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Research article

Carbon stock dynamics in soil as influenced by perennial grass-legume mixtures in southern dry zone of Karnataka

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Abstract

A field experiment was conducted at Zonal Agricultural Research Station, Vishweshwaraiah Canal Farm, Mandya, University of Agricultural Sciences, Bangalore from July 2020 to June 2022 to study the carbon stock dynamics in soil as influenced by different perennial grass-legume mixtures in southern dry zone of Karnataka. The experiment was laid out in a randomized complete block design comprising of twelve treatments and replicated thrice. The data revealed that among different grass-legume mixtures, paired row system of B×N hybrid + *Desmanthus* (2:5) recorded considerably higher credit of soil organic carbon (0.018%) and carbon sequestration in soil (1.12 Mg ha^{-1}) followed by paired row system of Guinea grass + *Desmanthus* (2:3) (0.016% and 0.99 Mg ha^{-1}, respectively) at the end of the second year. Further, significantly higher green fodder, dry matter and crude protein yield (1802.7, 355.7 and 41.5 q ha^{-1} year^{-1}, respectively), gross and net returns (Rs. 3,44,072 and 2,58,752 ha^{-1} year^{-1}, respectively) as well as benefit cost ratio (4.05) were observed with paired row system of B×N hybrid + *Desmanthus* (2:5) cropping system on a pooled basis which was on par with paired row system of Guinea grass + *Desmanthus* (2:3) with respect to crude protein yield (38.3 q ha^{-1} year^{-1}) and B:C ratio (3.67) as compared to other grass-legume mixtures. Considering these results, B×N hybrid paired row + *Desmanthus* (2:5) followed by Guinea grass paired row + *Desmanthus* (2:3) were found as the most promising fodder cropping systems for meeting both farmer needs and soil sustainability.

Keywords: Biomass yield, Carbon sequestration, Crude protein yield, *Desmanthus*, Economics, Grasses

Introduction

Soil organic carbon (SOC) plays a major role in the soil's biological, chemical and physical properties and aggregation between soil particles largely may help in preventing soil structural degradation, thereby increasing the physical stability (Lal, 2003). Maintaining optimum levels of soil organic carbon is vital for soil quality, increased water retention capacity, nutrient enrichment and soil faunal activity, thereby increasing soil fertility and crop productivity (Ghosh and Mahanta, 2014; Ghosh *et al*., 2022). Increasing carbon sequestration in agricultural soils and making soil a net sink for atmospheric carbon can be achieved by adoption of scientific management practices (Jiang *et al*., 2006). Long-term experiments related to the field have been conducted to study changes in the sustainability of crop production in relation to the physical, chemical and biological properties of soils and to establish the effects of manure and fertilizer application on the soil organic carbon (Meng *et al*., 2005) and carbon sequestration (Anonymous, 2005). Studies on carbon sequestration through fodder crops have also been done in few locations, but the documentation of the study results is very meager. Hence, in the present study, cultivation of perennial grass/ cereal fodder crops *viz*., B×N hybrid, guinea grass and perennial fodder sorghum and their mixture with perennial fodder legume *Desmanthus* at different row ratios were assessed to study the carbon stock dynamics in soils of the southern dry zone of Karnataka.

Materials and Methods

Location of the study: A field experiment was conducted during 2020-21 and 2021-22 at Zonal Agricultural Research Station, Vishweshwaraiah Canal Farm, Mandya, University of Agricultural Sciences, Bangalore from July 2020 to June 2022 to study the carbon stock dynamics in soils as influenced by perennial grass-legume mixtures in Southern dry zone of Karnataka under irrigated condition. The soil of the experimental site was sandy loam and is derived from granite-gneiss under sub Tropical semi-arid climate. These soils are classified as fine, kaolinitic, is hyperthermic, Typic Kandiustalf as per USDA classification. The soil of the experimental site was neutral in reaction (7.44) with electrical conductivity of 0.38 dS m^{-1}, medium in organic carbon (0.51%), low in available nitrogen (263.42 kg ha^{-1}), medium in available phosphorous (47.61 kg ha^{-1}) and potassium (161.28 kg ha^{-1}).

