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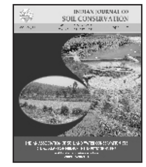

Effect of runoff and soil loss on soil hydraulic parameters and forage yield of four grass species under arid vertisols

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ABSTRACT

Field experiments with grass species *Cenchrus ciliaris, Dichanthium annulatum, Cymbopogon martini* and *Vetiveria zizanioides* and control (no grass) were conducted during 1995 to 2004 in an arid vertisol at Bellary, Karnataka, India to identify a suitable grass that would reduce runoff and soil loss, and improve soil hydraulic parameters and Forage Yield (FY). Observations were recorded on runoff, soil loss and FY every year; while infiltration rate, hydraulic conductivity, Bulk Density (BD) and organic carbon were recorded at the start (1995) and end year (2004). *D. annulatum* gave significantly lower runoff and soil loss, while *C. martini* gave significantly higher FY. *C. ciliaris, C. martini* and *D. annulatum* gave significantly higher infiltration, hydraulic conductivity and organic carbon compared to *V. zizanioides* and control. The infiltration rate was positively correlated with both organic carbon and FY. The BD in grass plots was significantly lower compared to control in 0-15 cm, while it did not differ in 15-30 cm soil depth. *C. martini* attained significantly higher mean FY of 9996 kg ha^{-1} compared to *D. annulatum* (6152 kg ha^{-1}), *C. ciliaris* (5649 kg ha^{-1}) and *V. zizanioides* (3525 kg ha^{-1}). An increase in runoff increased the FY, while an increase in soil loss decreased the FY in all the 4 grasses. *C. martini* was found to have maximum Sustainability Yield Index (SYI) of 0.338, followed by *D. annulatum* with SYI of 0.160 and *C. ciliaris* with SYI of 0.149, while *V. zizanioides* was unsustainable over years. The long-term study indicated that *C. martini* and *D. annulatum* were superior to minimize runoff and soil loss and improve hydraulic parameters and attain higher FY in an arid vertisol.

1. INTRODUCTION

The sustainability of agriculture in arid and semi-arid regions depends critically on maintaining favorable soil hydrologic properties. The soils having low infiltration capacity pose challenges for management of runoff and erosion. The low vegetation cover and high rainfall intensities that occur in arid regions result in sparse infiltration, excess overland flow and sheet erosion. The vertisol region has low productivity, due to high runoff and soil loss caused by intense rainfall. High rainfall intensity, poor soil permeability and non-adoption of soil conservation measures aggravate runoff and erosion problems (Adhikari *et al.*, 1993). Many studies reported a high infiltration rate due to low BD of surface soil, high organic carbon and presence of stable macro-aggregates (Wilkinson, 1975; Wilkinson and Aina, 1976 and Lal, 1979); and earthworm activity which result in development of large water conducting channels (Mbagwu, 1987 and 1990). Obi and Asiegbu (1980) reported that eroded soils could be protected by improving infiltration with adequate vegetative cover.

Grasses would increase the soil organic matter, which help in developing an ideal soil structure for agriculture, higher infiltration capacity and water holding capacity, rapid establishment of cover to protect soil against erosion, and fodder contribution during dry periods (Kaul and Rao, 1961; Behera and Panigrahi, 1996; Panigrahi *et al.*, 1996 and Panigrahi, 2007). A proper vegetative cover would also reduce runoff velocity and enhance opportunity time for infiltration. A surface cover of live plants or crop residue increases infiltration rates by reducing compaction from the impact of rainfall, crusting and decreasing soil water evaporation (Radke and Berry, 1993). Considering planting of *C. ciliaris* and *S. hamata* alongwith a tree specie accelerated the rate of soil regeneration and reduced runoff from 70 to 22% of annual precipitation and soil loss from 41 to 1.9 t ha^{-1} yr^{-1} (Hazara, 2000). Silvi-pastoral system would conserve rainwater and bring favorable impact on flood moderation and ecological rehabilitation of degraded lands (Yadav *et al.*, 2005). Nagender Rao *et al.* (2009) observed highest infiltration rates under agri-silvi-horticultural system compared to cumulative infiltration under silvi-pasture system. In a study by Ramulu *et al.* (2017), the authors assessed about the effects of tree and crop based systems on soil infiltration, water holding capacity, BD and soil fertility of nutrients in a semi-arid alfisol.

