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Role of some riparian wetland plants in reducing erosion of organic carbon and selected cations

Raju Kumar, R.S. Ambasht, Ajit K. Srivastava, N.K. Srivastava

Ecology Research Laboratory, Centre of Advanced Study in Botany, Banaras Hindu University, Varanasi-221 005, India

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Abstract

Five riparian herbaceous plants, *Leonotis nepetaefolia*, *Cassia tora*, *Ageratum conyzoides*, *Parthenium hysterophorus* and *Sida acuta*, dominant on the banks of the Rihand river at Renukoot (India), were selected to assess experimentally their quantitative role in conserving organic-C, Na, K and Ca. Young seedlings from the river bank were planted on sloping experimental plots made of alluvial soil. Simulated rainfall totalling 42.5 mm was applied at 300 mm h^{-1} on five vegetated and one bare plots. Runoff water and eroded soil were collected from each experimental plot in artificial reservoirs and their quantities were measured. The soil conservation value of the five selected species ranged between 33 and 84% while the water conservation value varied between 19 and 50%. The overall nutrient conservation value, based on the losses in runoff water and eroded soil taken together, varied from 30 to 83% for organic-C, 19 to 78% for Na, 13 to 72% for K and 29 to 52% for Ca under different species. Loss of these four nutrients in response to 42.5 mm simulated rainfall was much higher than their input through rainfall. Loss value for the nutrients were in following order: organic-C > Ca > K > Na. The fraction of organic-C transported down the slope was higher in eroded soil (averaging 73%) and of exchangeable bases in runoff water (averaging 86% for Na, 82% for K and 90% for Ca). Flow-weighted concentrations of all the studied nutrients were consistently greater from bare stands. Number of fine roots was found to play greater role in the case of organic-C (92%; $p < 0.01$) and Na (70%; $p < 0.05$) runoff and their conservation by different plant species but canopy cover played greater role for K (58%; $p < 0.08$) and Ca (90%; $p < 0.01$).

1. Introduction

Riparian wetlands have well-defined landscape features with an elongated shape and very high edge index. Riparian wetlands are delicately balanced and mostly in stressed

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conditions. They experience natural periodic flooding, siltation and erosion; anthropogenic forces of grazing by domestic animals; scraping for fodder; and agricultural operations that accelerate erosion. Dumping of waste and continuous flow of city sewage and industrial effluents into river systems are common along cities and industries. Riparian ecosystems are ecotones between uplands and aquatic bodies. A proper management of vegetation on such ecotones can effectively modify, dilute, or concentrate substances before they enter the stream zone. Dense vegetation on these stands can help to reduce sediment inputs, provide important sources of organic matter, and stabilize stream banks (Osborne and Kovacic, 1993). The positive role of riparian forests working as nutrient filters has been clearly demonstrated by Lowrance et al. (1984). Ambasht et al. (1984) and Singh and Ambasht (1990) have measured the efficiencies of a few riparian herbs of the Gomati River in water and soil conservation and Kumar et al. (1992a,b) have measured the various forms of N and P conservation efficiencies of selected plants of Rihand River banks.

Soil organic-C is one of the first soil constituents removed by soil erosion since it is of low density and is concentrated near the soil surface (Lucas et al., 1977). Its loss through erosion will have an important ecosystem effect because organic-C plays a major role in cation exchange, a source of mineral N and as a sink for fertilizer N (Schreiber and McGregor, 1979; Gilliam et al., 1982; Langdale and Lowrance, 1984). Exchangeable bases (Na, K and Ca) are essential nutrients whose importance in plant growth is well recognized (Sparks and Huang, 1985). Their selective removal with runoff sediment is important from water quality and soil fertility aspects. The kinetics of soil P (Sharpley, 1987) and K (Sharpley et al., 1988) desorption have been described by an empirical equation. The transport of agricultural nutrients and pesticides has been the subject of extensive field research and modelling efforts (McDowell and McGregor, 1984) especially the N and P (Knisel, 1980) associated with sediments.

Although nutrient loss through erosion is an acknowledged problem for long-term soil productivity and water quality, the role of riparian vegetation in reducing nutrient movement from such slopes remains poorly quantified. This paper is primarily concerned with (1) concentration and nutrient loss through runoff in relation to input through rainfall under different ground cover conditions, (2) the relative role of roots, canopy cover, littermass and soil antecedent moisture content in regulating runoff processes across the riparian slopes, (3) nutrients (organic-C, Na, K and Ca) conservation efficiency of different plant species, and (4) the mode of nutrient transport down the slopes. Such a study will help to develop better management practices for riparian wetlands so as to effectively maintain fertility of soil, improve its nutrient sink capacity and reduce input to bodies of water (Lynch and Corbett, 1990; Petersen et al., 1992).

