Effect of Napier grass shoots characteristics on runoff and sediment outflow under concentrated overland flow conditions

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Abstract
Vegetation cover is very effective measures to control environmental conditions. In this study evaluate the potential of Napier grass to reduce the runoff and sediment outflow. Parameters include number of shoots, shoot length, number of leaves, leaf area index and experiments were performed in the hydrological simulation laboratory using a hydraulic tilting flume and controlled water circulation system. Extensive experiments were carried out using (i) control (ii) whole plant plot (iii) roots plot at 2% slope with 6.24 l/s runoff rate. Results summarized that Napier grass produced significantly lesser soil erosion and runoff as compared to the control. Further, it was observed that the sediment outflow and runoff generation significantly decreased with the growth stage. Roots were more effective in controlling sediment rates, while shoots were more effective in reducing runoff rate. The correlation analysis defined that both, runoff and sediment outflow, were highly negatively correlated with the shoot length.

Keywords: Napier grass, roots, runoff, sediment, shoots

1. Introduction
Soil erosion is a severe environmental problem. Soil erosion erodes and transports the above layer of soil and results in degradation. Land degradation not only causes decrease in agricultural productivity and disturbs food security (Eswaran et al., 2001) [12] but also formulates the deforestation and changes climatic conditions. As per an estimate about 40% of the world's agricultural land is affected by severe land degradation (Lan Sample, 2007) [17]. Soil erosion is about 10 to 20 times than the soil formation in no-tillage lands and100 times in conventional tillage lands (Adger and Coauthors, Fischlin, 2007) [1]. The total geographical area of India is 329 M ha, out of the total area of 147 M ha of the land is affected by land degradation. In this total amount of land degradation, 94 M ha caused by water erosion, 14 M ha from flood, 16 M ha from acidification, 9 M ha from wind erosion, 6 M ha from salinity, and 7 M ha from a combination of all above. From the above scenario, it is seen that a major portion of land degradation problems occur due to water erosion and therefore, it needs to be given special attention to prevent water erosion to sustain and enhance agricultural productivity and to maintain environmental conditions. Uttarakhand state faces a severe problems of water erosion because of steep slope, high rainfall, carelessly built roads, floods, landslides, etc. According to the report of NBSS & LUP-ICAR, Uttarakhand and Uttar Pradesh are the most severely affected states by water erosion after Andhra Pradesh and Telangana. About 10.09 M ha area in Uttarakhand is affected by the water and wind erosion (Oliver, 2019) [26].

Vegetation plays a significant role in the reduction of soil erosion as its canopy provides a protective cover to soil surface, while root system helps in binding the soil tightly against the erosive forces and stabilizes the slope (Li and Pan, 2018; Wainwright, Parsons and Abrahams, 2000; El Kateb et al., 2013; Cammeraat, Van Beek and Kooijman, 2005; Chirico et al., 2013; Jiao et al., 2009; Stokes et al., 2008; Snelder and Bryan, 1995; Meeuwig, 1970; Dadkhah and Gifford, 1980; Ziemer, 1981) [20, 35, 14, 8, 9, 19, 33, 31, 23, 11, 37]. Perennial grasses are more efficient in controlling soil erosion (Wu et al., 2009) because the perennial herb contain fibrous root system which are more efficient in reducing the soil erosion as compared to the taproot system (Wang et al., 2018) [36].
Napier grass having the fibrous root systems is very popular in hilly areas as a forage crop and prevents erosion and land slides and acts as a safety net against land degradation (Angima et al., 2002). A study to quantify the effectiveness of Napier grass to control sediment outflow and runoff at various stages of its growth will contribute greatly in understanding its mechanism which will help in designing of effective soil conservation programs. With above considerations in mind the present study was undertaken to assess the effect of Napier grass on sediment runoff rate at different growth stages and to evaluate the contribution of below ground biomass (roots) and above bio mass (shoots) on sediment outflow and runoff.

2. Materials and Methods

2.1 Experimental site and set up

The experimentation was carried out in the Hydrologic Simulation Laboratory in the department of Soil and Water Conservation Engineering at G.B. Pant University of Agriculture and Technology Pantnagar (Uttarakhand), India. Pantnagar has a sub-humid, sub-tropical climate and is located in the foot hills of Himalayas in U S Nagar District between 20° North latitude to 79.5° South longitude. The average annual rainfall at Pantnagar is 1405 mm, and the yearly average temperature is 24.1 °C.