C. ciliaris is a highly palatable and nutritious perennial grass for sheep and goats. It grows well in heavy, limestone and sandy soils, tolerates low pH and drought. It is a good soil binder and used as a cover crop on bunds for soil and water conservation purposes (Rai *et al.*, 1982). *D. annulatum* is an important perennial grass and covers large area of pasture and rangelands in India (Kumar *et al.*, 2008). Besides providing vegetative cover, it improves the health, milk and meat production of livestock (Agarwal *et al.*, 1999). *C. martini* is a tall perennial sweet-scented grass and is cultivated for palma rosa oil and also for production of chemical grade paper pulp (Dutt Dharm *et al.*, 2007). *V. zizanioides* is a densely tufted grass found throughout plains and lower hills in India. It is a source of oil used in medicine and perfumery (Sharma *et al.*, 1991). The pulp is suitable for manufacturing paper and straw board (Thakur *et al.*, 1989). It is tolerant to soil acidity, alkalinity, salinity, sodicity, agro-chemicals and elevated levels of heavy metals (Truong *et al.*, 1996; Truong, 1999 and Islam *et al.*, 2008). The present study was undertaken to identify a suitable grass for controlling runoff and soil loss and assess its effect on infiltration, hydraulic conductivity, BD and biomass production apart from organic carbon build-up in an arid vertisol.

2. MATERIALS AND METHODS

Experimental Details

The long term study was conducted for 10 years during 1995 to 2004 at ICAR-Indian Institute of Soil and Water Conservation, Bellary located under southern plateau and hill region in Karnataka. The area is located at Latitudes of 15'09''N, Longitudes of 76'51''E and Altitude of 445 m above mean sea level (msl). The region experiences arid climate with mean annual rainfall of 519 mm and potential evaporation of 1738 mm (Mandal *et al.*, 1999). The experimental site has a deep black soil and belongs to soil order vertisols. The clay content ranged from 45% on surface (0-15 cm) to 51% at 60-75 cm. The soil pH ranged from 8.0 to 8.4, while available N, P_2O_5 and K_2O were 281, 74 and 579 kg ha^{-1}, respectively. The soils were poor in aggregation and structure was sub-angular to angular blocky. They are highly dispersible and sheet erosion is a common phenomenon. The clay minerals are of montmorillonite and beidellite groups with cation exchange capacity of 1.0 meq g^{-1} of clay.

Five unique plots of 50 m^2 (10 x 5 m) each and running in north-south direction with 1% slope were used to measure runoff and soil loss. The runoff (mm) and soil loss (kg ha^{-1}) were measured by installing multi-slot devisor at the downstream end of each plot. Rainfall was measured with a tipping-bucket rain gauge. Grass suckers were planted during 3rd week of August 1995 in 4 plots at 0.5 x 0.5 m spacing in staggered manner, while 5th plot was maintained as control (without grass) for measuring runoff and soil loss every year. Four grass species *viz.*, *C. ciliaris*, *C. martini*, *D. annulatum* and *V. zizanioides* were grown on 4 planted plots to assess yield potential and effect on soil properties. The grasses were cut every year and weighed for FY.

Statistical Analysis

The effect of runoff on soil loss could be assessed based on a regression model as:

$$SL = \pm \alpha \pm \beta (RO) \qquad ... (1)$$

In model (1), α is intercept and β is slope of soil loss for an unit change in runoff.

The predictability of FY of a grass specie could be assessed based on a regression model of FY through runoff and soil loss as:

$$FY = \pm \alpha \pm \beta 1 (RO) \pm \beta 2 (SL) \quad ...(2)$$

In model (2), α is the intercept; β1 and β2 indicate the rate of change in FY for an unit change in the runoff and soil loss, respectively.

The increase or decrease in the FY of a grass specie could be assessed based on a regression model as:

$$FY = \pm \alpha \pm \beta 1 (Year) \quad ...(3)$$

In model (3), α is intercept and β is the rate of change of FY per year during the study period. The superiority of grasses could be assessed based on the regression coefficients, coefficient of determination (R^2) and Prediction Error (PE) based on a model (Draper and Smith, 1998).

