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Fodder Grass Strips: An Affordable Technology for Sustainable Rainfed Agriculture in India

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Abstract: Rainfed agriculture, though resource-poor, contributes to around 40 percent of total food production in India. Fodder grass-strip-based systems improve soil's physical and biological properties, control soil erosion, and help in slope stabilization without compromising productivity. Permanent fodder grass strips can effectively check the depletion of soil nutrients and can also act as sediment traps vis-à-vis meeting the green fodder requirement for small ruminants. This study was carried out with the major objective to quantify the impact of grass-strip-based cropping systems on soil quality. Further fodder quality assessment was carried out using the grass quality index for small ruminant feed and the profitability of different treatments was analyzed. Random block design (RBD) with three treatments which included two types of fodder grass (*Brachiaria ruziziensis* and *Stylosanthes hamata)* on both sides of the cropped field was used for the study. The results showed that the soil quality increased from 0.39 to 0.52 and the runoff reduced significantly with soil loss reduction by 65-70 percent. The fodder quality assessment showed that the palatability of *Stylosanthes hamata* and *Brachiaria ruziziensis* was about 65 percent and 40 percent, respectively. The fodder grass strip increased the net returns by 30 percent. This easily adaptable natural resource management technology reduces soil nutrient loss and will help resource-poor rainfed farmers to maintain soil health and productivity under variable rainfall conditions with fair support to small ruminants.

Keywords: soil quality; fodder quality; surface runoff; fodder-based cropping system

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1. Introduction

Rainfed farming coupled with uneven rainfall distribution due to changing climate leads to high yield fluctuations. The sudden downpour causes high soil loss from the agricultural field, resulting in erosion of the topsoil layer [1]. The conventional methods of preventing soil erosion/loss are vegetation, matting the soil, application of mulches, constructing windbreakers, turning the slope area into a flat surface, etc. However, farmers are reluctant to use these methods due to engagement of some part of their land towards non-cropping activities [2]. Due to factors such as heavy downpours during the monsoon season, weak soil aggregate stability, and insufficient vegetative cover, soil erosion rates are generally high to extremely high throughout the world's rainfed regions [3]. Soil erosion is a serious problem in this region, causing low crop yields, fragile agricultural production systems, and increased vulnerability to droughts due to high nutrient losses and low soil water use efficiency [4]. There is a detrimental effect on the ecosystem and there is a lot of sediment produced in the areas further downstream [5]. For this reason, it is essential to the region's continued agricultural production that methods are developed to lessen the rate of soil and water erosion, increase the efficiency with which soil water is used, make the soil more resistant to drought, and lessen environmental repercussions.

Presently, the rainfed regions of India account for around 40 percent of the total food grain production and support two-thirds of livestock and 40 percent of the human population, including the livelihoods of 80 percent of small and marginal farmers [6]. Thus, a need for a biological method was felt to prevent soil loss; moreover, it should be able to support the huge livestock population too by supplying quality fodder. In tropical rainfed regions, grass strips, such as those investigated in the study, may provide cost-effective solutions to combat soil erosion on a large scale [7]. Intercropping of grasses and dryland crops, most of the time, is not feasible in micro-farming situations [8].

Green filter strips (grass strips) can effectively trap soil sediments, reducing soil loss from the field [9]. However, due to the low risk-bearing capacity of rainfed farmers in India and the increasing total agricultural production costs, it will be crucial to implement best management practices to keep soils healthy, conserve agronomic inputs, minimize environmental impacts, and achieve reasonable yields. Nutrient removal by soil erosion restricts land productivity. One ton of soil erosion can remove 4 kg N, 1 kg P, 20 kg K, and 2 kg Ca [10]. Grass systems have been observed to be helpful in enhancing other soil properties (e.g., soil's physical and biological properties) involved in soil erosion control, slope stabilization, and food production [11]. Using grass strips is one of the low-cost measures in soil conservation, especially for slowing down runoff.

Forage belts at the sloping end of the field boundary and at the top field boundary are key to a cost-effective and practical solution to large-scale soil erosion control that can be adopted as a new and improved technology [12] to support farmers with small ruminants in rainfed farming systems. Quantitative data on their influence on soil quality and the productivity and profitability of such systems are very limited [12].

Hence, this study was taken up with the objective of evaluating various options of grass strips in varied slopes of small land holdings which can prevent soil erosion effectively and support green fodder for small ruminants, leading to the establishment of sustainability in rainfed farming, and can economize production performance. Cropping of grass strips on both sides (at the slope end and the top of the sloping field) is easy to adopt, cost-effective, and durable for small farms and is without mechanical hindrance in cultivation planning and management. Technology could offer minimization of soil loss with a reduction in nutrient nitrogen loss from the cropped field, thereby resulting in overall improvement in soil quality as well as providing the green fodder needs of small ruminants. The present investigation aimed to suggest a farming model which could support mixed farming as well as reduce soil loss.