2. Materials and methods

The Rihand River is a small river originating in the hilly tracts of Madhya Pradesh State. It flows northward in Uttar Pradesh along the industrial and coal mining belt of Singrauli, Anpara, Renukoot and Obra and joins the River Son, a tributary of the River

Ganga. In the Indian tropics, riparian vegetation is dense in the rainy season, moderate in winter and non-existent in summer. Places of gentle slopes and even topography allows easy ploughing along the margin. Cereal crops of winter like wheat, grains and mustard are grown for 4 months from November to February in the Gangetic plains. Five dominant herbaceous species *Leonotis nepetaefolia* (L.) Br., *Cassia tora L.*, *Ageratum conyzoides* L., *Parthenium hysterophores* L., and *Sida acuta* Burm f. found in extensive patches on Rihand riparian slopes were selected to determine their efficiency in reducing soil water, organic-C, Na, K and Ca losses. Transplants of these species were raised in 1991 on artificially prepared experimental sloping plots and runoff measurements were made from these and an equal sized bare plot as per the method of Ambasht (1970). *Leonotis nepetaefolia* (Lamiaceae), a tall herb with a stout quadrangular finely pubescent stem and ovate leaves, attained a stature of 80–95 cm in the experimental plots. *Cassia tora* (Fabaceae) is an annual herb 50–100 cm tall, with pinnate leaves and ovate-oblong leaflet. *Ageratum conyzoides* (Asteraceae) is a soft annual herb, 30–70 cm long with leaves opposite and ovate in shape. *Parthenium hysterophorus* (Asteraceae), an annual herb, grows gregariously in wastelands, reaching a height of 50–100 cm. *Sida acuta* (Malvaceae) is a branched herb. Its stem is smooth or slightly rough with minute stellate hairs, lanceolate leaves, oblong and rounded at the base.

These river bank species were grown on 4.7 m^2 (2.61 × 1.8) m^2 sloping plots (30% slope) in the Botanical Garden of the Banaras Hindu University. Garden soil contained 55% sand, 26% silt and 17% clay. Cemented collection tanks were prepared at the lower end of each sloping plot to collect the runoff water and eroded soil. Among the six plots studied one species each was planted on five plots and the sixth plot was maintained bare. At the time of planting density was kept uniform (121 individuals m^{-2}) but later the extent of cover increased to different levels in different plots, depending upon the growth behaviour of the species (Kumar et al., 1992a, b). Naturally growing weeds were normally removed at the early growth stage. Sprinkling to simulate heavy rainfall was performed when the canopy was sufficient to cover the ground surface adequately. Sprinkling on vegetated and bare plots was done for 8.5 min using a multipore nozzle with 2 mm pore diameter from a 1 m height at a constant intensity of 300 mm h^{-1}. The high simulated rain intensity was selected for the experiment to generate sufficient kinetic energy to cause adequate runoff in a short period. The experiment was carried out in triplicate. It was repeated at 10-day interval thrice in order to restore, as far as possible, the plot characteristics after each treatment. Results of three treatments were averaged and then the soil, water, organic-C, Na, K and Ca conservation efficiency percentage for each of the studied species were calculated. The volume of water applied, the runoff volume and the weight of soil from each plot were measured from the collection reservoirs. Samples were taken immediately after each run to avoid evaporative losses, 0.45 μm pore size filter was used to separate water runoff and deposited soil for the estimation of organic-C, Na, K and Ca. Soil samples were oven-dried for 36 h at 80°C and sieved through 0.5-mm sieve before analysis. Organic-C was measured by Walkley and Black's methods and Na, K and Ca by flame photometer for deposited soil (Jackson, 1967). These nutrients in the runoff water were analyzed by selecting suitable methods as described in Standard Methods (American Public Health Association, 1985).

The conservation value of each of the five species for soil, water and nutrients was calculated using the formula given by Ambasht et al. (1984) and Kumar et al. (1992b):

$$\text{Conservation value}\,(C_v) = 100\,(1 - S_p/S_o)$$

where, S_p and S_o are the quantities removed from vegetated and bare plots, respectively, of soil, water and nutrients under identical erosive stresses.

The number of terminal rootlets was counted by digging the monoliths of 1 m^3 size and then immersing them in water to get the fine rootlets intact. Canopy cover percent was measured by the line transect method. Littermass was measured on oven dry-weight basis. Soil antecedent moisture content is the percent moisture present in surface soil (0–10 cm) immediately before each rainfall treatment and is presented on oven dry-weight basis (Jackson, 1967).

2.1. Statistical analysis

The multiple stepwise regression equation was performed using the MSTAT computer program package to assess the relative influence of roots, canopy cover, surface littermass and soil moisture, individually as well as cumulatively on the quantity of nutrient eroded and their conservation in relation to different plant species. Only those independent variables which are known to play more important roles in influencing nutrient movement were considered.