Using the Mean Forage Yield (MFY) of a grass specie and its PE based on model (2), and maximum yield (Y_{max}) attained by any grass specie during the study period, the SYI of the grass specie could be derived (Maruthi Sankar *et al.*, 2011 and Ramachandrappa *et al.*, 2016) as:

$$SYI = [MFY - PE] / [Y_{max}] \quad ...(3)$$

Based on the SYI values, superior grass specie could be identified for attaining maximum sustainable yield over years.

Cumulative Infiltration at Different Time Intervals

To compare infiltration rates among different grass species and control, three sites (top, middle and bottom) were identified as replications in each treatment by dividing the plot equally across their length. Infiltration tests were conducted at the start (1995) and end (2004) of experiment using double ring infiltrometers (inner ring of 30 cm and outer ring of 60 cm diameter). The rings were inserted into soil to a depth of 10 cm. Constant head infiltration measurement was recorded in each treatment under each replication based on standard procedure as discussed by Bouwere (1986). Cumulative infiltration values were recorded by observing changes in infiltration over time for a period of 12 hours.

Saturated Hydraulic Conductivity, Bulk Density and Organic Carbon

Three surface (0-15 cm) and sub-surface (15-30 cm) soil samples were collected from each plot planted with a grass specie under each of the 3 replications at start (1995) and end (2004) of the experiment to determine BD and soil water content preceding the infiltration measurements (Blake and Hartge, 1986). The samples were analyzed for organic carbon (%) based on Walkley and Black (1934) method. Saturated hydraulic conductivity was estimated using Darcy's equation by maintaining constant water head of 1.5 ± 0.2 cm in the soil sample. The differences in grass species for infiltration, hydraulic conductivity, BD and organic carbon were compared based on Least Significant Difference (LSD) criteria (Gomez and Gomez, 1984).

3. RESULTS AND DISCUSSION

Performance of Grasses for Reducing Runoff and Soil Loss

The location received mean rainfall of 482 mm with coefficient of variation of 36.5% during 1995 to 2004, ranging from 221 mm (in 1997) to 825 mm (in 1996). There was a significant decrease in the annual rainfall received during the study period with coefficient of determination (R^2) of 0.119 as indicated in Fig. 1. The above mean annual rainfall of 482 mm was received during 1996 (825 mm), 1998 (622 mm), 1999 (522 mm), 2000 (546 mm) and 2001 (567 mm). Maximum mean monthly rainfall for different months during this period were 148.8 mm in October, followed by 89.8 mm in September, 59.4 mm in June, 56.7 mm in August, 49.0 mm in July, 39.1 mm in May and 23.2 mm in April.

The runoff and erosion measured in each plot varied widely over years. The mean runoff and erosion was significantly higher from control plot compared to grass plots (Table 1). The runoff ranged

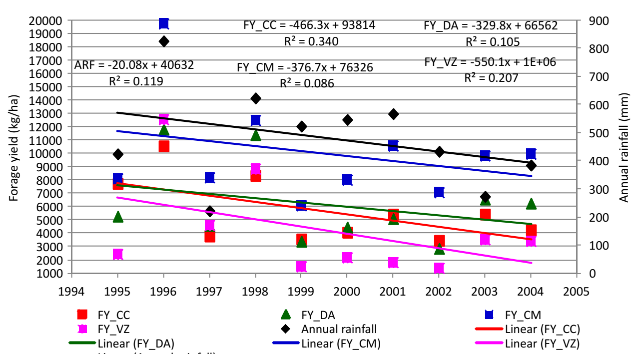

Fig. 1. Annual rainfall (ARF) received and forage yield (FY) attained during 1995 to 2001

Table: 1
Performance of grasses for forage yield, runoff and soil loss at Bellary

Grasses	Runoff (mm)		Soil loss (kg ha^{-1})		Forage yield (kg ha^{-1})	
	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)
C. Ciliaris	52.8	82.3	666	111.2	5649	42.8
D. annulatum	46.5	69.8	523	120.4	6152	50.0
C. martini	49.4	90.6	670	135.8	9996	38.9
V. zizanioides	69.0	68.4	1170	120.3	3525	115.9
Control	127.9	87.0	3252	99.0		
Sem (±)	12.5		404		461	
LSD (p < 0.05)	35.9		1159		1339	
LSD (p < 0.01)	48.1		1554		1808	