2. Materials and Methods

An experimental plot area of approximately 2.8 ha was established at the Hayathnagar Research Farm of the Central Research Institute for Dryland Agriculture, Hyderabad, India (between 17.33 to 17.36 decimal degrees latitude and 78.58 to 78.61 decimal degrees longitude). The area falls under a semi-arid (arid) climate with a mean annual rainfall of 746.2 mm. The slope varies between 1 and 3%, with some divergent and complex slopes leading to significant erosion hazards. Treatment was applied on 1, 2, and 3% sloped land with (i) 2-m strips of *Brachiaria ruziziensis* and (ii) *Stylosanthes hamata* at the bottom of the trial plot (area: 15×30 m^2), (iii) 2-m strips of *Brachiaria ruziziensis* at the bottom and top, and (iv) *Stylosanthes hamata* at the bottom and top of the plot, and (v) a control plot with no grass strips. For each grass strip, measurements were made for the various parameters studied based on a catenary arrangement.

2.1. Rainfall Scenario

Deficit rainfall is regarded as a crisis that gives agriculture policymakers time to prepare and plan to combat it. Deficit rainfall, or intense conditions such as drought, has emerged as one of the leading causes of both livestock fatalities and economic losses in agriculture. On average, every third year experiences a rainfall deficit in the study area [13]. The average rainfall in the majority of the semi-arid regions of India is 750 mm where 80% of the rainfall occurs in the southwest monsoon season. Since the present study was carried out in farm conditions that are truly representative of the dryland regions of India, datasets for the experiment were systematically collected for four years (2016–2019). Out of these four years, two years had normal rainfall situations (categorized as NRF) and two years had a rainfall deficit (categorized as DRF). The rainfall during the experimental period is portrayed in Figure 1. Thus, the performance of the farming system in the variable rainfall years has been compared in order to establish the grass strip system as being more resilient.

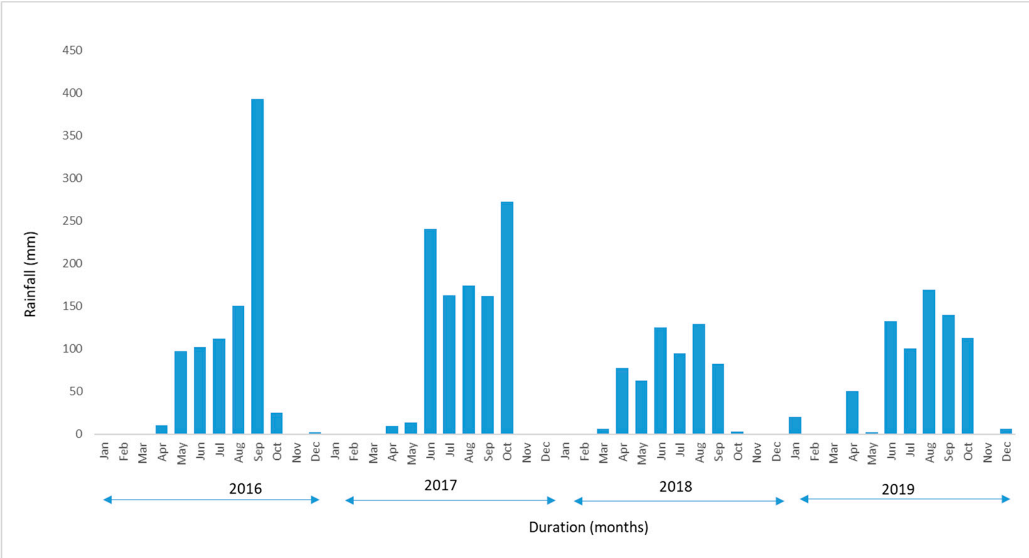

Figure 1. Rainfall distribution during the study period (2016 to 2019).

2.2. Soil Sampling

To understand the effects of grasses at different slope positions on soil properties, composite soil samples were collected from cropped fields at the upper and lower slope positions of the plots. The soil samples were taken at a 5 m distance from the strips to maintain sample uniformity. The experimental plots were used for castor–redgram production with uniform agronomic practices such as nutrient management and weed control. As presented in Table 1, a total of 60 samples were taken from 15 to 20 cm sampling depths for chemical properties and nutrient content analysis.

Table 1. Description of soil samples collected for laboratory analysis.

Land Management Practices	Slope Position within the Plot	Replication at 1%, 2%, and 3% Slope
2 m strip of *Brachiaria ruziziensis*	Upper Lower	4
2 m strip of *Brachiaria ruziziensis*	Lower	4
2 m strip of *Stylosanthes hamata*	Upper Lower	4
2 m strip of *Stylosanthes hamata*	Lower	4
Experimental plot without a grass strip	-	4
Total composite soil samples		**60**

A composite soil sample (500 g each) was collected for further soil analysis. A total of 16 physical, chemical, and biological soil properties were analyzed for each sample using the standard method mentioned in the literature [14–16].

2.3. Runoff Study

The runoff was collected at the base of each plot using a tipping bucket device (Figure 2). The tipping bucket device consists of a tipping bucket and a magnetic counter. The runoff water from each plot was channeled through a channel and ended up in a two-bucket (side) tipping bucket with a known tipping volume (10 L in our case). As soon as the bucket is filled, this is automatically recorded by a magnetic counter attached to the system. The count recorded by the magnetic counter multiplied by the tipping volume of each bucket gave the runoff volume from each plot. A 1000 mL sample was taken from the effluent for nutrient quantification. Sampling took place after each erosive precipitation. Further away from the direct sediment, a sub-sample of 250 g was air-dried and the nutrient loss in the sediments was estimated [17].

