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Effect of fibrous root system to control soil erosion under concentrated overland flow conditions

Sushma Tamta, Akhilesh Kumar and Jitendra Chandra Chandola

Sushma Tamta
Subject Matter Specialist, Department of Agricultural Engineering, KVK, DRPCAU Pusa, Bihar, India

Akhilesh Kumar
Former Professor, Department of Soil and Water Conservation Engineering, G. B. Pant University of Agriculture and Technology Pantnagar, Uttarakhand, India

Jitendra Chandra Chandola
Subject Matter Specialist, Department of Horticulture, KVK Saran, DRPCAU Pusa, Bihar, India

Corresponding Author:
Sushma Tamta
Subject Matter Specialist, Department of Agricultural Engineering, KVK, DRPCAU Pusa, Bihar, India

Abstract
Soil erosion is a critical environmental problem of world wide. In this regards, vegetation plays a significant role to reduce soil erosion. Plants having fibrous root systems are more efficient to reduce soil erosion as compared to tap root system. An experiment was conducted at GBPUA&T Pantnagar to identify the effect of lemon grass roots and shoots to reduce soil erosion under concentrated flow conditions. An experiments were performed in a hydraulic tilting flume and controlled water circulation system. An experiments were carried out using three treatments 1. Control 2. Whole plant plot and 3. Roots plot at 1% slope with 6.6 l/s/m, 9.0 l/s/m, 10.7 l/s/m and 12.4 l/s/m runoff rate. Results summarized that Lemon grass plot significantly reduced soil erosion as compared to the control plot. Further, it was also observed that the sediment outflow generation significantly decreased with the growth stage. The sediment outflow reduction from whole plant plot increased from 48.17% to 62.01% on 90 DAP, 67.30% to 73.27% on 120 DAP; and 77.39% to 82.48% on 150 DAP for selected rates of overland flow. Roots were more effective in controlling sediment rates compared to shoots.

Keywords: Lemon grass, sediment concentration, sediment outflow, growth stages & runoff rate

1. Introduction

Land, water and vegetation are precious natural resources and source of human sustenance and security. Soil erosion is the wearing away of land surfaces by the action of natural process such as water and wind. Erosion by water is classified into splash erosion, sheet erosion, rill erosion and gully erosion.

In world- wide soil erosion become a serious environmental problem (Portenga and Bierman 2011) [14]. It damage the soil (Marques *et al*. 2008) [7] and decreases productivity (Lantican *et al*. 2003) [5]. It is combination of natural and anthropogenic activities. Soil erosion is not only reduce the productivity but it is also causes extreme climate change. Soil erosion causes – extreme hydrological events such as flood and drought, increase siltation of reservoir etc. Soil erosion is affected by several factors such as climate, topography, vegetation and type of soil. There are several models has been used to calculate sediment yield such as USLE, MUSLE, RUSLE etc.

Soil erosion is reduced by many methods such as bunding and terracing, providing mulching, retaining walls, improve drainage, avoid soil compaction etc. Besides these methods, the best method to control the erosion is by providing vegetative cover by growing plants. Plants which is having a fibours root systems are more efficient to reduce the soil erosion as compare to the tap root system (De Baets and Poesen, 2010; Eab *et al*., 2015; Qiang *et al*., 2015; Vannoppen *et al*., 2017; Wang *et al*., 2018) [1, 4, 17, 25, 27]. Vegetation has long been recognized as an efficient way to prevent soil erosion, and is widely used as an important measure of soil and water conservation (Morgan and Rickson, 2003) [10]. Grasses have an important effect on slope runoff and sediment. Based on field experiments in which grass stems and leaves were cut close to ground surface. Vegetation reduce soil erosion by rainfall intercepting and the kinetic energy of raindrops. Vegetation can also improve infiltration by enhancing its physicochemical properties, decrease erosion energy and runoff, and entrap detached sediment particles, loss of soil and water; and reduce migration of pollutants. The extent to which grass affects runoff and sedimentation depends on runoff velocity, grass density, and grass submergence. Thus, factors that influence soil erosion include precipitation, vegetation, and slope gradient, among others (Messing *et al*., 2003; Vahabi & Nikkami, 2008; Zuazo & Pleguezuelo, 2008) [8, 23, 28-29]. Runoff and its capability for erosion increase with rainfall intensity (Liu, Cao, Wang, & Qin, 2010) [6]. Vegetation influences the process of erosion. Grass strips of different widths can reduce soil loss by 50% to 99%, and grass density is identified as a key factor affecting sediment reduction (Van Dijket *al*., 1996) [24]. Runoff and sediment loss have been shown to decrease exponentially with vegetation coverage (Moore *et al*. 1979; Snelder and Bryan, 1995) [9, 19]. Pan *et al*. (2006) [13] showed that grasses and moss significantly reduced sediment yield.

