Pankaj Panwar and Rajesh Kaushal. New India Publishing Agency. New Delhi, pp.245-269.

Google Scholar

Hocking, D. and Mattick, A. (1993). Dynamic carrying capacity analysis as tool for conceptualizing and planning range management improvements, with a case study from India. Pastoral Development Network, ODI (PDN).

Google Scholar

ISFR (2021). India State of Forest Report 2021, Forest Survey of India, Ministry of Environment, Forest & Climate Change, Dehradun, India.

Google Scholar

Islam, M. A., Mugloo, J. A., Raj, A., Bhat, G. M., Wani, A. A., Gatoo, A. A., Malik, A. R., Pala, N. A. and Shah, M. (2022). Agroforestry strategy for revitalizing fodder security in Kashmir Himalaya, India. *Agricultural Research*, **11**(3): 528-538.

Google Scholar

Jansen, H. G. P., Ibrahim, M. A., Nieuwenhuyse, A., Mannetje Joenje, M. and Abarca, S. (1997). Economics of Improved Pasture and Silvipastoral Technologies in the Atlantic Zone of Costa Rica. *Tropical Grassland*, **31**: 588-598.

Google Scholar

Katoch, B. S. and Dogra, K. K. (1999). *Present scenario and strategies for improving the nutritional status and carrying capacity of the natural grasslands/pastures of Himachal Pradesh*. A report, Department of Animal Nutrition, College of Veterinary and Animal Sciences. CSK HPKV Palampur, Himachal Pradesh, India. 11p.

Google Scholar

Katoch, R. (2009). Tree fodder: An alternative source of quality fodder in Himachal Pradesh. *Journal of Range Management and Agroforestry*, **30**(1): 16–24.

Google Scholar

Katoch, R. (2019). Tree fodder for mitigating the forage requirement in Himalayan region. *Range Management and Agroforestry*, **40**(2): 173-180.

Google Scholar

Keshwa, G. L. and Mahindra, S. (2004). Biomass production and soil fertility from *Dichrostachys cinerea* + *Cenchrus* silvipastoral system in arid and semi-arid regions. *Indian Journal of Agronomy* **49**(4): 293-295.

Google Scholar

Kumar, S. and Shankar, V. (1987). Grass covers of the Guhiya catchment of upper Luni Basin1.Present and potential herbage production and carrying capacity. *Indian Journal of Forestry*, **9**(2): 126-134.

Google Scholar

Lata, S., Chauhan, V. and Paul, S. (2023). Prevalent silvipastoral system units among different farmer categories in Himachal Pradesh, north western Himalaya, India. *Journal of Plant Development Sciences*, **15**(3): 189-196.

Google Scholar

Lata, S., Kamakshi, Paul, S., Barman, T. and Sharma, D. (2024). Traditional silvipastoral systems: an important sustainable agroforestry system for greening, restoration of wasteland and livelihood security in Himachal Pradesh, India. *Indian Forester*, **150** (9): 861-868.

Google Scholar

Lata, S., Paul, S., Chauhan, V. and Varsha (2024). Phytosociological analysis of functional components in silvipastoral land use systems of Himachal Pradesh, India. *International Journal of Environment and Climate Change*, **14**(2): 675-685.

Google Scholar

Meshesha, D. T., Moahmmed, M. and Yosuf, D. (2019). Estimating carrying capacity and stocking rates of rangelands in Harshin district eastern Somali region, Ethiopia. *Ecology and Evaluation*, 1-11.

Google Scholar

Palsaniya, D.R., Dhyani, S. K. and Rai, P. (2011). *Silvipasture in India: present perspectives and challenges ahead*. Scientific Publishers India. 207p.

Google Scholar

Pathania, M. S. and Dev, I. (2011). Fodder supply from private lands in two agroclimatic zones of Himachal Pradesh. *Indian Journal of Animal Sciences*, **81**(7): 740–743.

Google Scholar

Patidhar, M., Rajora, M. P. and Singh, R. (2008). Forage production potential of different silvi-pastoral systems under arid conditions of Rajasthan. *Indian Journal of Agronomy*, **53**(3): 234-238.
Google Scholar

Peri, P. L., Lucas, R. J., Moot, D. J., Varella, A. C. and McNeil, D. L. (2001). *Optimizing Yield and Quality of Orchard Grass Pasture in Temperate Silvipastoral Systems*. XIX International Grassland Congress, São Pedro, São Paulo, Brazil from February 11 through February 21, 2001. https://uknowledge.uky.edu/igc/19/18/1
Google Scholar

Rai, P., Rao, G. R., Ramana B. V., Chaturvedi, O. P. and Singh, U. P. (2008). Growth and production of *Anogeissus latifolia* under Silvipastoral system. *Range Management and Agroforestry*, **27**(1): 9-12.
Google Scholar

Rai, P. (2012). Silvipastoral system for livestock production: performance of small ruminants. *Indian Journal of Agroforestry*, **14**(1): 23–28.
Google Scholar