1. Tipping bucket; 2. Magnetic counter; 3. Sample collection point

Figure 2. Tipping bucket device used for measuring soil loss in all of the treatment plots.

2.4. Soil Quality Assessment

The weighted additive approach by Karlen and Stott, 1994 [18] and Fernandes et al., 2011, [19] was used to estimate the soil quality index (SQI). This method uses a linear scoring function to first assign a unitless value between 0 and 1 to each soil parameter. Non-linear scoring functions were avoided because they may not accurately predict endpoint variables or crop yields [20]. The soil factors were classified into three categories using three mathematical algorithm functions: (a) more is better (e.g., organic carbon and available water capacity); (b) less is better (e.g., bulk density); and (c) "optimal" (e.g., pH and EC). An "optimal" trait is one that has a positive effect up to a point whereafter the effect is considered negative [19]. After normalizing the soil attributes using the weighted addition method originally proposed by Karlen and Stott [18], we combined the scores into a single index value for each soil. A minimal dataset (MDS) was selected based on expert opinion. Expert opinion used a conceptual approach to MDS selection. This approach only included metrics deemed essential to contribute to the feature of interest (Table 2). MDS variables and their assessments in each supporting soil function were selected from the available data according to project investigator consensus, recommendations from the literature, and local general management concerns [20–24]. All of the selected observations were transformed into four classes using a linear scoring function, with class I scoring the four best. After the selected observations were converted to numbers (range 1–4) (Table 2), we integrated them into indices for each soil parameter using a weighted summation approach [18,20,23]. The soil quality index values were normalized on a scale of 0 to 1 using a linear scoring function and summing the weights for all of the soil functions to 1.0 [25].

$$\text{Scaled score (S) for soil parameters} = (\text{weight} \times \text{score})$$

$$\text{SQI} = \sum \text{Sx} * \text{S(min)}/(\text{S(max)} - \text{S(min)}) + \ldots\ \ldots\ \ldots. + \sum \text{Sn} * \text{S(min)}/(\text{S(max)} - \text{S(min)}))$$

Sx = Scaled score of soil parameters

S(min) = Minimum scaled score

S(max) = Maximum scaled score

Table 2. The framework of soil parameters and their weights along with scores for assessing the soil quality index.

Soil Parameters	Weights	Class I with Score 4	Class II with Score 3	Class III with Score 2	Class IV with Score 1
pH	0.03	6.5- 7.5	6–6.5/7.5–8	5.5–6/8–8.5	<5.5/>8.5
EC (µs/ms)	0.03	0–0.8	0.8–1.6	1.6–3.2	>3.2
N(kg/ha)	0.15	>560	560–420	280–420	<280
P(kg/ha)	0.1	>25	15–25	15 to 10	<10
K (kg/ha)	0.05	>280	200–280	200–120	<120
Ca (ppm)	0.03	>300	300–200	200–100	<100
Mg (ppm)	0.03	>150	150–100	100–50	<50
Zn (ppm)	0.03	>2.0	1.0–2.0	0.5–1.0	<0.5
Fe (ppm)	0.03	>10.0	5.5–10	2.5–5.5	<2.5
Mn (ppm)	0.03	>10.0	4.0–10.0	2.0–4.0	<2.0
Cu (ppm)	0.03	>2.0	0.5–2.0	0.2–0.5	<0.2
Water stable aggregate (%)	0.1	75–100	75–25	25.0–10	<10
Mean weight diameter (mm)	0.15	>5.0	2.00–5.00	1.00–2.0	<1
Infiltration (mm/hr)	0.03	>150	150–100	100–70	70-60
Bulk density (g/cm3)	0.03	1.3–1.4	1.2–1.3 or 1.4–1.5	1.1–1.2 or 1.5–1.6	<1.1/>1.6
Organic carbon (%)	0.15	>1	1–0.75	0.75–0.5	<0.5

(Source: Compiled from Mandal et al., Karlen et al., Andrews et al., and Mukherjee et al. [18,20,24,26]).

2.5. Fodder Quality Assessment

For the fodder quality assessment, a region-specific methodology was applied. Long-term data (2012–2018) were used for assessing the various productivity criteria, their ranges, and support for sheep rearing from the productivity, leafiness, fodder quality, etc., at the Hayathnagar Research Farm, ICAR-Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad, India. There was a significant difference in the productivity of leguminous fodder (*Stylosanthes hamata (Stylo)*) and non-leguminous fodder, Congo grass (*Brachiaria ruziziensis*). The grasses are essential forage for livestock in the region, are well-palatable for sheep and goats, and have good nutritive value. For evaluation, the fodder was harvested at twelve-week intervals from an area of 1 m^2 in triplicate at each harvesting stage. The biomass yield was measured by weighing the fodder harvested. Depending on the fodder yield and nutrient content, for both leguminous and non-leguminous fodder, the number of sheep (Deccani breed) raised ranged from 20 to 45. Thus, this range of values was considered for the construction of allotting scores to different indicators towards an expression of fodder productivity, quality, and support to livestock. The scoring was arrived at by equally dividing the range obtained into parts to impart the score from 1 to 4 (Table 3). The grass quality index (GQI) was estimated using the weighted additive approach initially suggested by Karlen et al., 1994 [18] and Fernandes et al., 2011 [19].