Concentrated flow erosion is defined as the detachment and displacement of soil particles by concentrated water flow, resulting in the development of rills and gullies. The difference between rills and gullies depends on their location and the dimensions of the channels. Concentrated flow erosion affects large areas of NW Europe and is a serious problem in the Loess Belt of Belgium, where silt loam soils in hilly regions are intensively cultivated (Nachtergaele and Poesen, 1999) [12]. However, routine filling of the gullies during farm operations often masks the severity of the problem (Poesen and Govers, 1990) [16]. Prosser *et al*. (1995) [15] concluded that flow resistance and critical shear stress of concentrated overland flow in sediment translocation decreased compared to those of a complete grass cover.

The hydrological effects of shoots canopy have been well studied. Vegetation cover prevent soil erosion by: i) it provides protection of the soil surface against raindrop impact and against erosion by surface runoff, ii) it reduces runoff volume and velocity by increasing infiltration rate and surface roughness and iii) it reduces sediment transport by trapping sediments (Morgan, 2005; Zuazo *et al*., 2008, Tamta and Kumar, 2020; Tamta *et al*., 2023) [11, 28-29, 21, 22].

Many scientists worked to reduce the soil erosion by adopting vegetative measures. In their study, they greatly focused on the effect of above ground biomass on soil erosion, whereas less attention has been given to the role of below ground biomass on soil erosion. Plant roots are more effective in controlling rill and gully erosion rates; plant cover is more effective in controlling splash detachment and interrill erosion rates. In this study, quantified the effect of roots and shoots of lemon grass on soil erosion under concentrated overland flow conditions.

2. Materials and Methods

2.1 Site description

This experiment was conducted at the Department of Soil and Water Conservation Engineering, College of Technology G.B.P.U.A & T Pantnagar in Uttarakhand, India. The latitude and longitude of Pantnagar are 20^{o} North and 19.5^{o} south, respectively. The climate of Pantnagar is sub-humid, subtropic. The annual rainfall is 1405 mm, and the average yearly temperature is about 24.1 °C.

2.2 Soil collection

Soil samples were collected from the CRC (Crop Research Centre) Pantnagar for experimenting. Firstly soil was crushed, and debris was removed and then after the soil was filled in the experimental plot (A tilting flume).

2.3 Experimental design

The hydraulic tilting flume used was 10 m long and 0.6 m wide. Sufficient holes were made at the bottom side of the flume for natural drainage of water. Before filling the soil into the flume, firstly, sand and gravel layers were placed in the flume to allow the flume condition the same as a natural condition. In this study, two treatments were used for performing experiments- (i) Bare plot (ii) Lemon grass at 90 DAP, 120 DAP, and 150 DAP (days after planting) under overland flow conditions (6.6 l/s/m, 9.0 l/s/m, 10.7 l/s/m and 12.4 l/s/m) at 1% land slope.

Lemon grass (*Cymbopogon*) having the fibrous root system was used in this study. Lemon grass is very efficient in reducing soil erosion because of sufficient biomass, so it has adequate capacity to minimize the erosivity and erodibility. The Lemon grass seedlings were planted in the experimental plot with a plant spacing 30 cm *30 cm and proper care was taken to have a proper growth.

2.4 Runoff and sediment transport rate measurement

Firstly, the experiment was performed at the bare plot for selected runoff rates and land slope. The runoff from the flume was collected in a collection tank and from this collected runoff; small representative runoff samples were collected. Runoff samples were dried in the oven for 24 hours at 105 °C and the weight of dried samples was observed to know sediment concentration. After that, Lemon grass was planted in the flume and after three months of planting experiments were performed to observe sediment concentration. Experiments were repeated for various stages of Lemon grass till 150 DAP under different runoff rates at the selected land slope i.e. 1%.