Treatments: The experiment was laid out in randomized complete block design with three replications, comprising of twelve treatments *viz.*, T_1: B×N hybrid + *Desmanthus* (1:1), T_2: B×N hybrid + *Desmanthus* (2:1), T_3: B×N hybrid + *Desmanthus* (paired row of B×N hybrid as 60 cm within the pair and 180 cm between the pair with 2:5 row ratio), T_4: Guinea grass + *Desmanthus* (1:1), T_5: Guinea grass + *Desmanthus* (2:1), T_6: Guinea grass + *Desmanthus* (paired row of guinea grass as 45 cm within the pair and 120 cm between the pair with 2:3 row ratio), T_7: Perennial fodder sorghum + *Desmanthus* (4:1), T_8: Perennial fodder sorghum + *Desmanthus* (8:2), T_9: B×N hybrid (sole), T_{10}: Guinea grass (sole), T_{11}: Perennial fodder sorghum (sole) and T_{12}: *Desmanthus* (sole). B×N hybrid grass, guinea grass and perennial fodder sorghum are the most preferred perennial fodder grasses and cereal fodders in the southern dry zone of Karnataka, owing to their fast-growing nature and higher productivity from a limited area. *Desmanthus* is a perennial fodder legume which is a protein rich shrub suited to any kind of agro-climatic conditions. All the selected fodder species have properties of rapid field establishment, withstand heavy pruning, good regeneration capacity and are suitable for cut and carry method of feeding system.

Crop establishment: Two nodded stem cuttings of B×N hybrid grass was planted in the furrow @ 1 sett per hill at a spacing of 90 cm × 60 cm in normal planting whereas 60 cm × 45 cm in paired system of planting (60 cm within the pair and 180 cm between the pair). The rooted slips of guinea grass were planted in the furrow @ 2 rooted slips per hill at a spacing of 60 cm × 45 cm in normal planting whereas 45 cm × 30 cm in paired system of planting (45 cm within the pair and 120 cm between the pair) as per the treatment. Further, perennial fodder sorghum and *Desmanthus* were established using seeds with a spacing of 30 cm × 10 cm. The details of nutrients applied for each fodder crop was recorded (Table 1). The first cut for all the fodder crops was given at 75 days after planting and sowing by leaving stubbles of grasses and cereal at a height of 15 cm above the soil and 30 cm above the soil in *Desmanthus* and subsequent harvests were carried out at 45 days interval in B×N hybrid, perennial fodder sorghum and *Desmanthus* while 32 days interval in guinea grass. At the time of harvest, the green fodder yield of each fodder crop from the net plot area was recorded separately for seven cuts in B×N hybrid grass, perennial fodder sorghum and *Desmanthus* and nine cuts in guinea grass in the first year. Whereas in the second year, a total of eight cuts in B×N hybrid grass, perennial fodder sorghum and *Desmanthus* and eleven cuts in guinea grass were taken.

Observations recorded: Observations recorded on biomass yield (green fodder and dry matter yields), crude protein yield and carbon sequestration. The known quantity of sample was taken at each harvest and kept in a thermostatically controlled oven at 70 ± 2°C temperature and dried till it attained constant weight for the computation of dry matter content. The fresh fodder yield from net plot area taken at each harvest was multiplied by the dry matter content and summed up to get the annual dry matter yield per hectare. The oven-dried plant samples were ground thoroughly to pass through 2 mm sieve and used for analyzing the nitrogen. Total nitrogen of oven-dried samples from each harvest was determined by the micro Kjeldahl procedure and crude protein yield was calculated by multiplying with dry matter yield from each harvest and summed up to get annual crude protein yield per hectare.

Carbon sequestration: The concentration of carbon accumulated in the experimental field was estimated before and after the cropping period during 2020-21 and 2021-22. In addition, soil organic carbon (SOC) concentration during the initial period of the experiment (2020-21) was taken for comparison of carbon stock dynamics in the soil of the experimental field. The field was dug out up to 30 cm depth and soil samples were collected by using a core sampler. Then, soil samples were analyzed in the laboratory. Data on bulk density and carbon concentrations were used to compute the amount of carbon per unit area (Pearson *et al*., 2007). For the mineral soil, the amount of carbon per unit area was calculated by the formula: C (Mg ha^{-1}) = [Soil bulk density (g cm^{-3}) × soil depth (cm) × % C] × 100; In this equation, percent carbon was expressed as a decimal fraction; for example, 2.2 % C was expressed as 0.022. The equation was applied to convert the mean SOC to CO_2 equivalents per unit area (IPCC, 2003); Csoc = SOC × 44/12, Where Csoc = SOC in terms of CO_2 equivalent (Mg ha^{-1}); SOC = Carbon sequestration (Mg ha^{-1}); 44/12= ratio of molecular weight of CO_2 to carbon.