The experimental set up (Fig 1) consists of hydraulic tilting flume 10 m x 1.2 m x 0.6 m as a test plot and a controlled water circulation system to create concentrated flow. In this experiment, the flume was divided into two parts widthwise; one part was used as a planted plot and the second one as a root plot. The flume was filled with soil and was compacted uniformly, to obtain the bulk density similar to the field bulk density of soil. To create natural drainage to percolating water a well designed 5 cm thick sand and gravel filter at the base of the flume was provided. The water through this filter passes from the bottom of the flume through small bottom holes in the flume. Napier grass was planted in the soil filled flume with the plant to plant and row to row spacing of 30 and 50 cm respectively. Three treatments were performed (i) Control (no crop), (ii) planted plot (this contains shoots and roots both) (iii) roots plot in which shoots clipped at the soil surface before starting the experiment.

2.2 Measurement of runoff and sediment

Observations of runoff and sediment outflow were performed after three months of planting at three different stages of the crop starting from March 2019 to May 2019. Experiments were conducted at 4 weeks intervals using concentrated overland flow conditions. The control, planted plot and root plot (shoots clipped off before the test) were used in each experiment. The flume was set at a 2% slope put under 6.24 l/s discharge rate for a specified duration and runoff was observed till the end. Before starting the experiment every time uniform soil moisture conditions were maintained by saturating the soil.

After each experiment, runoff from the experimental plot was collected in the runoff collection tank and three representative runoff samples of 250 ml were collected. These samples were brought to laboratory to analyse for sediment concentration. A 100 CC take sample was taken in aluminium containers which were placed in the hot air oven for 24 hours at 105 °C. The dry sediment weight was obtained by subtracting the container sample weight after the drying and sediment concentration was obtained in PPM. This concentration when multiplied with the total runoff volume provided the total weight of sediment.

2.3 Determination of plant parameters

Different parameters of plant like shoot length, number of leaves, number of tillers, and leaf area index were measured at the end of each experiment. The number of stems (N.T.) were determined by counting the number of the stems of 3 randomly selected plants and averaged to a single plant. The number of leaves (N.L.) were determined by counting the leaves of 3 randomly selected plants and then averaged. Similarly, Shoot length (S.L.) was the length of 3 randomly selected plants from the base to the tip of the tallest part of a plant. Leaf area index (LAI) was determined by using the following relationship as proposed by Sestak et al., 1971.

Leaf area index (LAI) = A/P

… (1)

Where, A is the area of leaves of a plant P is land area occupied by a single plant.

The statistical description of various shoot parameters used in this study is indexed in Table 1.

| Item                  | Leaf area index | Shoot length (cm) | Number of stems | Number of leaves |
|-----------------------|-----------------|-------------------|-----------------|------------------|
| Minimum               | 7.502           | 134               | 34              | 151              |
| Maximum               | 15.968          | 242               | 44              | 299              |
| Mean                  | 11.771          | 187.667           | 39              | 228.667          |
| STD                   | 4.233           | 54.003            | 5               | 74.270           |
| CV                    | 0.360           | 0.288             | 0.128           | 0.325            |

Note: STD, standard deviation; CV, coefficient of variation

2.4 Data analysis

In this study, it was considered that the reduction in sediment concentration and runoff caused by whole plant was the cumulative effect of roots and shoots. The following
The relationship was used to calculate reduction in sediment outflow and runoff rate by the plant.

\[
CS_p = \frac{S_f - S_p}{S_f} \times 100 \quad \text{... (2)}
\]

\[
CR_p = \frac{R_f - R_p}{R_f} \times 100\% \quad \text{... (3)}
\]

where, \(CS_p\) and \(CR_p\) are the plant contribution in percent reduction in sediment and runoff respectively. \(S_f\) and \(R_f\) are the sediment and runoff rate in the bare plot and \(S_p\) and \(R_p\) are the sediment and runoff rate in the planted plot. The following relationship was used to calculate the sediment and runoff reduction rate by the roots.