Table 3. The framework of fodder quality indicators and their weights along with scores.

Fodder Quality Indicators	Fodder	Weights	Scoring			
			Class IV with Score 1	Class III with Score 2	Class II with Score 3	Class I with Score 4
Fodder productivity (t/ha)	*Stylo*	0.2	<8	8–11	12–15	>15
	Brachiaria		<20	20–24	25–29	>29
Leafiness (%)	*Stylo*	0.1	<50	50–54	55–59	>59
	Brachiaria		<50	50–54	55–59	>59
Crude protein (%)	*Stylo*	0.15	<20	20–24	25–29	>29
	Brachiaria		<6	6–7	7–8	>8
Crude fiber (%)	*Stylo*	0.15	>15	13–15	10–12	<10
	Brachiaria		>34	30–34	25–29	<25
No. of sheep supported by 1 ha area fodder	*Stylo*	0.1	<25	25–29	29–34	>34
	Brachiaria		<25	25–29	29–34	>34
Palatability	*Stylo*	0.2	<70	70–79	80–89	>89
	Brachiaria		<50	50–59	60–69	>69
Average daily gain (g/d)	*Stylo*	0.1	<25	25–32	33–40	>40
	Brachiaria		<20	20–24	25–29	>29

2.6. Economic Assessment

The financial gains that farmers receive from a given technology determine whether it is adopted or abandoned [26].

The economic analyses focused on the cost of cultivation under various treatments. The input costs include the cost of seed/grass slips, pesticides, fertilizer, hiring charges for human labor and machines, labor for land preparation and harvesting, etc. The seed costs varied based on the crop and grass varieties in the treatments while the other costs remained the same. The cost of each treatment was calculated independently, taking into account all of the inputs used and the practices followed for cultivation.

In addition, the gross returns from each treatment were calculated as given below:

$$\text{Gross returns} = \text{Total income (Rs/ha), i.e., (income from seed yield + income from grass)}$$

The net returns of the treatments were calculated to bring out the profitability across the treatments.

The net profit from each treatment was calculated separately by using the following formula:

$$\text{Net return} = \text{Gross return (ha}^{-1}) - \text{Cost of cultivation (ha}^{-1})$$

The benefit–cost ratio is an important criterion in selecting the most profitable treatments, which will bring maximum economic benefits to farmers.

The benefit–cost ratio was calculated using the following formula:

$$\text{Benefit-cost ratio (BCR)} = \text{Net returns (ha}^{-1})/\text{Total cost of cultivation (ha}^{-1})$$

The data were segregated into two categories based on years with normal rainfall distribution (NRF) and years with deficit rainfall distribution (DRF). The net returns of all of the treatments and the benefit–cost (BC) ratio of the treatments was then calculated for normal and deficit rainfall years.

2.7. Statistical Analysis

The experiments were laid out in a randomized complete block design with three treatments (lower, lower and upper, and the control), two different grasses (*Brachiaria ruziziensis* and *Stylosanthes hamata*), three slopes (1, 2, and 3 percent) and four years as replicates. ANOVA for RCBD was used to analyze the experimental findings for each treatment [27]. The variables in the study are soil's physical, chemical, and biological characteristics, etc. The comparison of different system was made on the basis of various indices calculated on the basis of a weighted additive approach as indicated in the material and method. The F-test was used to establish the statistical significance of the treatments, and LSD at 5% probability was used to compare the treatments. In the study, a pooled analysis of the results from the years 2016–2017 and 2018–2019 was used as the block of these two years had remarkably similar rainfall totals in the study area. The years 2016 and 2017 were normal rainfall years (NRF), receiving 950 mm of rainfall during the growing season for crops, whereas the years 2018 and 2019 were deficit rainfall years (DRF), receiving just 650 mm.

3. Results

3.1. Erosion Budget

For the four observation seasons, there was a 65 percent and 70 percent reduction in soil loss from the plots with 2 m grass strips (on the upper and lower end of the plot), (Figure 3). Soil losses were limited to 1500–1000 kg/ha for all of the treatments except for the control plot, where they reached 2000 and 2500 kg/ha.