Economics and statistical analysis: The economics of cultivation was worked out based on the cost of cultivation and the prevailing market price of green

Table 1. Details of nutrients applied for each perennial fodder crop

Crops	Nutrients applied (kg ha^{-1} year^{-1})			FYM (t ha^{-1})
	Total ($N:P_2O_5:K_2O$)	Basal ($N:P_2O_5:K_2O$)	N top dress after each cut	
Desmanthus	25:50:25	25:50:25	-	10
B×N hybrid	180:120:80	18:120:80	27	20
Guinea grass	200:50:25	20:50:25	22.5	25
Perennial fodder sorghum	180:50:40	45:50:40	22.5	10

fodder. The experimental data generated from the experiment were subjected to statistical analysis by adopting Fisher's method of analysis of variance as outlined by Gomez and Gomez (1984) for randomized complete block design. Wherever 'F' test was significant for comparison among the treatment means, a critical difference (CD) at 5% level of probability was worked out.

Results and Discussion

Green fodder yield: The perennial cropping systems involving grass + legume intercropping recorded higher total green fodder yield as compared to sole cropping system (Table 2). Among different cropping systems based on pooled analysis, paired row system of B×N hybrid + *Desmanthus* (2:5) (Paired row: 60 cm x 180 cm) recorded significantly higher total green fodder yield (1802.7 q ha^{-1} year^{-1}), which was found on par with B×N hybrid + *Desmanthus* in 1:1 and 2:1 row ratio (1653.5 and 1584.7 q ha^{-1} year^{-1}, respectively) as compared to other fodder cropping systems. The magnitude of increase in total green fodder yield in paired row system of B×N hybrid + *Desmanthus*, B×N hybrid + *Desmanthus* in 1:1 and 2:1 row ratio was to the tune of 123, 105 and 96%, respectively, over sole *Desmanthus*. The sole crop of *Desmanthus* recorded significantly lower green fodder yield (807.4 q ha^{-1} year^{-1}) on a pooled basis. A similar trend was observed during both years of study. The complementary nature of legume intercrop under these cropping systems might have resulted in efficient utilization of available resources like nutrients, water and solar energy, which led to higher plant height, leaf stem ratio and dry matter accumulation besides additional nitrogen supply by legume crops through atmospheric nitrogen fixation due to more proportion of legume component in a paired row system. The lower green fodder yield in sole *Desmanthus* might be due to the lower genetic yield potential of a legume crop as compared to cereal fodder crops. These results were in accordance with the earlier findings (Patil *et al*., 2018; Kumar *et al*., 2021; Manoj *et al*., 2021; Thomas *et al*., 2021a; 2021b).

Dry matter yield: Among different fodder cropping systems, paired row system of B×N hybrid + *Desmanthus* (2:5) (Paired row: 60 cm x 180 cm) recorded significantly higher total dry matter yield of 355.7 q ha^{-1} year^{-1} and found on par with perennial system of B×N hybrid + *Desmanthus* in 1:1 and 1:2 row ratio (324.4 and 311.8 q ha^{-1} year^{-1}, respectively) followed by paired system of Guinea grass + *Desmanthus* (2:3) and sole crop of B×N hybrid (309.9 and 305.6 q ha^{-1} year^{-1}, respectively) as compared to other fodder cropping systems on pooled basis (Table 2). The magnitude of increase in total dry matter yield in a paired row system of B×N hybrid + *Desmanthus* (2:5) was to the tune of 120 and 16% over sole *Desmanthus* and B×N hybrid, respectively. Whereas, the sole crop of *Desmanthus* recorded significantly lower total dry matter yield (161.4 q ha^{-1} year^{-1}). A similar trend was noticed during both the years of experimentation. The higher total dry matter yield in perennial fodder intercropping system modules might be due to the higher green fodder yield of the component crops, even with considerably lower dry matter content. The lower total dry matter yield in sole *Desmanthus*, even with medium dry matter content might be due to lesser green fodder yield as compared to the other crops and cropping systems. These results were confined to the findings of Kumar *et al.* (2021), Manoj *et al.* (2021), Thomas *et al.* (2021a) and Thomas *et al.* (2021b).