3. Results and discussion

3.1. Experimental plot characteristics

Among the six studied stands (five vegetated and one bare); *Leonotis* (Table 1) had the maximum number of terminal rootlets (4.67×10^5 m^{-2}), canopy cover (98%) and soil moisture content (12%) while the maximum littermass of 122 g m^{-2} was observed in *Cassia* stand. The bare plot soil had the maximum bulk density of 1.4.

Table 1
Attributes of experimental plots

	Bare	*Leonotis*	*Cassia*	*Ageratum*	*Parthenium*	*Sida*
No. of terminal rootlets ($\times 10^5$ m^{-2})	0	4.67 ± 0.13	3.43 ± 0.11	4.27 ± 0.17	3.20 ± 0.11	1.90 ± 0.03
Canopy cover (%)	0	98.00 ± 2.6	82.00 ± 3.2	72.00 ± 2.1	76.00 ± 1.8	79.00 ± 2.0
Litter mass (g m^{-2})	0	51.00 ± 4.3	122.00 ± 3.7	92.00 ± 6.6	113.00 ± 3.6	88.00 ± 2.3
Soil antecedent moisture content (%)	6.5 ± 0.3	12.00 ± 0.4	10.70 ± 0.5	8.00 ± 0.4	8.40 ± 0.4	11.00 ± 0.7

Values are means ± S.E.

3.2. *Input vs. runoff*

Nutrient movement down the slope through runoff (loss through soil and water taken together) was fairly high compared to input of nutrients through simulated rainfall. Organic-C movement was 75 to 452 times higher than the input of 48 g ha^{-1} (Fig. 1), Na 2 to 11 times higher than the input of 1110 g ha^{-1} (Fig. 2), K movement 3 to 11 times greater than the input of 510 g ha^{-1} (Fig. 3), and Ca movement 6 to 12 times higher than the input of 1780 g ha^{-1} (Fig. 4). These higher loss values may be attributed to desorption of nutrients from the surface soil particles under the beating action of raindrops and their subsequent suspension and transport. Amount wise, loss of organic-C was higher than of other nutrients studied, because its relatively low density and higher concentration near the soil surface (Lucas et al., 1977). Also, the proportional loss value

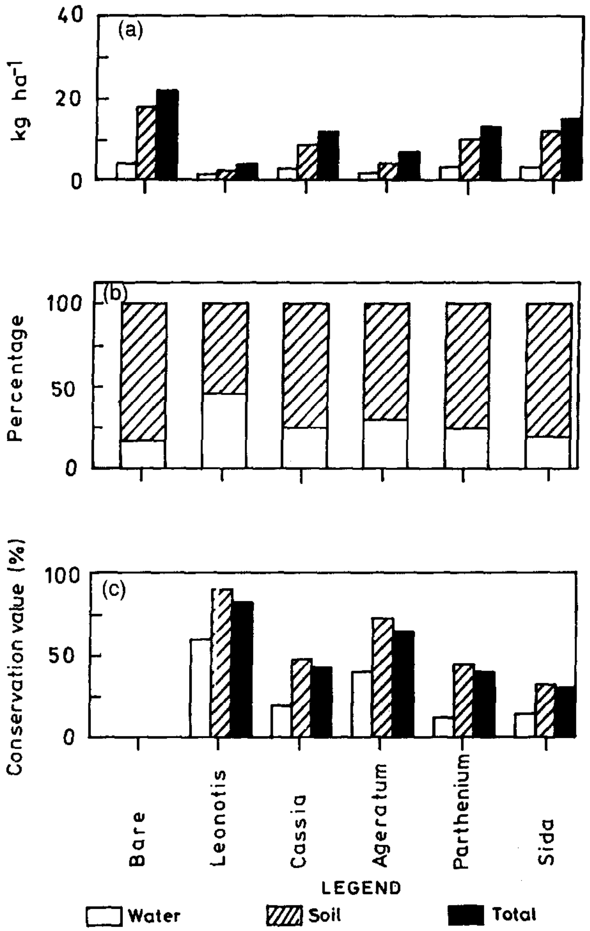

Fig. 1. (a) Organic-C movement, (b) percent share of water and soil in its movement, and (c) consevation value of different plant species in response to 42.5 mm simulated rainfall at 30 cm h^{-1} rain intensity.