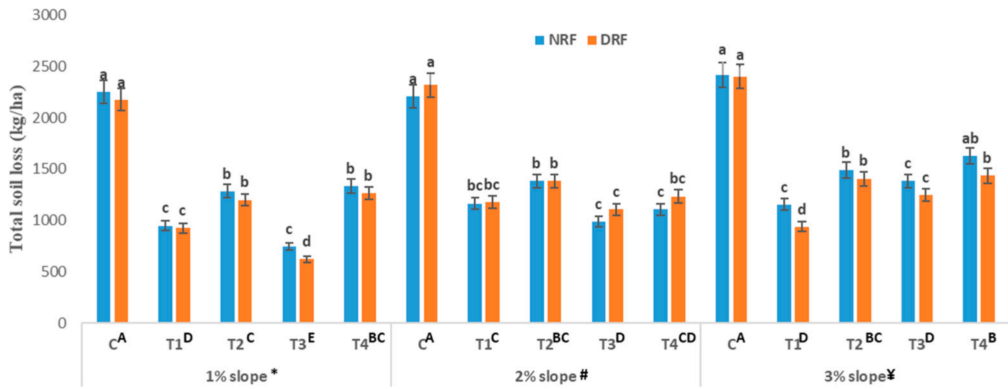

Figure 3. Effect of grass strips on total soil loss across variable slopes (1–3%) in normal and deficit rainfall years. ^{ABCDE} all differ significantly at the 1% level of significance between the treatments irrespective of slopes. ^{abcd} all differ significantly at the 5% level of significance between the treatments within a particular slope level in different rainfall situations. $^{*\#¥}$ all differ significantly at the 1% level of significance between the slopes. T_1, the top and bottom *Stylosanthes* strip; T_2, only the bottom strip of *Stylosanthes*; T_3, the top and bottom the *Brachiaria* strip; T_4, only the bottom strip of *Brachiaria*.

Available N Loss: The high rain intensity in the DRF years led to higher nitrogen losses from the experimental plots under 2 percent slope in comparison to the 1 and 3 percent slopes, but there was no significant difference in the normal and deficit rainfall years under the control treatments. In comparison to the control, all of the treatments with grass as a component reduced the nitrogen loss from runoff. The effect of the grass strips on the total soil loss across the variable slopes (1–3%) in the normal and deficit rainfall years are shown in Figure 4. Across the slope, all of the treatments differ significantly at the 1 percent level of significance (Figure 4).

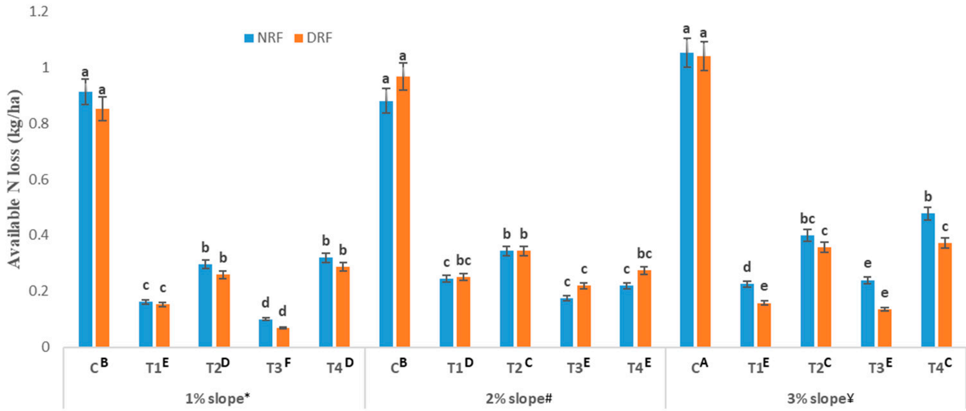

Figure 4. Available nitrogen (N) loss through runoff sediments across variable slopes (1–3%) in the normal and deficit rainfall years. ABCDEF all differ significantly at the 1% level of significance between the treatments irrespective of the slopes. abcde all differ significantly at the 5% level of significance between the treatments within a particular slope level in different rainfall situations. *#¥ all differ significantly at the 1% level of significance between the slopes. T1, the top and bottom *Stylosanthes* strip; T2, only the bottom strip of *Stylosanthes*; T3, the top and bottom *Brachiaria* strip; and T4, only the bottom strip of *Brachiaria*.

3.2. Soil Quality

Each year's soil quality was determined for the treatments using 16 physical, chemical, and biological indicators, such as soil aggregates, infiltration, organic carbon, and available nitrogen, phosphorous, and potassium, etc., during the experimental year it was noticed that the control plot's soil quality slightly declined. Among the treatments across the slope, the top and bottom *Brachiaria* strip (T3) happened to be the best performer, followed by the top and bottom *Stylosanthes* strip (T1) (Figure 5). The soil quality was found to be better in all of the treatments compared to the control. The field with the grass strips experienced a gradual increase in soil quality from 0.39 to 0.52.