Crude protein yield: Among different cropping systems, the paired row system of B×N hybrid + *Desmanthus* (60 cm within the pair × 180 cm between the pair) resulted in significantly higher total crude protein yield (41.5 q ha^{-1} year^{-1}) which was at par with paired row system of Guinea grass + *Desmanthus* (45 cm within the pair × 120 cm between the pair) with a crude protein yield of 38.3 q ha^{-1} year^{-1} on pooled basis (Table 2). The magnitude of increase in total crude protein yield in a paired system of B×N hybrid + *Desmanthus* (2:5) and Guinea grass + *Desmanthus* (2:3) was to the tune of 48 and 45%, respectively over sole B×N hybrid and sole guinea grass, respectively. On the other hand, significantly lower crude protein yield was noticed with sole fodder sorghum (22.1 q ha^{-1} year^{-1}) followed by Sorghum + *Desmanthus* in 8:2 and 4:1 row ratio (22.5 and 22.4 q ha^{-1} year^{-1}, respectively) cultivated throughout the year. The trend was similar during both years of study. The crude protein yield is the function of dry matter yield and crude protein content

Table 2. Green fodder, dry matter and crude protein yield of different perennial grass-legume mixtures

Treatments	Green fodder yield			Dry matter yield			Crude protein yield		
	(q* ha^{-1} year^{-1})								
	1st year	2nd year	Mean	1st year	2nd year	Mean	1st year	2nd year	Mean
T_1	1574.9	1732.1	1653.5	310.6	338.1	324.4	31.9	35.0	33.4
T_2	1509.3	1660.1	1584.7	297.5	326.0	311.8	28.6	31.7	30.1
T_3	1717.2	1888.3	1802.7	339.6	371.9	355.7	39.5	43.5	41.5
T_4	1363.8	1521.3	1442.6	284.0	316.2	300.1	33.7	37.4	35.5
T_5	1278.6	1452.9	1365.8	267.9	304.0	286.0	29.4	33.4	31.4
T_6	1399.7	1582.6	1491.1	291.5	328.2	309.9	36.0	40.6	38.3
T_7	1030.0	1132.8	1081.4	233.7	257.6	245.6	21.2	23.6	22.4
T_8	1065.3	1171.7	1118.5	243.2	268.1	255.7	21.3	23.7	22.5
T_9	1471.5	1623.6	1547.6	291.0	320.1	305.6	26.7	29.6	28.1
T_{10}	1168.3	1349.9	1259.1	246.9	284.7	265.8	24.4	28.3	26.4
T_{11}	1117.1	1228.7	1172.9	256.8	283.1	269.9	20.9	23.3	22.1
T_{12}	769.5	845.3	807.4	154.2	168.5	161.4	31.4	34.5	33.0
SEM	74.4	82.6	75.8	18.5	18.0	17.2	1.9	2.0	1.8
CD ($p < 0.05$)	218.3	242.4	222.2	54.4	52.7	50.6	5.5	5.8	5.2

*10 quintals (q) = 1 ton; T_1: B×N hybrid + *Desmanthus* (1:1); T_2: B×N hybrid + *Desmanthus* (2:1); T_3: B×N hybrid + *Desmanthus* (2:5) (paired row: 60 cm x 180 cm); T_4: Guinea grass + *Desmanthus* (1:1); T_5: Guinea grass + *Desmanthus* (2:1); T_6: Guinea grass + *Desmanthus* (2:3) (paired row: 45 cm x 120 cm); T_7: Perennial fodder sorghum + *Desmanthus* (4:1); T_8: Perennial fodder sorghum + *Desmanthus* (8:2); T_9: B×N hybrid (sole); T_{10}: Guinea grass (sole); T_{11}: Perennial fodder sorghum (sole); T_{12}: *Desmanthus* (sole)