\[
CS_r = \frac{S_f - S_r}{S_f} \times 100 \quad \text{... (4)}
\]

\[
CR_r = \frac{R_f - R_r}{R_f} \times 100\% \quad \text{... (5)}
\]

Where, \(CS_r\) and \(CR_r\) are the root contribution in percent reduction in sediment and runoff respectively. \(S_r\) and \(R_r\) are the sediment and runoff rate in the root plot and \(S_p\) and \(R_p\) are the sediment and runoff rate in the planted plot. The following equation calculates the reduction of sediment and runoff reduction rate by the shoots.

\[
CS_s = CS_p - CS_f \quad \text{... (6)}
\]

\[
CR_s = CR_p - CR_r \quad \text{... (7)}
\]

Where, \(CS_s\) and \(CR_s\) are the shoot contribution to sediment and runoff reduction.

### 3. Result and Discussion

#### 3.1 Runoff and sediment

The effect of Napier grass, whole plant on the runoff and sediment yield reduction during different growth stages is shown in Figure 1. The whole plant plot had a notable effect on runoff and sediment yield reduction. It can be perceived that the sediment yield and the runoff decreased as Napier grass growth increased. Compared to the bare plot, runoff rates in the Napier grass plot during three growth stages varied from 5.466 to 9.595 mm/min, with a reduction in the range of 34% - 62%. The sediment transport rates decreased from 14.584 to 4.428 to g/m²/min, with a reduction in the range of 69.76% - 90.81% (Table 2). These observations revealed that the growing of Napier grass had a significant effect on reduction of sediment yield than runoff. Third growth stage of Napier grass had the least sediment transport rate, sediment concentration, and runoff rate (4.428 g/m²/min, 810 ppm and 5.466 mm/min respectively) and thus had the maximum reduction in runoff volume and sediment concentration (62.37% and 75.60% respectively). These results defined that, the effectiveness in controlling sediment concentration and runoff rate varied depending on the establishment status of the Napier Grass.

#### Table 2: Runoff and sediment rate under different growth stages for the whole plant and root plot of Napier grass and compared the reduction in these parameters with a bare plot

| Treatment            | Runoff rate (mm/min) | Runoff volume (cc) | Sediment rate (g/m²/min) | Sediment concentration (gm) | Reduction (%) | Runoff Volume | Sediment concentration |
|----------------------|----------------------|--------------------|--------------------------|----------------------------|---------------|---------------|------------------------|
| Bare plot            | 14.524               | 623100             | 48.221                   | 0.332                      | -             | -             | -                      |
| Plant plot (Ist stage) | 9.595               | 411612             | 14.584                   | 0.152                      | 33.94         | 54.22         |                        |
| Plant plot (IInd stage) | 8.388              | 359860             | 11.576                   | 0.138                      | 42.25         | 58.43         |                        |
| Plant plot (IIR stage) | 5.466               | 234500             | 4.428                    | 0.081                      | 62.37         | 75.60         |                        |
| Root plot (Ist stage) | 13.028              | 558910             | 27.750                   | 0.213                      | 10.30         | 35.84         |                        |
| Root plot (IInd stage) | 12.329             | 528900             | 26.014                   | 0.211                      | 15.12         | 36.45         |                        |
| Root plot (IIR stage) | 10.315              | 442500             | 20.629                   | 0.200                      | 28.98         | 39.76         |                        |

Figure 2 illustrates the effectiveness of Napier Grass in runoff and sediment yield reductions. It could be seen that the reduction in sediment concentration was higher than the runoff which indicated that Napier grass is more effective to control the soil erosion and sediment outflow than controlling runoff. The reduction in runoff increased from 33.94% in the first stage to 62.37% in the third stage while reduction in sediment concentration reached up to 75.60% in the third stage.

![Fig 2: Reduction (%) in runoff volume (A) and sediment concentration (B) by Napier grass](image-url)
The observations presented in Table 2 make it evident that runoff and sediment transport rates significantly increased after clipping off the shoot part of Napier grass. Runoff and sediment transport rates in Napier grass-root plots were 10.315 – 13.028 mm/min and 20.629 - 27.750 g/m²/min, respectively, during all growth stages, with average rise of 2.4 times as compared to the whole plant plots. Similarly, in Napier grass-root plot runoff volume and sediment concentration decreased by 10.30% to 28.98% and 35.84% to 39.76%, respectively, as compared to the bare plot under different stages. Similar to the whole plant experiments, the performance of Napier grass roots in the third stage was found to be the best as compared to the first and second stages for controlling runoff and sediment outflow.