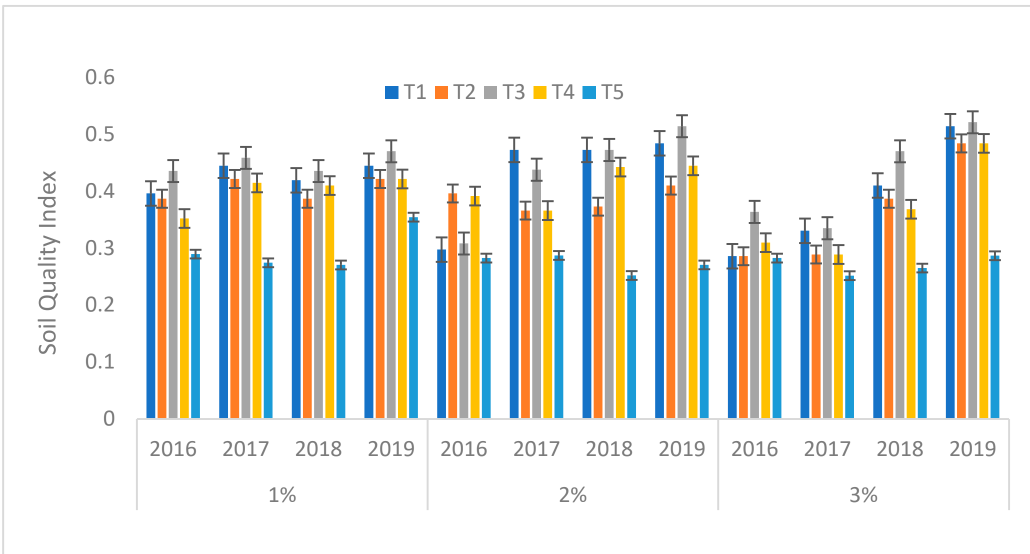

Figure 5. Soil quality index for treatments across variable slopes (1–3%). T1, the top and bottom *Stylosanthes* strip; T2, only the bottom strip of *Stylosanthes*; T3, the top and bottom *Brachiaria* strip; T4, only the bottom strip of *Brachiaria*; and T5, the control.

3.3. Fodder for Small Ruminants

Leguminous fodder, *Stylosanthes hamata*, produced a biomass yield of 7 to 18 t/ha and *Brachiaria ruziziensis*, a non-leguminous feed, produced a biomass yield of 18–33 t/ha for the same time duration. In both of the fodder crops, the leafiness fluctuated throughout the year from 40 percent to 80 percent. The number of sheep (Deccani breed) raised from the available biomass varied from 20 to 45, depending on the fodder yield for both of the grasses (*Stylosanthes hamata* and *Brachiaria ruziziensis*). It was found that the palatability (percent of offered feed) of *Stylosanthes* was on average 65 percent and of *Brachiaria*, it was 40 percent. Fifteen to thirty-five gm/d average daily gain was observed in the sheep reared on chopped *Brachiaria* while 20–45 gm/d average daily gain was seen in the case of the *Stylosanthes* fodder. Green fodder cutting was started at 90 days after establishment and was subsequently carried out every 60 days. The permanent grass fodder belt can therefore be harvested five times a year. The permanent grass fodder belt could potentially prevent soil erosion apart from providing forage to the ruminants. The grass quality index (Figure 6) for treatments in the 1 percent slope does not vary significantly at 1% significance, while in the 2 percent slope, T3 was significantly different from the other treatments, and in 3 percent slope, T3 and T2 were significantly different from the other treatments.

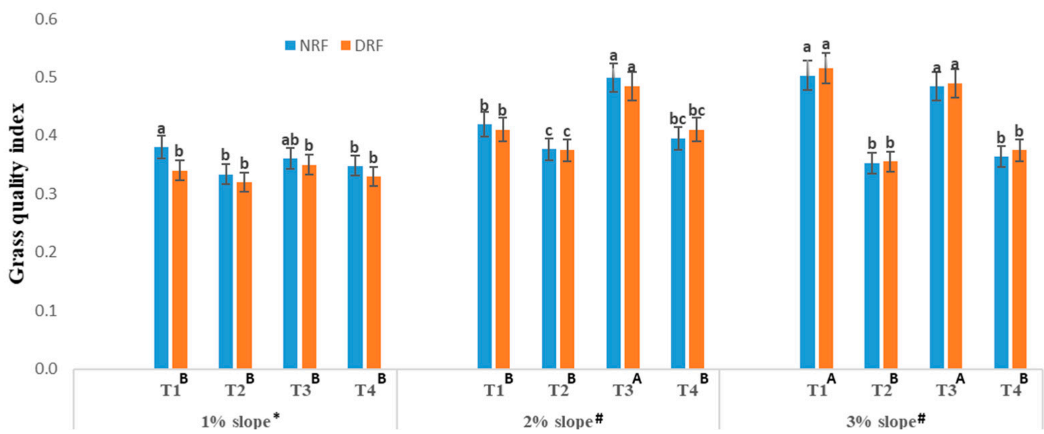

Figure 6. Grass quality index across variable slopes (1–3%) in two different rainfall situations. [A] and [B] both differ significantly at the 1% level of significance between the treatments irrespective of the slopes. [abc] all differ significantly at the 5% level of significance between the treatments within a particular slope level in different rainfall situations. [*#] both differ significantly at the 5% level of significance between the slopes. T1, the top and bottom *Stylosanthes* strip; T2, only the bottom strip of *Stylosanthes*; T3, the top and bottom *Brachiaria* strip; and T4, only the bottom strip of *Brachiaria*.

3.4. Economic Benefits

During the DRF years, the net returns from the treatments were reduced by 7.63 percent compared to a normal year (Figure 7). The benefit–cost ratio (BCR) derived during a normal year was thus 2.63 and for a DRF years, it was 2.32. Among the five experimental treatments, T1 (the top and bottom *Stylosanthes* strip) had the highest benefit–cost ratio. The T3 treatment (the top and bottom *Brachiaria* strip) had the highest net returns in the DRF and normal years. The net returns from the T5 (control) were the lowest, and in the DRF years, there was an average loss of ₹ 170/ha. There was benefit of about ₹ 30,000/ha, when fodder grass along with the castor–redgram crop was grown. The T1 and T3 treatments were found to be the most beneficial among the different treatments in the experiment.