of the fodder. The higher crude protein yield in a paired row system of B×N hybrid + *Desmanthus* (2:5) and Guinea grass + *Desmanthus* (2:3) was mainly due to the higher dry matter yield of the main crop and higher crude protein content of the intercrop of *Desmanthus,* which resulted in higher total crude protein yield of the system. The significantly lower crude protein yield in sorghum was mainly due to the lower content of crude protein even with a considerable amount of dry matter content and dry matter yield. These results were in conformity with the findings of Suksombat and Buakeeree (2006), Jha and Tiwari (2018), Hindoriya *et al.* (2019), Singh *et al.* (2019) and Manoj *et al.* (2020) and Thomas *et al.* (2021b).

Soil organic carbon content: The data pertaining to soil organic carbon was also recorded (Table 3). Organic carbon is considered as a storehouse of nutrients, enzymes as well as antibiotics which plays an important role in maintaining soil health. All the fodder cropping systems showed an increasing sign of organic carbon content in the soil. Among different perennial fodder cropping systems, higher carbon credit was observed under paired row system of B×N hybrid + *Desmanthus* (2:5) cropping system (0.018%) followed by paired row system Guinea grass + *Desmanthus* (2:3) and B×N hybrid + *Desmanthus* in 1:1 row ratio (0.016 and 0.014%, respectively). However, the lower carbon credit was noticed under the sole cropping of sorghum (0.008%) at the end of the second year. A similar trend was observed during the first year of study. The higher soil organic carbon content under these fodder cropping systems might be attributed to higher above-ground biomass, deeper and higher root biomass, reduced tillage, the addition of crop remaining and also the addition of nitrogen by legume crop through biological nitrogen fixation. These results corroborated the findings of earlier workers (Sivakumar *et al.*, 2014; Ram, 2015; Bama and Babu, 2016; Meena *et al.*, 2017; Sarkar *et al.*, 2017; Patil *et al.*, 2018; Manoj, 2020; Thomas *et al.*, 2021b).

Carbon sequestration: The different fodder cropping systems had different potential for carbon sequestration in soil (Table 4). Among the cropping systems at the end of the second year, higher credit of carbon sequestration was observed under the paired row system of B×N hybrid + *Desmanthus* (2:5) (1.12 Mg ha^{-1}) followed by paired row system Guinea grass + *Desmanthus* (2:3) and B×N hybrid + *Desmanthus* in 1:1 row ratio (0.99 and 0.88 Mg ha^{-1}, respectively). Lower carbon sequestration credit was noticed under the monocropping of sorghum (0.53 Mg ha^{-1}). The increased soil organic carbon content might be the reason for higher carbon sequestration by these fodder cropping systems due to huge above ground biomass and addition of senescent leaves and post-harvest remainings into the soil (Walker and Borek, 2008). These results were in accordance with the findings of Sivakumar *et al.* (2014),

Table 3. Soil organic carbon content under different perennial grass-legume mixtures

Treatments	Soil organic carbon (%)					
	Initial (A)	After 1st year (B)	Credit (B-A)	After 2nd year (C)	Credit (C-B)	Total credit (C-A)
T_1	0.525	0.535	+ 0.010	0.539	0.004	+ 0.014
T_2	0.507	0.516	+ 0.009	0.519	0.003	+ 0.012
T_3	0.530	0.541	+ 0.011	0.548	0.007	+ 0.018
T_4	0.522	0.531	+ 0.009	0.535	0.004	+ 0.013
T_5	0.517	0.525	+ 0.008	0.528	0.003	+ 0.011
T_6	0.527	0.537	+ 0.010	0.543	0.006	+ 0.016
T_7	0.514	0.518	+ 0.004	0.522	0.004	+ 0.008
T_8	0.513	0.519	+ 0.006	0.522	0.003	+ 0.009
T_9	0.521	0.527	+ 0.006	0.532	0.005	+ 0.011
T_{10}	0.516	0.521	+ 0.005	0.525	0.004	+ 0.009
T_{11}	0.512	0.516	+ 0.004	0.520	0.004	+ 0.008
T_{12}	0.519	0.524	+ 0.005	0.528	0.004	+ 0.009

