Short-term effect of forage grasses on carbon sustainability, fodder security, and soil properties in poor soils of semi-arid India

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Abstract. Grasses are essential sources of fodder for livestock and provide options for climate resilience due to their broad range of adoption. They are also valuable resources for soil quality enhancement. Therefore, a six-year field study using nine grasses (2013 to 2019) was initiated in a semi-arid region of central India. The study aimed to assess the short-term impact of these nine grasses on soil carbon stock, selected soil physio-chemical and biological properties, and green fodder yield. Results (after six years) revealed that a greater carbon stock (7.0 and 7.2 Mg ha^{-1}), carbon sustainability index (71.6 and 89.3), and sustainable yield index for green fodder (0.89 and 0.91), respectively, were observed in lampagrass [*Heteropogon contortus* (L.)] and guineagrass [*Megathyrsus maximus* (Jacq.)]. These improvements could be due to the greater root length (1700 and 2220 cm plant^{-1}) and root weight density of grasses in the upper soil layer (0–10 cm, 70%), and the higher green biomass production (~44.1 t ha^{-1} year^{-1}). These beneficial changes might have further led to the lower soil bulk density (~1.05 g cm^{-3}), higher water-filled porosity (14.7 and 16.1%), and soil organic carbon content (~0.67%) over other grasses and barren soil. Consequently, the highest total bacterial count (21.9 and 44.5 × 10^{7} CFU g^{-1}), soil microbial biomass carbon and enzyme activities such as acid phosphatase (17.7 and 22.6 µg p-nitrophenyl g^{-1} h^{-1}) and alkaline phosphatase (9.6 and 15.9 µg p-nitrophenyl g^{-1} h^{-1}) were noticed in lampagrass and guineagrass rhizospheres. Therefore, cultivation of perennial grasses in the low fertile soils of semi-arid environments can be an eco-friendly approach to enhance soil fertility, green fodder supply, and soil carbon build-up.