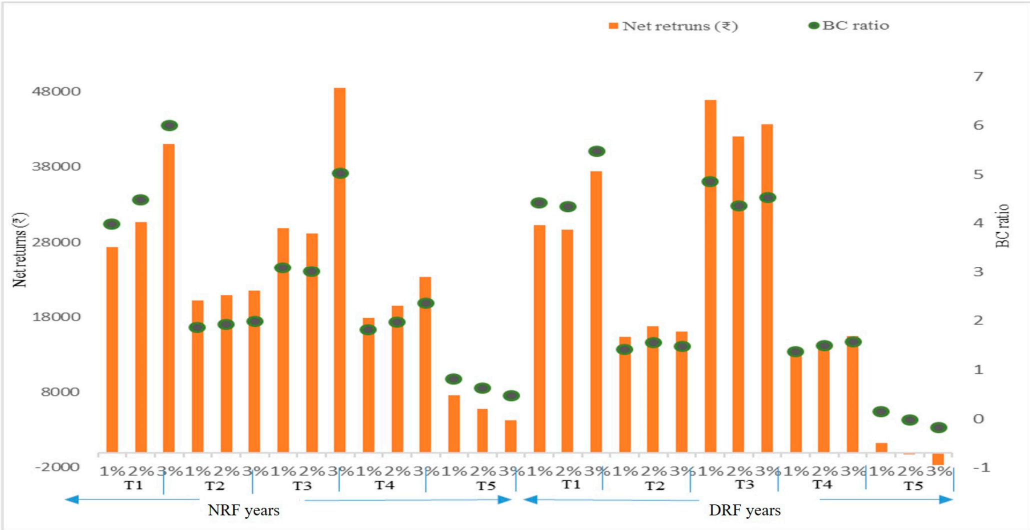

Figure 7. Effect of treatments on net returns across variable slopes (1–3%) in normal and deficit rainfall years.

In slopes of 1% and 3%, the Brachiaria strips on the upper and lower sides of the plot had greater a BC ratio: 2.50 in the DRF years and 3.38 in the NRF years and 2.59 in the DRF years and 3.42 in the NRF years, respectively, while Stylosanthes at the upper and lower side performed better at a 2% slope with a BC ratio of 2.66 (DRF years) and 3.50 (NRF years). Castor–redgram rotation in the cropping system with striped grass on the upper and lower side of the slope fetched better crop productivity with a 30 percent total increase in net returns.

4. Discussion

Due to the extremely high stocking density of livestock in semi-arid regions, upland farmers who raise small ruminants are particularly vulnerable to the effects of climate change. Their suffering is made worse by unpredictable rainfall patterns, frequent extreme weather events, and other resource-degrading events that push the carrying capacity of the land [28]. Rainfed farmers, the majority of whom are smallholders, use varied integrated production strategies to raise small ruminants primarily on grazing resources. As a risk-aversion technique and to assure household food and financial security, farmers prefer to develop systems that serve their interests in diversity [29]. It would be very beneficial for rainfed farmers to have technology that can integrate annual food crop systems with support for their animals, minimal soil disturbance, a variety of crop species, continuous ground cover, support for small ruminants, nutrient supply through nitrogen fixation and nutrient cycling, improve soil structure and water infiltration, enhance organic matter in the soil surface, and promote biodiversity.

4.1. Brachiaria Fodder Strip on Both Sides of the Cultivated Field Has a Positive Effect on Soil Quality

As the coupling of grasses into croplands increases SOC, labile C, and microbial biomass, *Brachiaria* grass strips (on the upper and lower-side of the sloppy field) demonstrated higher performance by benefiting the main crop [30,31]. With sufficient anchoring, the creeping forage grass *Brachiaria rhuzinensis* may withstand less rich soils and adapt well to them. It also has high soil-binding abilities [32]. It has a good ground cover which can suppress weeds apart from providing quality fodder for livestock [33]. There was almost no variation in soil organic carbon within the experiment duration, though changes in aggregate formation and microbial and earthworm activities suggest below-ground carbon cycling activities. These activities were found more in Brachiaria grasses compared to

Stylosanthes grasses [34]. Different slopes and grass strips' positions significantly influence soil quality [35].

Soil aggregate stability is one parameter on which the quantity and composition of organic matter have short and longer-term effects [36], as organic matters are integral for increasing aggregate cohesiveness and preventing water from entering aggregates through hydrophobicity [37]. Significant increases in aggregate stability have been found under permanent grass covers compared to cultivated arable soils [38,39]. Fodder grass strips on either side of a field slope have a number of natural resource management (NRM) advantages, such as preventing soil and nutrient loss, extending the time for infiltration inside the standing crop field, and producing biomass yields of 10–15 t ha^{-1} in addition to the concurrent crop/grain yield. As the volume of eroded sediments from runoff increased, Berg et al. (1988) [40] also noted an increase in N losses. It is a particularly efficient method for farms of small and marginal farmers in rainfed areas that are tackling the enormous challenge of reducing erosion from their land and enhancing soil health due to erratic high-intensity rainfall that frequently occurs in this area. *Brachiaria* grass is a "climate-smart" feed that generates a lot of palatable and nutrient-rich biomass for animals, performs well on infertile soils, sequesters carbon in the soil, and offers a number of environmental advantages [41]. We anticipate that incorporating *Brachiaria* grass into a system of mixed crops–livestock will increase the availability of feed and the productivity of animals, resulting in greater food and nutrition security [42].