Table 4. Carbon sequestration in soil and carbon dioxide equivalents per unit area under different perennial grass-legume mixtures

Treatments	Carbon sequestration (Mg ha^{-1})				Carbon dioxide equivalents (Mg ha^{-1})			
	Initial (A)	After 1st year (B)	After 2nd year (C)	Total credit (C-A)	Initial (A)	After 1st year (B)	After 2nd year (C)	Total credit (C-A)
T_1	21.61	22.17	22.49	+ 0.88	79.23	81.27	82.47	+ 3.24
T_2	20.99	21.52	21.77	+ 0.78	76.96	78.90	79.81	+ 2.85
T_3	21.86	22.48	22.98	+ 1.12	80.16	82.42	84.27	+ 4.11
T_4	21.52	22.03	22.31	+ 0.79	78.90	80.78	81.80	+ 2.91
T_5	21.30	21.75	21.97	+ 0.67	78.08	79.75	80.56	+ 2.47
T_6	21.80	22.36	22.79	+ 0.99	79.94	81.99	83.56	+ 3.62
T_7	21.13	21.38	21.67	+ 0.55	77.46	78.40	79.47	+ 2.01
T_8	21.21	21.53	21.75	+ 0.54	77.76	78.96	79.76	+ 2.00
T_9	21.51	21.87	22.20	+ 0.69	78.86	80.17	81.40	+ 2.54
T_{10}	21.25	21.57	21.83	+ 0.58	77.93	79.09	80.04	+ 2.11
T_{11}	21.03	21.27	21.56	+ 0.53	77.10	77.99	79.05	+ 1.95
T_{12}	21.47	21.76	22.03	+ 0.56	78.73	79.77	80.79	+ 2.06

Bama and Babu (2016), Prajapati (2017), Manoj (2020) and Thomas *et al.* (2021a).

Carbon dioxide (CO_2) equivalents per unit area: The paired row system of B×N hybrid + *Desmanthus* (2:5) recorded higher credit of carbon dioxide equivalents per unit area (4.11 Mg ha^{-1}) followed by paired row system Guinea grass + *Desmanthus* (2:3) and B×N hybrid + *Desmanthus* in 1:1 row ratio (3.62 and 3.24 Mg ha^{-1}, respectively) at the end of second year (Table 4). The lower credit of carbon dioxide equivalents per unit area was noticed under the monoculture of sorghum (1.95 Mg ha^{-1}). The increased soil organic carbon content and carbon sequestration might be the reason for higher carbon dioxide equivalents per unit area. The similar kind of results was also reported by Prajapati (2017), Sarkar *et al.* (2017) and Manoj (2020).

Economics: Among different perennial grass-legume mixtures, the paired row system of B×N hybrid + *Desmanthus* (2:5) recorded significantly higher gross returns (Rs. 3,44,072 ha^{-1} year^{-1}) (Table 5) and found on

Table 5. Economics of different perennial grass-legume mixtures (two years mean data)

Treatments	Cost of cultivation	Gross returns	Net returns	B:C ratio
	(Rs. ha^{-1} year^{-1})			
T_1	82995	300962	217968	3.64
T_2	81059	282030	200971	3.49
T_3	85320	344072	258752	4.05
T_4	77366	272758	195392	3.54
T_5	72841	249777	176937	3.44
T_6	78511	287289	208778	3.67
T_7	65058	196306	131248	3.02
T_8	65730	200647	134917	3.06
T_9	79969	270824	190855	3.40
T_{10}	65605	220338	154733	3.37
T_{11}	64076	205256	141180	3.21
T_{12}	59790	201851	142061	3.39
SEM	-	17834	17834	0.14
CD ($p < 0.05$)	-	52309	52309	0.40