SEM: Standard error of mean; LSD: Least significant difference; CV: Coefficient of variation

from 3.1 mm (1995) to 131.9 mm (1998) under *C. ciliaris*; 0.7 mm (1995) to 96.2 mm (1998) under *D. annulatum*; 4.2 mm (1997) to 142.7 mm (1999) under *C. martini*; 4.0 mm (1997) to 146.4 mm (1998) under *V. zizanioides*; and 19.4 mm (1995) to 328.5 mm (1996) under control with mean of 52.8, 46.5, 49.4, 69.0 and 127.9 mm, respectively. Based on LSD criteria, the 4 grasses were statistically at par *($p = 0.05$)* with each other and gave a significantly lower runoff compared to control. *D. annulatum* was superior with significantly lower mean runoff of 46.5 mm compared to control of 127.9 mm. However, *C. ciliaris*, *C. martini* and *V. zizanioides* were at par *($p = 0.05$)* with *D. annulatum* in reducing runoff over years.

The soil loss ranged from 42 kg ha^{-1} (1995) to 2143 kg ha^{-1} (2001) under *C. ciliaris*; 8 kg ha^{-1} (1995) to 1980 kg ha^{-1} (2001) under *D. annulatum*; 70 kg ha^{-1} (1997) to 2993 kg ha^{-1} (1999) under *C. martini*; 84 kg ha^{-1} (1997) to 4314 kg ha^{-1} (1999) under *V. zizanioides*; and 444 kg ha^{-1} (2003) to 9980 kg ha^{-1} (1998) under control with mean of 666, 523, 670, 1170 and 3252 kg ha^{-1}, respectively. The 4 grasses were at par *($p = 0.05$)* with each other and gave significantly lower soil loss compared to control. The lowest runoff and soil loss occurred under *D. annulatum* compared to other grasses and control over years. *D. annulatum* gave significantly lower mean soil loss of 523 kg ha^{-1} compared to control of 3252 kg ha^{-1}. However, *C. ciliaris*, *C. martini* and *V. zizanioides* were at par *($p = 0.05$)* with *D. annulatum* in reducing soil loss over years.

The FY ranged from 3450 kg ha^{-1} (2002) to 10540 kg ha^{-1} (1996) under *C. ciliaris*; 2840 kg ha^{-1} (2002) to 11790 kg ha^{-1} (1996) under *D. annulatum*; 6080 kg ha^{-1} (1999) to 19730 kg ha^{-1} (1996) under *C. martini*; and 1380 kg ha^{-1} (2002) to 12540 kg ha^{-1} (1996) under *V. zizanioides* with mean of 5649, 6152, 9996 and 3525 kg ha^{-1}, respectively. *C. martini*, *D. annulatum* and *C. ciliaris* attained a significantly higher yield compared to *V. zizanioides*. *C. martini* was superior with significantly higher yield compared to *D. annulatum* and *C. ciliaris*. Maximum mean yield of 9996 kg ha^{-1} was attained by *C. martini*, followed by 6152 kg ha^{-1} by *D. annulatum*; 5649 kg ha^{-1} by *C. ciliaris* and 3525 kg ha^{-1} by *V. zizanioides*. *D. annulatum* gave minimum runoff and soil loss, while *C. martini* attained maximum FY over years. There was a significant decrease in the FY of grasses during the study period with maximum R^2 of 0.340 for *C. ciliaris*, followed by 0.207 for *V. zizanioides*, 0.105 for *D. annulatum* and 0.086 for *C. martini* to as indicated in Fig. 1. However, the rate of decrease was maximum of -550.1 kg ha^{-1} $year^{-1}$ for *V. zizanioides*, followed by -466.3 kg ha^{-1} $year^{-1}$ for *C. ciliaris*, -376.7 kg ha^{-1} $year^{-1}$ for *C. martini* and -329.8 kg ha^{-1} $year^{-1}$ for *D. annulatum*.