4.2. Grass Strip and Soil Conservation

The investigation into the variation in sediment concentrations during a rainstorm event demonstrates how the intensity of the precipitation and flow affects the instantaneous sediment concentration. The downstream of the grass strip experiences a significant reduction in sediment export because of runoff infiltration and sediment trapping. The soil environment improves with improved soil infiltration [43]. Fodder grass strips maintained for years have the ability to reduce the negative impact of sheet erosion while also providing feed for ruminants [44].

In fields with a slope, using grass strips on either side has a long-term impact on productivity and sustainable agriculture. The typical practice of planting grass strips down slopes may limit soil loss at the end of the field, but fodder grass strip cropping on both sides of the field reduces the intensity of rainfall at the upper part, thus the flow of water as runoff within the cropped field can be reduced (Figure 8), thus improving the overall nutrient status (soil quality), conserving soil moisture of the field, and also meeting farmers' needs for fodder. Consequently, the idea of planting grasses on both sides of the field (in a strip of two meters) enhances soil health and greatly lowers runoff from cultivated fields [45]. The loss of available nitrogen through soil erosion will reduce the net primary productivity and further affect the long-term susceptibility even through effective input management [46]. The results of this study indicate that the treatment with the top and bottom *Brachiaria* strips played a critical role in preventing N loss in the sloping lands as compared to the other treatments.

4.3. The Grass Strip and Its Role in Supporting Livestock Production Systems

In terms of green fodder, dry fodder, and concentrates, India is experiencing deficits of 35.6, 11.0, and 44.0 percent, respectively [47]. In India, fodder crop production accounts for just 5 percent of the total gross cropped area. Grass strips may be a boon for the rainfed production system in the semi-arid tropics towards improving fodder availability using underexploited culturable as well as fallow lands in India. In the present investigation, the installation of grass strips, irrespective of species, has improved the soil quality (physical, chemical, and biological properties) in the experimental field. Both types of grass strips were able to reduce the available nitrogen loss; however, *Brachiaria* outperformed *Stylosanthes* strips in terms of retaining better soil quality and better economic benefits (BCR) during the normal rainfall year as well as the drought year. In terms of total aboveground biomass, palatability, and plant height, *Stylosanthes* was a better performer. In contrast to *Brachiaria*, *Stylosanthes* are the erect type of grass appropriate for a cut-and-carry method [48]. These potential forage grasses might be included in cropping systems, producing high biomass as well as regenerating soil fertility and protecting the land cut-off at slope ends.

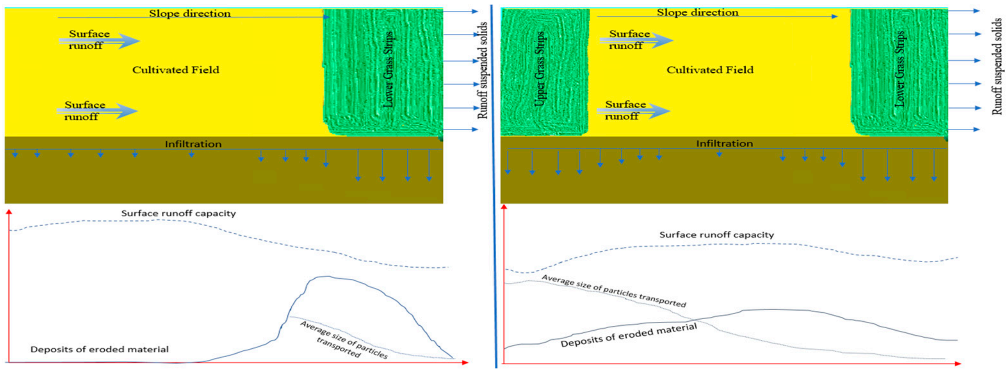

Figure 8. Schema of the field with 2 m grass strips on cultivable cropped land. Source: [45].

5. Conclusions

Brachiaria strips at the upper and lower side of the field offered the highest soil protection with respect to splash- and rain-impacted soil detachment compared to *Stylosanthes*. These variations are probably related to the morphological traits of the plant species with regard to soil cover. Because nutrient losses were inversely correlated with soil loss, *Brachiaria* grass strips should also improve the preservation of soil quality. Grass coverings encouraged infiltration and decreased soil detachment from rainfall. Using thick fodders could help rainfed agricultural systems to integrate crops and cattle more effectively.

Eco-friendly management techniques are required to reduce negative effects on the environment and provide acceptable yields. Fodder grass strips planted on both sides of sloped fields are affordable, long-lasting, and likely to gain public approval due to their many advantages, including the lack of mechanical obstacles to crop planning and management and the provision of fodder for small ruminants. The study offers proof that *Brachiaria* is an important source of feed and through the integration of grain and cattle fodder production, it may enable the sustainable intensification of smallholder agriculture.

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