3.2 Contribution of shoots and roots in reductions of runoff and sediment transport rate

Reduction of soil erosion by vegetation comprised cumulative effects of plant shoots and roots. Analysis of the contribution of shoots and roots in reduction of runoff and sediment concentration during different growth stages showed that the Napier grass shoots contributed more in runoff reduction which was found to be in the range of 23.64% - 33.38% (Fig. 3A). Besides that, the Napier grass roots made a more significant contribution to the sediment concentration reduction which was observed in the range of 35.84% - 39.75% (Fig. 3B). Therefore it could be said that above-ground biomass is more effective in runoff reduction as compared to the below-ground biomass throughout the whole growth stages of Napier grass.

3.3 Effect of various shoot parameters on runoff and sediment concentration

Table 3 ((A) and (B)) showed the effect of various shoot parameters such as, Leaf area index (X₁), Shoot length (X₂), number of stems (X₃), and number of leaves (X₄) on runoff volume and sediment concentration based on correlation. As observed in Table 3, all four variables had inverse effects on runoff volume and sediment concentration, indicating an increase in X₁, X₂, X₃, and X₄ creates a lower amount of runoff volume and sediment concentration. Further, shoot length had the highest total indirect effect on runoff volume (R² = 97.48) (Table 3 A) and sediment concentration (R² = 94.74) (Table 3 B) followed by the number of stems, Leaf area index, and the number of leaves respectively, representing in order of X₂>X₃>X₁>X₄. Although the direct effect of the number of leaf on runoff volume (R² = 94.89) and sediment concentration (R² = 91.23) was lowest among the four variables.

There exists a linear correlation between shoot length, runoff runoff rate and sediment concentration (Figure 4). A linear regression analysis illustrated that with an increase in shoot length, runoff volume (R² = 95.03) and sediment concentration (R² = 89.76) showed a linear decrease (Fig. 3).

Table 3A: The relationship between shoots parameter and runoff for 6.24 l/s discharge rate

|        | Y | X1          | X2          | X3          | X4          |
|--------|---|-------------|-------------|-------------|-------------|
| Y      | 1 |             |             |             |             |
| X1     | -0.96886 | 1           |             |             |             |
| X2     | -0.97484 | 0.999677    | 1           |             |             |
| X3     | -0.9724  | 0.999892    | 0.999943    | 1           |             |
| X4     | -0.94889 | 0.997489    | 0.995366    | 0.996337    | 1           |

Table 3B: The relationship between shoots parameter and sediment concentration for 6.24 l/s discharge rate

|        | Y | X1          | X2          | X3          | X4          |
|--------|---|-------------|-------------|-------------|-------------|
| Y      | 1 |             |             |             |             |
| X1     | -0.93899 | 1           |             |             |             |
| X2     | -0.94743 | 0.999677    | 1           |             |             |
| X3     | -0.94396 | 0.999892    | 0.999943    | 1           |             |
| X4     | -0.91228 | 0.997489    | 0.995366    | 0.996337    | 1           |
4. Conclusion
The observations clearly established the vital significance of Napier Grass cover on control soil erosion and runoff which was found to be increasing with the growth stages. During the third growth stage, the reductions in sediment concentration and runoff reached 75.60% and 62.37%, respectively. Moreover, both shoots and roots played an effective role in the reduction of soil erosion. The contribution of the roots in controlling sediment concentration was more significant than that of the shoots; on the contrary, the contribution of shoots was found to be better in runoff reduction than that of roots. This study also established the correlation between shoot parameters (shoot length, leaf area index, number of leaves and number of stems) to sediment concentration and runoff. The results explained that shoot length was greatly influencing runoff and sediment concentration than other parameters (leaf area index, number of leaves and number of stems). The results of this study are likely to provide useful information to decide appropriate cropping system based on its root and shoot characteristics while designing a soil and water conservation program.

5. References
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