Effect of Runoff on Soil Loss under Different Grasses

The effect of runoff on soil loss was assessed under each grass based on model (1) and the changes in soil loss for an unit change in runoff are depicted in Fig. 2. The regression coefficients measuring effect of runoff on soil loss along with R^2 values are given in Fig. 2. Runoff was significantly correlated with soil loss under all grass species, while it was not correlated under control. The effect of runoff on soil loss was lowest with rate of change of 11.73 kg ha^{-1} mm^{-1} under *D. annulatum* compared to maximum of 24.89 kg ha^{-1} mm^{-1} under *V. zizanioides*. Significantly higher R^2 for predicting soil loss through runoff was observed under *C. martini* (0.85), followed by *V. zizanioides*

(0.70), *C. ciliaris* (0.65) and *D. annulatum* (0.37); while it was non-significant under control (0.29).

Effect of Runoff and Soil Loss on Forage Yield (FY)

The effects of runoff and soil loss on FY were assessed based on model (2). The regression coefficients of runoff and soil loss on FY of each grass are given in Table 3. The runoff had a positive correlation with FY, while soil loss had negative correlation with yield of all grasses. An increase in runoff improved the FY in all the 4 grasses. The rate of change in FY for an unit change in runoff ranged from 5.462 kg ha^{-1} in *C. ciliaris* to 138.10 kg ha^{-1} in *C. martini*. An increase in soil loss decreased the FY in all grasses. The rate of change in FY for an unit change in soil loss ranged from -0.158 kg ha^{-1} in *C. ciliaris to* 7.149 kg ha^{-1} in *C. martini*. Based on the analysis, *C. martini* had maximum SYI of 0.338, followed by *D. annulatum* with SYI of 0.160 and *C. ciliaris* with SYI of 0.149, while *V. zizanioides* was unsustainable during the study period. Chunale (2004) observed that *D. annulatum* and *C. ciliaris* were at par (p = 0.05) and attained significantly higher yield compared to other grasses. Bruce *et al.* (1992) reported that increased biomass had increased the aggregate stability and water infiltration in a loamy sand soil.

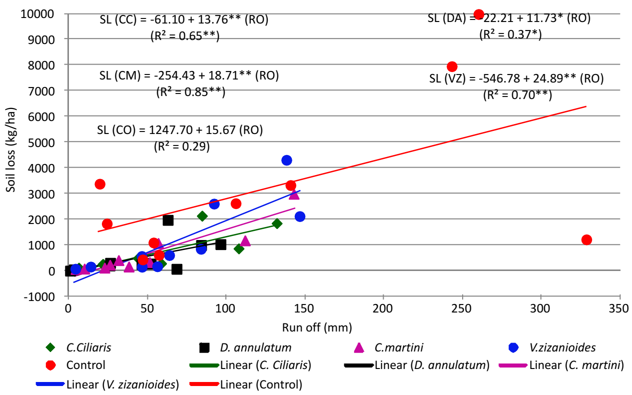

Fig. 2. Relationship between runoff and soil loss in different grasses from 1995 to 2004

Cumulative Infiltration

The 60-minute cumulative infiltration was measured to assess effect of grasses on the depth of infiltration. Based on LSD criteria, the mean cumulative infiltration was significantly higher throughout 60 minutes under *C. ciliaris* (14.1 cm) compared to *V. zizanioides* (5.4 cm) and control (4.4 cm) as given in Table 2. The cumulative infiltration did not differ under *C. ciliaris, C. martini* and *D. annulatum* at the end of 60 minutes. *C. martini* and *D. annulatum* gave significantly higher cumulative infiltration over control and *V. zizanioides*. *C. ciliaris, C. martini and D. annulatum* had a positive effect on soil properties by significantly increasing the infiltration capacity

Table: 2
Effect of grasses on infiltration, hydraulic conductivity, organic carbon and bulk density

Grass	Cumulative infiltration (cm)	Infiltration rate (cm hr^{-1})	Hydraulic conductivity (cm hr^{-1})		Organic carbon (%)		Bulk density (kg m^{-3})	
	60-min	60-min	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Control (1995)	4.4	2.1	0.69	1.07	0.28	0.29	1960	1810
C. ciliaris	14.1	9.3	1.08	1.19	0.39	0.50	1800	1780
C. martini	12.3	8.8	1.03	1.12	0.38	0.47	1780	1760
D. annulatum	10.2	5.7	1.12	1.21	0.33	0.51	1810	1790
V. zizanioides	5.4	2.6	0.71	0.87	0.28	0.30	1750	1750
Sem (±)	1.6	1.6	0.05	0.17	0.01	0.02	30	40
LSD (p< 0.05)	4.9	5.2	0.16	NS	0.02	0.08	90	NS
CV (%)	29.1	49.5	9.8	26.5	3.0	10.1	2.7	4.2