par with B×N hybrid + *Desmanthus* in 1:1 row proportion (Rs. 3,00,962 ha^{-1} year^{-1}). In contrast, the lower gross returns were noticed with the Sorghum + *Desmanthus* (4:1) cropping system (Rs. 1,96,306 ha^{-1} year^{-1}) (Table 5). On the other hand, significantly higher net returns were registered with paired row system of B×N hybrid + *Desmanthus* (2:5) (Rs. 2,58,752 ha^{-1} year^{-1}), which was at par with B×N hybrid + *Desmanthus* in 1:1 row ratio and paired row system of Guinea grass + *Desmanthus* (2:3) (Rs. 2,17,968 and Rs. 2,08,778 ha^{-1} year^{-1}). Further, the lower net returns were observed with the Sorghum + *Desmanthus* (4:1) cropping system (Rs. 1,31,248 ha^{-1} year^{-1}). However, a significantly higher benefit-cost ratio was recorded by the paired row system of B×N hybrid + *Desmanthus* (2:5) cropping system (4.05) and it was on par with the paired row system of Guinea grass + *Desmanthus* (2:3) (3.67). In contrast, a lower benefit-cost ratio was registered with sorghum + *Desmanthus* grown in 4:1 row proportion (3.02) followed by 8:2 row ratio (3.06). The higher gross returns, net returns and benefit-cost ratio were mainly attributed to higher green fodder yield. These results were in line with the findings of Patil *et al.,* (2018), Vinothraj *et al.,* (2019), Manoj *et al.,* (2020), Thomas *et al.,* (2021a; 2021b).

Conclusion

The present study revealed the potentiality of perennial fodder grass-legume mixtures under intensively managed cut and carry feeding systems to yield high-quality fodder along with higher credit of carbon sequestration as compared to conventional grass or legume monoculture. The monoculture of B×N hybrid and guinea grass is the current popular system among the farmers in the locality, and both are higher yielders of dry matter, but fodder quality was much lower. Hence, considering the credit of soil organic carbon content, carbon sequestration, biomass yield, quality yield and benefit-cost ratio, the grass-legume mixture of B×N hybrid paired row + *Desmanthus* (2:5) followed by Guinea grass paired row + *Desmanthus* (2:3) was found to be the most promising systems for meeting both farmers need as well as soil sustainability.

References

Anonymous. 2005. *Crop Production Guide*. Tamil Nadu Agricultural University, Department of Agriculture, Government of Tamil Nadu.

Bama, K. S. and C. Babu. 2016. Perennial forages as a tool for sequestering atmospheric carbon by best management practices for better soil quality and environmental safety. *Forage Research* 42: 149-157.

Ghosh, A., S. K. Mahanta, M. C. Manna, S. Singh, R. Bhattacharyya, V. C. Tyagi, J. B. Singh, S. N. Ram, R. Srinivasan, A. K. Singh, Ajita Gupta, P. Govindasamy and S. N. Rokde. 2022. Long-term grazing mediates soil organic carbon dynamics by reorienting enzyme activities and elemental stoichiometry in semi-arid tropical inceptisol. *Journal of Soil Science and Plant Nutrition*. doi.org/10.1007/s42729-021-00742-3.

Ghosh, P.K. and S.K. Mahanta. 2014. Carbon sequestration in grassland systems. *Range Management and Agroforestry* 35: 173-181.

Gomez, A. A. and A. A. Gomez. 1984. *Statistical Procedure for Agriculture Research.* 2nd edn, John Willey and Sons, New York.

Hindoriya, P. S., R. K. Meena, R. Kumar, M. Singh, H. Ram, V. K. Meena, D. Ginwal and S. Dutta. 2019. Productivity and profitability of cereal-legume forages *vis-a-vis* their effect on soil nutrient status in Indo-Gangetic Plains. *Legume Research* 42: 812-817.

IPCC. 2003. *Good Practices Guidance for Land Use, Land Use change and Forestry*. Institute for Global Environmental Strategies (IGES) for the Intergovernmental Panel on Climate Change (IPCC), Kanagawa, Japan.

Jha, S. K. and N. Tiwari. 2018. Evaluation of intensive fodder cropping systems for round the year green fodder production in Chhattisgarh. *Forage Research* 44: 115-118.

Jiang, D., H. Hengsdijk, T. B. Dai, W. De Boer, Q. Jiang and W. X. Cao. 2006. Long-term effects of manure and inorganic fertilizers on yield and soil fertility foe a winter-maize system in Jiangsu, China. *Pedosphere* 16: 25-32.

Kumar, S., D. Machiwal, R. Dev, M. Surshkumar and D. Dayal. 2021. Performance of grasses and legumes as influenced by their strip intercropping association in typical arid Kachchh, Gujarat. *Range Management and Agroforestry* 42: 186-190.