Introduction

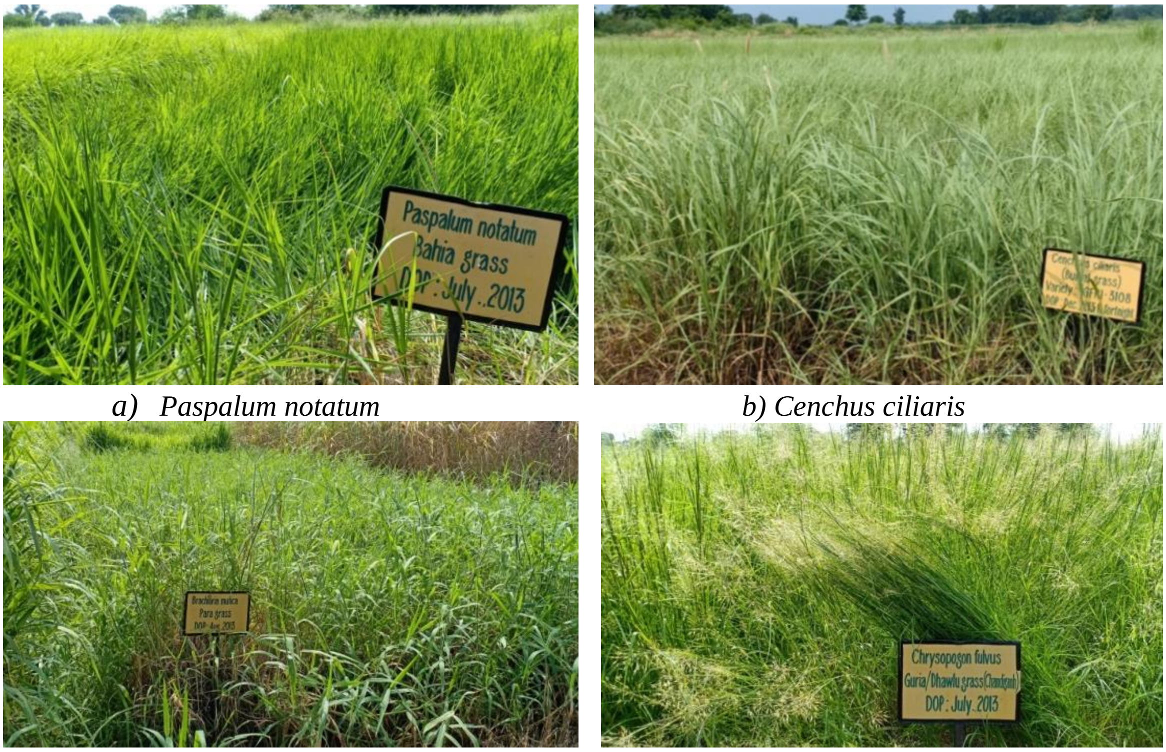
Livestock is the primary source of family income and nutritional security in semi-arid regions worldwide. To sustain the fodder needs in resource-scarce areas, grasses play a significant role as stable foods, and most forage resources are grasses (75%). Therefore, grasses are in demand primarily for forage due to their high foliage and secondarily for ecosystem services (Singh et al. 2022). Grasslands represent 26% of total world cropland, and 85% of productive farmland mainly consists of forage grasses (Boval and Dixon 2012). Besides fodder value, these grasses play a vital role in the ecosystem services like water cycling, nutrient cycling, soil binding, carbon sequestration, climate change mitigation, and biodiversity, especially in semi-arid regions (Franzluebbers 2012; Halli et al. 2022). Grasses play an important role in improving soil health by regulating soil moisture, heat loss, temperature, fertility, and biological activity and reducing soil erosion loss due to an extensive fibrous root system. Hence, grasses can supplement mechanical measures of soil and water conservation due to better anchorage, armor, catch, reinforcement, and storage. Mandal et al. (2017) opined that planting grasses like *Pennisetum purpureum* Schumach and *Saccharum munja* Roxb enhanced soil water storage capacity by two times over barren soils. Furthermore, the greater biomass production ability of grasses helps in the mitigation of CO_2 emissions. Moreover, decaying residues and roots contribute to soil carbon build-up and act as the energy source for soil biodiversity. However, detailed information on the effect of various grasses with forage potential on the overall soil properties in a semi-arid environment is sparse (Wilekson et al. 2010). Indeed, the results of this study would assist in selecting suitable grass species for improved green fodder yield and other services. Thus, a field study (6 years) was conducted to quantify the short-term impact of different tropical grasses on soil properties, green fodder yield, and sustainability in a semi-arid climate.

Methods

The experiment was carried out during 2013-19 at Central Research Farm of Indian Grassland and Fodder Research Institute, Jhansi, India. The soil texture of the experimental site was a coarse sandy loam with a slight alkali pH, average electrical conductivity, and low organic carbon concentration (0.28%). The soil was also low in available N (202 kg ha^{-1}), P (6 kg ha^{-1}), and K (115 kg ha^{-1}). Nine perennial tropical forage grasses were included in this study and planted during the rainy period (July 2013) according to the recommended package of practices of Indian Grassland and Fodder Research Institute, Jhansi (Table 1). The experiment was laid out in a randomized complete block design (RCBD) with three replications. Grass root morphology was studied at 30 days after the harvest of green fodder, and root samples were collected using a core sampler (volume; 385 cm^3) and analyzed with a root scanner (Halli et al. 2021 & 2022). Different microbial groups were enumerated by serial dilution and standard plate count method. Used nutrient agar medium (total bacterial count) and Pikovskaya's agar medium (total phosphate solubilizing bacteria and fungi). Similarly, both acid and alkaline phosphatase activity were estimated using Tabatabai and Bremner (1969) procedure. After six years of observations, soil samples were also analyzed for pH, electrical conductivity, organic carbon concentration, available N, P, K, soil organic carbon stock, and sequestration rate. The green fodder yield of different grasses was recorded, and 3-4 cuts were taken in a year at an interval of 50 days. However, the general view of the selected range grasses at 50 days after cutting is depicted in Fig. 1. The green fodder yield sustainability index was calculated to determine the yield trend over the years (Meena et al. 2017). Total annual C input and output were calculated by considering the carbon emission equivalents of inputs used in the management and green biomass produced by grasses (Lal 2004). For statistical analysis, grasses, soil depth, and year were considered as fixed effects, and replications as a random effect. A mixed model (Proc GLIMMIX) was used for ANOVA for all the parameters (SAS v 9.3. SAS Institute, Inc., Cary, NC, USA). Fisher's least significance difference (LSD) test was used to separate the means at 5% ($\alpha < 0.05$) level of significance.