Fig 1: Experimental plot

2.5 Data analysis

Sediment concentration was determined as sediment mass per unit runoff volume. The sediment transport rate was calculated by sediment mass passes through a cross-section area per unit time. The sediment transport rate reduction (R_S) in % is the ratio of sediment transport rate from the bare plot-Lemon grass plant plot to the transport rate from the bare plot. The runoff rate reduction (R_R) in % is the ratio of runoff rate from the bare plot-Lemon grass plant plot to the runoff rate from the bare plot.

$$CS_P = \frac{S_f - S_p}{S_f} \times 100 \qquad (1)$$

Where, CS_P is the plant contribution in percent reduction in sediment. S_f and S_p are the sediment from bare plot and sediment in the planted plot respectively. The following relationship was used to calculate the sediment by the roots.

$$CS_r = \frac{S_f - S_r}{S_f} \times 100 \quad (2)$$

Where, CSr is the root contribution in percent reduction in sediment. S_f and S_r are the sediment in the root plot and sediment in the planted plot respectively.
The following equation calculates the reduction of sediment rate by the shoots.

$$CS_s = CS_p - CS_f \quad (3)$$

Where, CSs is the shoot contribution to sediment reduction.

3. Result and Discussion

3.1 Sediment outflow from bare plot

The sediment outflow from the bare plot from selected land slope at 1% and four overland flow rates of 6.6 l/s/m, 9.0 l/s/m, 10.7 l/s/m and 12.4 l/s/m shows in Table 1. To make visual comparisons and to assess the general trend, these observations were plotted graphically and are presented in Fig. 2. It was observed that the sediment concentration increased from 1890 ppm to 2510 ppm at 1% land slope with an increase in discharge from 6.6 l/s/m to 12.4 l/s/m. It was found that the sediment concentration increased significantly with the increase in discharge for a given condition.

Table 1: Observed sediment outflow at different rates of overland flow and land slopes from bare plot

Land slope, %	Rate of Overland flow, l/s/m	Average sediment concentration, PPM	Average sediment outflow, g/m²/min
1	6.6	1890	18.116
	9.0	2120	29.723
	10.7	2380	41.448
	12.4	2510	51.122

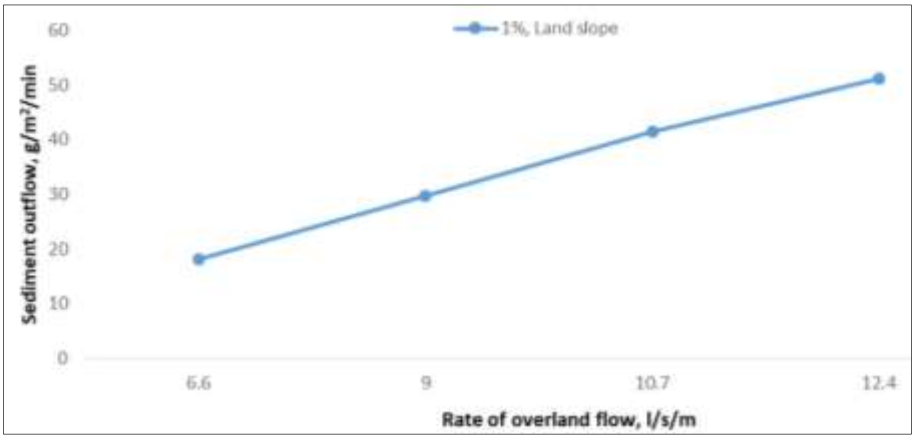

Fig 2: Observed runoff and sediment outflow at selected rates of overland flow from bare plot