Rao, G. R., Mishra, V. K., Gupta, B., Deshmukh, H. K., Reddy, P. S. and Kumar P. S. (2015). Herbage biomass, carrying capacity and relative Silvipastoral class of the Chirpine (*Pinus roxburghii* Sargent) based natural Silvipastoral systems in North-West Himalaya, *Journal of Global Biosciences*, **4**(1): 1941-1953.
Google Scholar

Rodrigues, K. D. S., Moustacas, V. S., Raia, V. D. A., Brito, B. S., Bassetto, K. V., Nogueira, C. D. C., Pena, R. H. R. and Castro, B. G. D. (2023). Importance of the silvipastoral system on the animal health and welfare of dairy cattle. *Brazilian Journal of Development*, **9**: 1155-1178.
Google Scholar

Roy, A. K., Agrawal, R. K., Bhardwaj, N. R., Mishra, A. K. and Mahanta, S. K. (2019). In: *Indian Fodder Scenario: Redefining State Wise Status* (eds. A. K. Roy, R. K. Agrawal, N. R. Bhardwaj). ICAR- AICRP on Forage Crops and Utilization, Jhansi, India, pp. 1-21.
Google Scholar

Roy, M. M. (2016). Carbon Sequestration in Silvi-pastoral Systems in Arid and Semiarid Regions of India. Proceedings of the 10th International Rangeland Congress (eds. A. Iwaasa, H.A.B. Lardner, M.Schellenberg, Willms, W, K. Larson), 51 Campus Drive, Saskatoon, SK S7N 5A8.http://2016 Canada. Rageland congress.
Google Scholar

Sewade, C., Azihou, A. F., Fandohan, A. B., GleleKakai, R. L., Mensah, G. A. and Houinato, M. R. B. (2017). Leaf biomass modeling, carrying capacity and species-specific performance in aerial fodder production of three priority browse species *Afzeliaa fricana*, *Pterocarpus erinaceus* and *Daniellia oliveri* in Benin. *Livestock Research for Rural Development*, **29**(10): 1-14.
Google Scholar

Sharma, P. D. and Minhas, R. S. (1993). Land use and the biophysical environment of Kinnaur District, Himachal Pradesh, India. *Mountain Research and Development*, **13**(1): 41-60.
Google Scholar

Silva, E. C., Gama, J. R. V., Rode, R. and Coelho, A. L. M. (2017). Tree Species Growth in a Silvipastoral System in Amazon. *African Journal of Agricultural Research*, **13**(3): 95-103.
Google Scholar

Singh, B., Mathur, H. N. and Joshi, P. (1980). Effect of shade on grassland production in the moist sub-tropical region of north India. *Indian Journal of Forestry*, **3**(4): 343-345.
Google Scholar

Singh, J. S. (1975). Structure and function of tropical grassland vegetation of India. *Polish Ecological Studies*, **2**:17-34.
Google Scholar

Singh, P. (1988). Indian rangelands status and improvement-Plenary Address to the 3rd International Rangeland Congress, Nov. 7-11, 1988. New Delhi, India. p. 40.
Google Scholar

Singh, R. P., Gupta, M. K. and Mathur, H. N. (1985). Effect of *Pinus roxburghii* plantations on the yield and composition of grasses in temperate region. *Indian Forester*, **111**(10): 787-793.
Google Scholar

Singh, R. P. (1987). A note on the grass production under *Cedrus deodara* forest in Himachal Pradesh. *Indian Forester*, **113**(9): 648-649.
Google Scholar

Souza, W. D., Barbosa, O. R., Marques, J. D. A., Costa, M. A. T., Gasparino E. and Limberger, E. (2010). Microclimate in silvipastoral systems with *Eucalyptus* in rank with different heights. *Revista Brasileira de Zootecnia*, **39**(3): 685-694.
Google Scholar

Topoo, P., Oraon, P. R., Singh, B. K. and Kumar, A. (2021). Biomass, productivity and carbon sequestration of *Tectona grandis* and *Gmelina arborea* - based silvipastoral system. *Current Science*, **121**(12): 1594-1599.
Google Scholar

Varella, A. C., Barro, R. S., Silva, R. S., Silva, J. L. S. D., Silva, V. P. D., J. C. and Saibro, D. (2016). Silvopastoral Systems in the Cold Zone of Brazil in P.L. Peri *et al*. (eds.), Silvopastoral Systems in Southern South America. *Advances in Agroforestry*, **11**. DOI 10.1007/978-3-319-24109-8_10
Google Scholar

Yadav, M. S., Singh, M., Sharma, S. K., Tewari, J. C. and Barman, U. (1997). *Silvipastoral systems in arid and semi-arid ecosystems*. Central Arid Zone Research Institute, Jodhpur 342 003, India. p. 472.
Google Scholar

Yadav, R. P., Sharma, P., Arya, S. L. and Panwar, P. (2014). *Acacia nilotica*-based silvipastoral systems for resource conservation and improved productivity from degraded lands of the Lower Himalayas. *Agroforestry Systems*, **88**: 851-863. Google Scholar