Table 1. Details of grasses used in the experiment

Sl No.	Common name	Botanical name	Spacing (cm × cm)
1	Paragrass	*Brachiaria mutica* (Forssk.) Stapf	50 × 30
2	Buffelgrass	*Cenchus ciliaris* L.	50 × 30
3	Rhodesgrass	*Chloris gayana* Kunth	50 × 30
4	Reddish-yellow beardgrass	*Chysopogon fulvus* (Spreng.) Chiov.	50 × 30
5	Marvelgrass	*Dichantium annulatum* (Forssk.) Stapf	50 × 30
6	Perennial tussock grass /Lampagrass	*Heteropogon contortus* (L.) P.Beauv. ex Roem. & Schult	50 × 30
7	Guineagrass (Hamil)	*Megathyrsus maximus* (Jacq.) B.K.Simon & S.W.L.Jacobs	50 × 30
8	Bahiagrass	*Paspalum notatum* Flüggé	50 × 30
9	African bristlegrass/ Golden timothy	*Setaria sphacelata* (Schumach.) Stapf & C.E.Hubb. ex M.B.Moss	50 × 30



a) *Paspalum notatum* b) *Cenchus ciliaris*

c) *Brachiaria mutica* d) *Chysopogon fulvus*

Figure 1. General view of selected grass species at 50 days after cutting

Results and Discussion

Planting grasses improved the soil's physical properties in the six years of cultivation. The data on growth, yield parameters, soil properties, and carbon build-up are given in Table 2. Grasses such as lampagrass and guineagrass performed better in improving soil properties over other grasses. Decreased soil bulk density, and increased greater water-filled porosity, and porosity probably enhanced the microbial and enzyme activities in the topsoil (0–15 cm). Consequently, total bacterial count, acid phosphatase, and alkaline phosphatase activities in the soil were increased with these grasses to 87.2 to 93.7%, 72.3 to 78.31%, and 84.3 to 90.5%, respectively, over barren land. Besides, greater organic C, N, P, and K in the topsoil (0–10 cm depth) also indicates favourable changes due to grasses. In a study at a similar location conducted by Ramakrishnan et al. (2021), the inclusion of grasses in a silvopastoral system enhanced the microbial counts and diversity due to increased activity of enzymes (dehydrogenase, acid phosphatase, and alkaline phosphatase) in the upper soil layer in comparison to lower soil layer. The fibrous root system of these grasses (lampagrass and guineagrass) with a greater root length and number of fine roots may have enhanced the soil-microbe connection due to higher surface area, thus encouraging diverse microbes and soil enzymes. After six years of cultivation, lampagrass and guineagrass improved the soil quality indicators in poor soils.

Furthermore, cultivation of these grasses did not require much soil disturbance, and involved minimum production inputs with only three protective irrigations throughout the year, and no pesticide applications; thus, the carbon footprint was low. Increased green fodder yield and root dry weight production in guineagrass, lampagrass, and reddish-yellow beard grass resulted in a higher carbon sustainability index over other grasses. Previous studies reported the potential of guineagrass and turf grasses to maintain higher carbon storage even in disturbed urban environments (Sumiyoshi et al. 2017; Amoatey and Solaiman 2020). Therefore, these grasses could be grown to reduce the carbon footprints of agriculture and restore environmental quality. Interestingly, guineagrass maintained a higher sustainable yield index (0.91) owing to lesser variation in the green fodder yield over six years. This might be due to sustained yield, excellent adaptation, prominent canopy characters, and supplementary root system (fine and longer roots with higher surface area, volume, and density; data not presented). The sustained yield could also be attributed to improved soil health indicators (organic carbon, moisture content, and microbial activity) in the rhizosphere of guineagrass and lampagrass. Similarly, Xu et al. (2020) highlighted that high soil organic carbon levels enhanced crop yield due to improved soil aggregations and nutrient availability. This study demonstrated that soil water and nutrient availability are the main factors that govern the growth and productivity of grasses in arid and semi-arid grasslands. In this connection, Hartnet et al. (2012) also reported that adaptive traits like efficient root systems of grasses are crucial for survivability and sustained performance in water and/or nutrient limitations. Therefore, guineagrass, lampagrass, and reddish-yellow beardgrass could play a vital role in supporting pastoral development and feed supply to livestock.