3.2 Observed Sediment Outflow from Whole Plant and Root plot of Lemon Grass at Different Growth Stages

Table 2 illustrated the observed average sediment concentration for whole plot of Lemon grass at 90 DAP was 1110 ppm, 1190 ppm, 1320 ppm and 1600 ppm at 1% land slope for respective discharges of 6.6 l/s/m, 9.0 l/s/m, 10.7 l/s/m and 12.4 l/s/m respectively. The sediment concentration for whole plant plot of Lemon grass at 90 DAP for 12.4 l/s/m discharge was found to be almost 1.4 times than that for 6.6 l/s/m discharge. Minimum and maximum values of sediment transport rate at 90 DAP from whole plant plot of Lemon grass were observed as 6.882 g/m^2/min and 26.496 g/m^2/min at 1% land slope. Fig. 3 which clearly illustrated the pattern of sediment outflow for the varying rate of flow. The highest sediment outflow rate was observed at 12.4 l/s/m discharge and the lowest sediment outflow observed for 6.6 l/s/m discharge. The average increment in sediment outflow rate at 12.4 l/s/m discharge was almost 3.7 times as compared to sediment outflow rate for 6.6 l/s/m discharge.
The sediment concentration from whole plant plot of Lemon grass at 120 DAP increased from 950 ppm to 1290 ppm at 1% land slope. It was also observed that an increase in rate of flow resulted in higher sediment concentration. Similarly, sediment outflow rate at 1% land slope was 4.843 g/m^2/min, 8.178 g/m^2/min, 12.289 g/m^2/min and 16.716 g/m^2/min with the selected rates of overland flow ranging from 6.6 l/s/m to 12.4 l/s/m.
The observed values of average sediment concentration for the whole plant of Lemon grass at 150 DAP at selected land slopes of 1% under different rates of overland were observed as 980 ppm, 1060 ppm, 1070 ppm and 1140 ppm. The average sediment outflow rate at 12.4 l/s/m discharge was found more than 4.13 times as compared to the sediment outflow rate for 6.6 l/s/m discharge.

Table 2: Observed sediment outflow at different rates of overland flow from whole plant plot and root plot

Land slope, %	Rate of overland flow, l/s/m	Average sediment concentration, ppm from whole plant plot			Average sediment concentration, ppm from Root plot		
		90 DAP	120 DAP	150 DAP	90 DAP	120 DAP	150 DAP
1	6.6	1110	950	980	1430	1290	1190
	9.0	1190	1050	1060	1600	1560	1430
	10.7	1320	1170	1070	1710	1810	1580
	12.4	1600	1290	1140	1920	1920	1720

The observations are presented graphically for visual analysis which clearly illustrated that the sediment outflow rate for whole plant plot increased with the increase in rate of overland flow. The sediment outflow rate for whole plant plot of Lemon grass followed a rapidly increasing trend in the entire range of selected discharges. Based on the observations, it could also be summarized that, whole plant plot of Lemon grass reduced sediment outflow rate significantly as compared to bare plot.

Table the values of sediment concentration for root plot of Lemon grass at 90 DAP which were 1430 ppm, 1600 ppm, 1710 ppm and 1920 ppm at 1% land slope for selected rates of overland flow in the range of 6.6 l/s/m to 12.4 l/s/m. The observed sediment outflow rates for root plot of Lemon grass at 90 DAP were found to be 12.103 g/m^2/min, 20.041 g/m^2/min, 28.067 g/m^2/min, and 36.818 g/m^2/min at 1% land slope as discharge varied from 6.6 l/s/m to 12.4 l/s/m. The average increment of sediment outflow for root plot at 12.4 l/s/m discharge was almost 2.9 times higher than that for 6.6 l/s/m discharge.

The observed sediment outflow rates for 6.6 l/s/m was 10.052 g/m^2/min, 18.048 g/m^2/min for 9.0 l/s/m, 25.933 g/m^2/min for 10.7 l/s/m, and finally sediment outflow rate for root plot of Lemon grass at 120 DAP was found to be 32.534 g/m^2/min for 12.4 l/s/m rate of overland flow. The average increment in sediment outflow rate from root plot at 12.4 l/s/m discharge was 3.16 times as compared to sediment outflow rate for 6.6 l/s/m discharge.