SEM: Standard error of mean; LSD: Least significant difference; CV: Coefficient of variation

Table: 3
Prediction of fodder yield of grass species through runoff and soil loss in a vertisol

Grass	Regression model	R^2	Prediction error (kg ha^{-1})	SYI
C. ciliaris	FY = 5255** + 5.462 RO + 0.158 SL	0.020	2718	0.149
D. annulatum	FY = 4196* + 60.64 RO - 1.65 SL	0.260	3000	0.160
C. martini	FY = 7964** + 138.101* RO - 7.149* SO	0.431	3325	0.338
V. zizanioides	FY = 1965 + 96.415 RO - 3.268 SL	0.472	3544	-0.001

based on the study. This was due to increased organic matter by roots and biomass fresh yields. Significantly lower infiltration observed under *V. zizanioides* and control was due to surface sealing, high BD, poor soil structure, low organic matter and biomass.

The infiltration rate at 60 minutes was high in *C. ciliaris*, followed by *C. martini*, *D. annulatum* and *V. zizanioides*. There were significant differences in infiltration rates under grasses measured at 60-minutes as given in Table 2. *C. ciliaris* (9.3 cm h^{-1}) and *C. martini* (8.8 cm h^{-1}) gave significantly higher infiltration compared to *V. zizanioides* (2.6 cm h^{-1}) and control (2.1 cm h^{-1}). No vegetation in control and low vegetation in *V. zizanioides* lead to higher soil loss and no build-up of organic carbon both in 0-15 and 15-30 cm soil depth. Higher vegetative growth of *C. ciliaris, C. martini, D. annulatum* lead to lower soil loss and higher build-up of organic carbon under 15-30 cm depth which facilitated more infiltration (5.7 to 9.3 cm) than control (2.1 cm). The improvement in infiltration provided by *C. ciliaris*, *C. martini* and *D. annulatum* was due to greater absorption of water through the profile by well developed roots and improved soil structure formed through decay roots, biomass and soil fauna activity. Our results are consistent with previous studies on influence of perennial vegetation and management systems on infiltration (Broersma *et al.*, 1995). Infiltration rates were greater under undisturbed forest sites and pastures than cultivated lands in Hawaii (Wood, 1977). Alfalfa roots increased infiltration rate by reforming macropores destroyed by tillage (Meek *et al.*, 1992). Edwards *et al.* (1988) studied aspects of infiltration under non-tilled soils and characterized macropores that affected soil infiltration.

Hydraulic Conductivity

Saturated hydraulic conductivity (Ks) was measured for 0-15 and 15-30 cm soil depths. The mean Ks of soils from plots with grass growth ranged from 0.69 cm h^{-1} for control to 1.12 cm h^{-1} for *D. annulatum* under surface soil (0-15 cm); and 0.87 cm h^{-1} for *V. zizanioides* to 1.21 cm h^{-1} for *D. annulatum* under sub-soil (15-30 cm). The grasses differed significantly in influencing hydraulic conductivity in surface soil, while they did not differ in sub-surface soil. *C. ciliaris, C. martini* and *D. annulatum* were at par *(p = 0.05)* and recorded significantly higher hydraulic conductivity compared to *V. zizanioides* and control; while *V. zizanioides* and control were at par (p = 0.05) in surface soil. The significant difference in hydraulic conductivity in surface soil was due to the fact that both root and shoot biomass improved the soil structure. In a similar study by Nambiar *et al.* (1968), the authors found that soil structure was considerably improved under *C. ciliaris* and *D. annulatum* compared to grazed area. Lindstrom *et al.* (1998) confirmed that the soil structure would improve when cultivated land is put under grass. The soil aggregate distribution, stability, air permeability and hydraulic conductivity would improve with a grass over a period of time.