Table 1. Growth and yield parameters, soil properties, yield trend, and carbon stock of tropical grasses over 6 years

Grasses	RL	GB	TBC	ACPH	ALPH	OC	BD	WFP	CS	CSI	SYI
Barren soil	-	-	2.8d	4.9e	1.5f	0.28e	1.3a	10.1c	3.8d	-	-
Paragrass	1520c	40.1bc	23.1b	17.8b	7.9c	0.44c	1.2b	15.0a	5.5b	74.3bc	0.83b
Buffelgrass	1160d-f	37.2cd	5.7c	11.1e	3.9g	0.38d	1.2b	12.9a-c	4.6b-d	67.6c	0.78c
Rhodesgrass	1110ef	39.9bc	7.1c	14.0d	5.7e	0.42cd	1.2b	14.0ab	5.0bc	69.5bc	0.80bc
Reddish-yellow beardgrass	1190de	41.9b	6.9c	15.1c	4.0g	0.40d	1.2b	13.5a-c	4.1cd	76.8b	0.83b
Marvelgrass	1550c	35.9d	6.3c	15.1c	5.0f	0.44c	1.2b	13.7ab	5.0bc	65.7c	0.80bc
Lampagrass	2220a	38.4cd	44.5a	22.6a	15.9a	0.73a	1.0c	16.1a	7.0a	71.6bc	0.89a
Guineagrass	1700b	49.4a	21.9b	17.7b	9.6b	0.62b	1.1b	14.7ab	7.2a	89.3a	0.91a
Bahiagrass	1060f	38.9cd	6.8c	14.9c	5.5e	0.42cd	1.2b	11.2bc	5.1b	68.9bc	0.79bc
African bristlegrass	1240d	30.1e	7.8c	17.9b	6.2d	0.39d	1.2b	13.4a-c	4.6b-d	55.4d	0.76c
p-value	<0.001	<0.001	<0.001	<.0001	<.0001	<.0001	<0.001	0.030	<0.001	<0.0001	<0.001

RL, total root length (0–10 cm, cm plant^{-1}); GB, green biomass production (t ha^{-1} year^{-1}); TBC, total bacterial count (× 10^7 CFU g^{-1}); ACPH, acid phosphatase (µg p-nitrophenyl g^{-1} h^{-1}); ALPH, alkaline phosphatase (µg p-nitrophenyl g^{-1} h^{-1}); OC, soil organic carbon (%); BD, bulk density (g cm^{-3}); WFP, Water filled porosity (%); CS, carbon stock (Mg ha^{-1}); CSI, carbon sustainability index, SYI, sustainable yield index for green fodder.

Conclusions

An adaptive root system and high biomass-producing potential are essential features for tropical grasses under high aridity index, erratic rainfall, extreme potential evaporation, and infertile soils. Our findings demonstrated that guineagrass and lampagrass are suitable grasses for producing higher and sustainable green biomass and maintaining soil organic carbon build-up due to robust root growth and better acclimatization. Greater above and below-ground growth of these grasses resulted in improved soil physical, chemical, and biological properties and carbon sustainability index. Therefore, one can address the issues of poor soil fertility, restoration, fodder security, and carbon footprint reduction by cultivating lampagrass and guineagrass on poor lands of semi-arid environments.

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