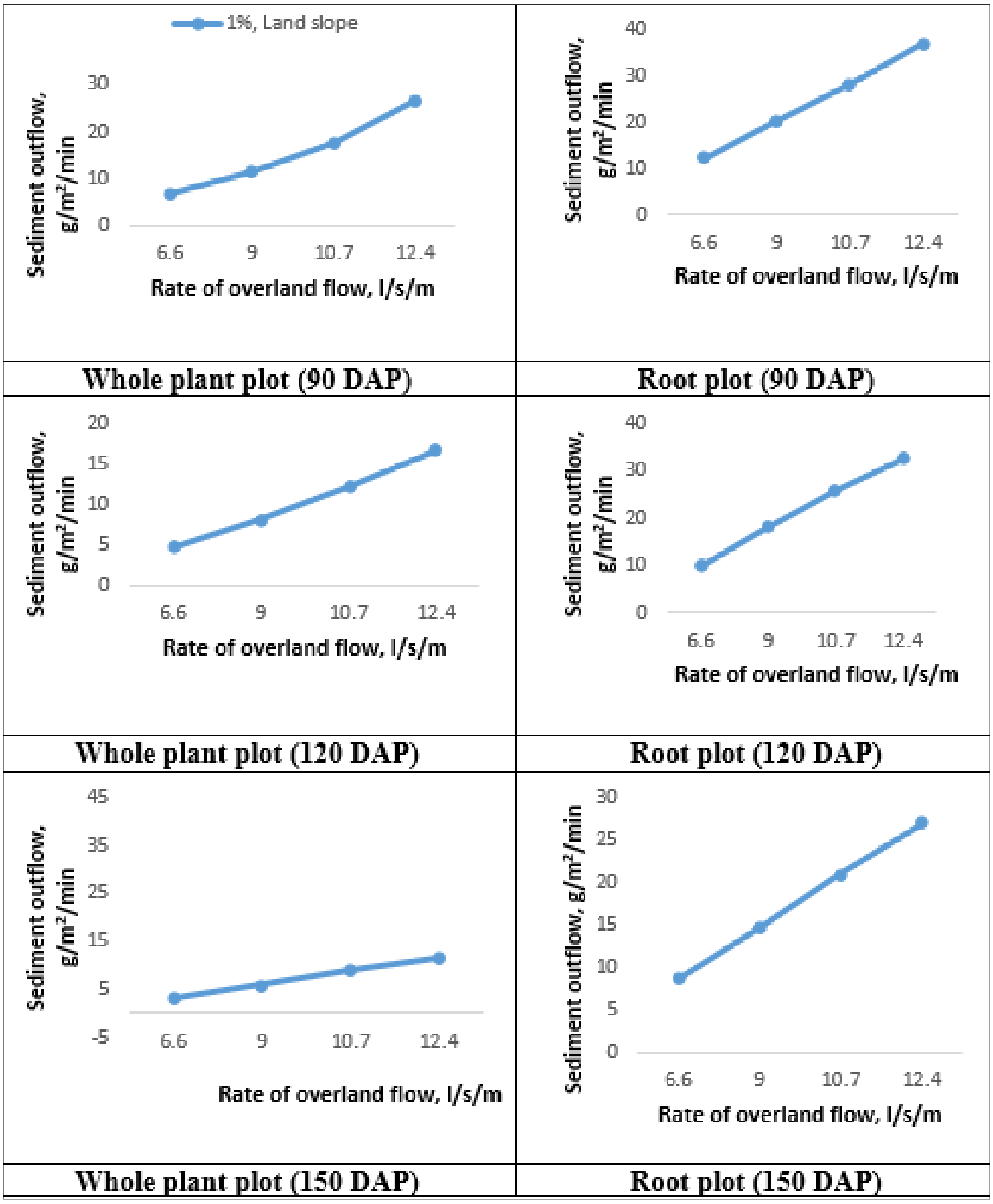

Fig 3: Sediment outflow rate from whole plant plot and root plot at different growth stages

The average sediment concentration for root plot of Lemon grass at 150 DAP increased from 1190 ppm, 1430 ppm, 1580 ppm and 1720 ppm at 1% land slope, when discharge increased from 6.6 l/s/m to 12.4 l/s/m. The average increment in sediment outflow rate from root plot of Lemon grass on 150 DAP at 12.4 l/s/m discharge was 3.17 times as compared to 6.6 l/s/m discharge.

Fig. 3 clearly indicated that the sediment outflow for root plot of Lemon grass increased with the increase in discharge. Sediment outflow rate significantly reduced from root plot as compared to the bare plot. It could be summarized from the observations and analysis that root plot produced sediment outflow at significantly lower rates as compared to the bare plot and with the extended growth period, Lemon grass became more effective in controlling sediment generation and its transportation as with the increase in growth stages of Lemon grass below-ground biomass got developed significantly.