Lal, R. 2003. Global potential of soil C sequestration to mitigate the greenhouse effect. *Critical Review on Plant Science* 22: 151-184.

Manoj, K. N. 2020. Studies on sustainable modules for year round green fodder production under irrigated condition. Ph.D. Thesis, University of Agricultural Sciences, Bangalore, India.

Manoj, K. N., B. G. Shekara, S. Sridhara, P. K. Jha and P. V. V. Prasad. 2021. Biomass quantity and quality from different year-round cereal-legume cropping systems as forage or fodder for livestock. *Sustainability,* 13: 9414. DOI: https://doi.org/10.3390/su13169414.

Manoj, K. N., B. G. Shekara, K. N. Kalyana Murthy and Mudalagiriappa. 2020. Productivity and profitability of forage cropping systems under irrigated conditions of southern dry zone of Karnataka. *Forage Research* 46: 198-201.

Meena, L. R., L. K. Meena, A. L. Meena and S. P. Singh. 2017. Effect of organic nutrient management on intercropping systems of *Cenchrus* and *Dolichos lablab* for quality fodder production and for improving soil health under semi-arid conditions of Rajasthan. *Forage Research* 43: 202-207.

Meng, L., Z. C. Cai and W. X. Ding. 2005. Carbon contents in soils and crops as affected by long-term fertilization. *Acta Pedologica Sinica* 42: 769-776.

Patil, L. M., V. K. Kauthale, T. G. Bhalani and D. J. Modi. 2018. Productivity and economics of different forage production systems in south Gujarat conditions of India. *Forage Research* 44: 14-18.

Pearson, T. R., S. L. Brown and R. A. Birdsey. 2007. Measurement guidelines for the sequestration of forest carbon. General Technical Report, USDA Forest Service. DOI: https://doi.org/10.2737/NRS-GTR-18.

Prajapati, B. 2017. Cropping systems for sustainable fodder and bioenergy production. Ph.D. Thesis, G B Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India.

Ram, S. N. 2015. Response of guinea grass (*Panicum maximum* JACQ.)- legumes intercropping to weed control. *Forage Research* 4: 15-18.

Sarkar, D., C. B. Meitei, A. Das, P. K. Ghosh and B. Mandal. 2017. Changes in soil organic carbon pools in a long-term trial with perennial fodder crops in acid soils of north-east India. *Grass* and *Forage Science* 73: 473-481.

Singh, H. N., M. R. Kumar, S. Magan, R. Kumar, H. Ram, M. V. Kumar and K. Manish. 2019. Evaluation of *Kharif* forage crops for biomass production and nutritional parameters in Indo-Gangetic plains of India. *Indian Journal of Animal Nutrition* 36: 25-29.

Sivakumar, T. V., S. M. Sundaram, V. M. Sankaran and J. S. I. Rajkumar. 2014. Sequestering of atmospheric carbon through fodder cultivation- a measure for mitigating global warming. In: *Proceedings of International Conference on Food, Agriculture and Biology* (June 11-12, 2014), Kuala Lumpur, Malaysia.

Suksombat, W. and K. Buakeeree. 2006. Effect of cutting interval and cutting height on yield and chemical composition of hedge lucerne (*Desmanthus virgatus*). *Asian Journal of Animal Science* 19: 31-34.

Thomas, U. C., R. K. Agrawal, M. R. Anita and P. Mubeena. 2021a. Carbon sequestration potential of grass based fodder production systems in humid tropics of Kerala. *Range Management and Agroforestry* 42: 104-109.

Thomas, U. C., R. K. Agrawal, M. R. Anita and P. Mubeena. 2021b. Intensive forage production through agati (*Sesbania grandiflora* (L.) Pers.) based fodder production systems in Kerala. *Range Management and Agroforestry* 42: 307-311.

Vinothraj, S., P. Alagesan, S. Saravanakumar and R. D. Srinivasan. 2019. Impact of mixed fodder cultivation in dairy cattle milk yield. *International Journal of Current Microbiology and Applied Science* 8: 1000-1003.

Walker, M. B. and R. Borek. 2008. Evaluation of carbon sequestration in energetic crops. *International Agrophysics* 22: 185-190.