Organic Carbon

There was a significant difference in the organic carbon under different grasses and control in surface soil (0-15 cm) and sub-soil (15-30 cm) depths (Table 2). In surface soil, *C. ciliaris* gave organic carbon of 0.39% and was at par *(p = 0.05)* with *C. martini* (0.38%). The soil organic carbon was significantly higher under these two grasses compared to *D. annulatum* (0.33%), *V. zizanioides* (0.28%) and control (0.28%). Similarly, *D. annulatum* gave significantly higher carbon compared to *V. zizanioides* and control, while *V. zizanioides* and control were at par *(p = 0.05)* with each other in surface soil. In sub-soil, *D. annulatum* (0.51%), *C. ciliaris* (0.50%) and *C. martini* (0.47%) were at par *(p = 0.05)* with each other and gave significantly higher organic carbon compared to *V. zizanioides* (0.30%) and control (0.29%). *V. zizanioides* and control were at par (p = 0.05) with each other for organic carbon in surface soil. In a study by Gebhar *et al.* (1994), the soil carbon significantly increased with perennial grass covers established by USDA at different locations. In a grass land, organic matter would help in developing an ideal soil structure, water holding capacity, ability to provide quick cover to soil against erosion and fodder contribution (Kaul and Rao, 1961).

Bulk Density (BD)

There was a significant difference in BD measured under different grasses and control in surface soil depth over years. The BD under *V. zizanioides* was significantly lower (1750 kg m^{-3}) compared to control (1960 kg m^{-3}). *C. ciliaris* (1800 kg m^{-3}), *C. martini* (1780 kg m^{-3}) *and D. annulatum* (1810 kg m^{-3}) were at par *(p = 0.05)* with *V. zizanioides*. In surface soil with grass growth, the BD under *V. zizanioides*, *C. ciliaris*, *C.*

martini and D. annulatum was significantly lower compared to control. In sub-soil, there was no significant difference in the BD of the soil observed under different grasses and control. As BD increased, the infiltration decreased under control. The BD of cultivated fields and grazed pastures was generally higher than those of grassland or forest soils (Bharati *et al.*, 2002; Jaiyeoba, 1995; Taboada and Lavado, 1993 and Meek *et al.*, 1992). The study indicated that establishing perennial grass would significantly decrease the BD over years.

Controls on Infiltration Capacity, Organic Matter and Bulk Density

The organic carbon in top 15 cm soil explained nearly all the variation in infiltration rate at 60-minutes. Relatively low infiltration rate in *V. zizanioides* plot after 60 minutes was explained by low soil organic matter. While difference in organic matter seems relatively small, it was a strong predictor of infiltration rate. Assuming that differences in organic matter among plots was due to grasses rather than pre-existing differences, this suggested that increase in organic carbon was the main mechanism underlying increase in infiltration, rather than decrease in BD. *V. zizanioides* also had lowest biomass production, suggesting that low biomass production influenced the organic carbon, which in turn impacted the infiltration rates. Thus grasses with high biomass production rates would result in high accumulation of organic carbon and increase in the infiltration capacity.

4. CONCLUSIONS

A study was conducted with *C. ciliaris, D. annulatum, C. martini, V. zizanioides* and Control to determine relationships among runoff, erosion, grass yield and soil hydrology during 1995 to 2004. *C. ciliaris*, *C. martini* and *D. annualatum* gave significantly higher cumulative infiltration and infiltration rate compared to *V. zizanioides* and control. They gave significantly higher hydraulic conductivity and organic carbon compared to *V. zizanioides* and control. The 4 grasses had a lower BD of 1750 to 1810 kg m^{-3} compared to control under surface soil depth. *C. martini* was superior with maximum mean FY of 9996 kg ha^{-1}, followed by *D. annulatum* (6152 kg ha^{-1}), *C. ciliaris* (5649 kg ha^{-1}) and *V. zizanioides* (3525 kg ha^{-1}). The improvement in infiltration and hydraulic conductivity provided by *C. ciliaris*, *C. martini* and *D. annulatum* was due to greater absorption of water through the profile by well developed roots and improved soil structure formed through decay roots, biomass and soil fauna activity. *C. martini* was found to have maximum SYI of 0.338, followed by *D. annulatum* with SYI of 0.160 and *C. ciliaris* with SYI of 0.149, while *V. zizanioides* was unsustainable based on the study.

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