3.3 Reduction in Sediment Outflow Rate from Whole Plant, Root and Shoot of Lemon Grass at 90 DAP, 120 DAP, And 150 DAP As Compared To Bare Plot

The observed values illustrated that the sediment outflow reduction from whole plant plot increased from 48.17% to 62.01% on 90 DAP, 67.30% to 73.27% on 120 DAP for selected rates of overland flow shows in Fig. 4. The sediment outflow reduction from whole plant plot was found to be 77.39% to 82.48% on 150 DAP when rate of overland flow increased from 6.6 l/s/m to 12.4 l/s/m at 1% land slope. Results outlined that, at different growth stages, the maximum and minimum reduction in sediment outflow rate from the whole plant were identified at low and high discharges respectively. Figure 4 shows that the Lemon grass whole plant was very useful to reduce the sediment outflow rate. The observations made it clear that maximum reduction in sediment outflow rate was at low discharge and at the third growth stage, when both roots and shoots are well developed and stabilized. Results made it very clear that, at different growth stages, the maximum reduction in sediment outflow rate was mainly accomplished by roots rather than shoots because roots have the strong capacity to bind soil particle tightly and improve the soil structure. Besides that roots contribution to sediment outflow rate reduction was maximum at minimum discharge and minimum at maximum discharge.

The observed values indicated that at 1% land slope, sediment outflow reduction from shoots was 28.82%, 28.69%, 25.47% and 20.19%; and from roots, the reduction percentage was 33.19%, 32.57%, 32.28% and 27.98% for 6.6 l/s/m, 9.0 l/s/m, 10.7 l/s/m and 12.4 l/s/m discharge respectively after 90 days of planting of Lemon grass. Moreover, after 120 days of planting, the reduction in sediment outflow rate from roots was 44.51%, 39.28%, 37.43% and 36.36% which is higher than that from shoots which were 28.75%, 33.21%, 32.92% and 30.94% as the rate of overland flow varied from 6.6 l/s/m to 12.4 l/s/m. Similarly, on 150 DAP of Lemon grass, the sediment outflow rate reduction for shoots varied from 28.98% to 30.91% while for roots the reduction in sediment outflow rate was varying in the range of 47.34% to 51.57% for similar conditions. From the above findings, it could be summarized, that in general, with the increase in the growth stage, the overall effectiveness of Lemon grass to reduce sediment outflow rate increased. It was also depicted from the figure that maximum reduction in sediment outflow rate was found at minimum discharge for roots, but did not show any specific trend in the case of shoots to reduce the sediment outflow rate with the discharge at a particular land slope.

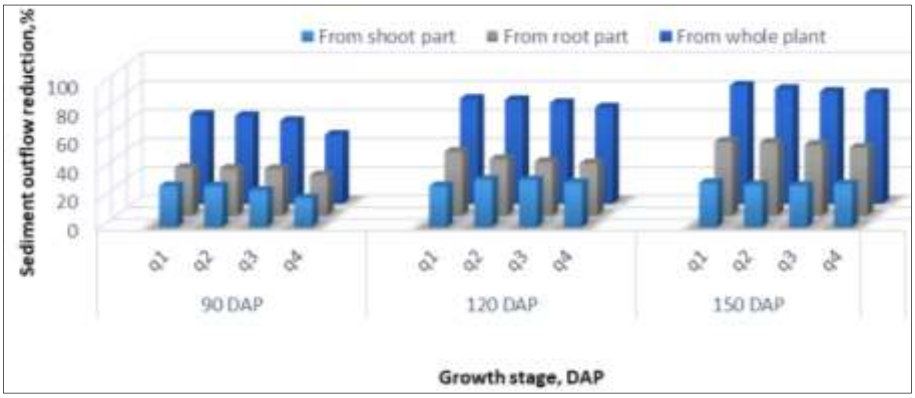

Fig 4: Contribution of whole plant, root and shoot on sediment outflow reduction with respect to bare plot

4. Conclusion

The sediment outflow rate for whole plant plot increased with the increase in rate of overland flow. The sediment outflow rate for whole plant plot of Lemon grass followed a rapidly increasing trend in the entire range of selected discharges. Whole plant plot of Lemon grass reduced sediment outflow rate significantly as compared to bare plot. It could be summarized that root plot produced sediment outflow at significantly lower rates as compared to the bare plot and with the extended growth period, Lemon grass became more effective in controlling sediment generation and its transportation as with the increase in growth stages of Lemon grass below-ground biomass got developed significantly. The sediment outflow reduction from whole plant plot increased from 48.17% to 62.01% on 90 DAP, 67.30% to 73.27% on 120 DAP; and 77.39% to 82.48% on 150 DAP for selected rates of overland flow. The result defines that with the increase in the growth stage, the overall effectiveness of Lemon grass to reduce sediment outflow rate increased. Sediment outflow rate significantly reduced from root plot as compared to the shoot plot.

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