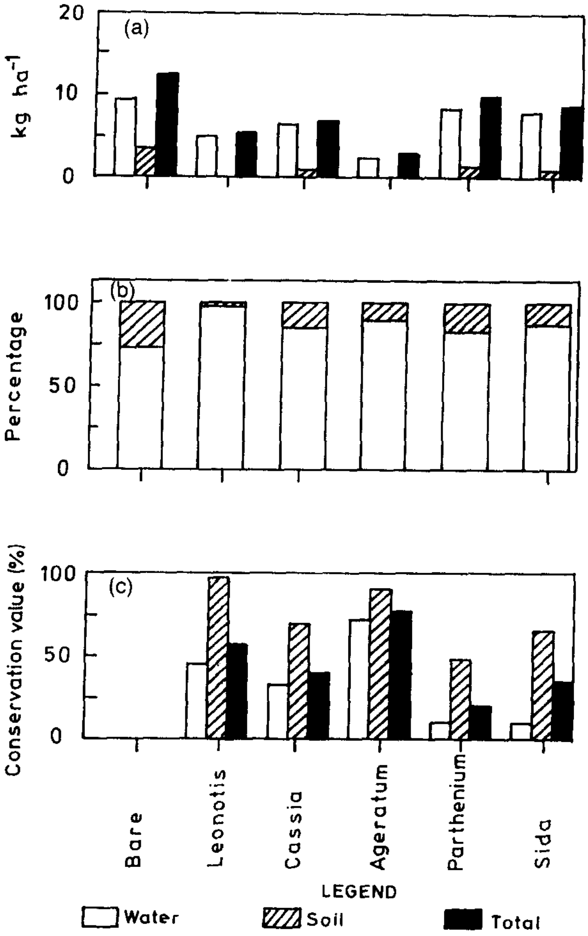

Fig. 2. (a) Potassium movement, (b) percent share of water and soil in its movement, and (c) conservation value of five different plant species in response to 42.5 mm simulated rainfall at 30 cm h^{-1} rain intensity.

for Na and K was fairly high because of the fact that the two cations are very feebly adsorbed to clay particles and highly mobile in soil column (Daji, 1985). Nutrient loss for different nutrients through runoff in relation to the given amount of nutrients input through rainfall was in the order of: organic-C > Ca > K > Na.

3.3. Mode of nutrient transport

The major fraction of organic-C transport down the slope from the six studied stands (five vegetated and one bare) was in particulate form. Percent contribution of particulate fraction in total movement (Fig. 1) varied from 56% (*Leonotis*) to 83% (bare). This mainly attributed to the insoluble nature of organic-C in water (Daji, 1985). The greater proportion of clay generally present in eroded sediment helped higher adsorption of the

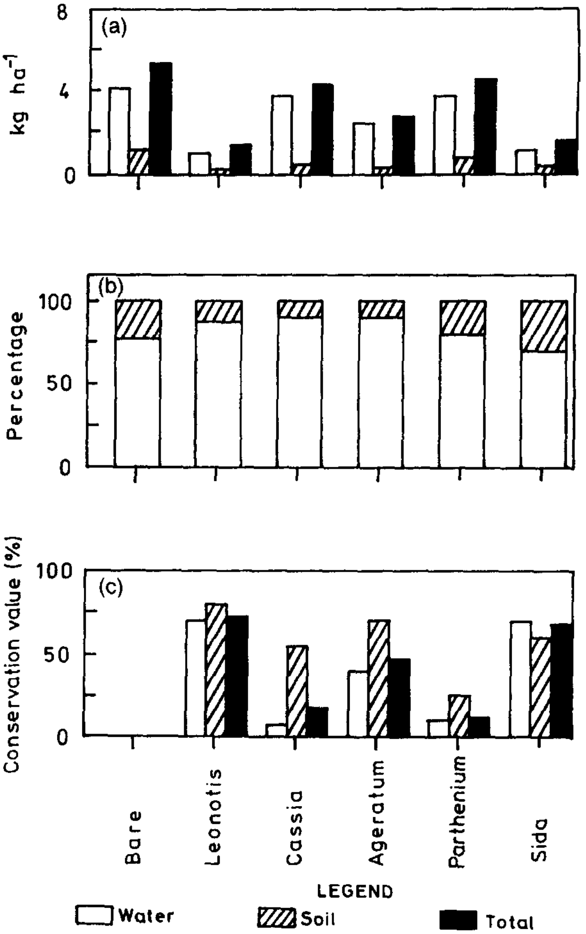

Fig. 3. (a) Calcium movement, (b) percent share of water and soil in its movement, and (c) conseervation value of different plant species in response to 42.5 mm simulated rainfall at 30 cm h^{-1} rain intensity.

nutrient to changed surface (Oades, 1988). Also, this organic matter may get protected in the pores of micro-aggregates where it is protected from microbial attack (Gregorich et al., 1989). It leads to higher loss values of nutrients in particulate form and not in soluble form. Similar results were also observed by Schreiber and McGregor (1979) during their study on transport of organic carbon in erosion from small watersheds in North Mississippi (USA) where they reported that runoff from conventional tilled corn crop had about 90% of the total carbon in the particulate phase. Lowrance and Williams (1988), during their study on carbon movement from agricultural field under different management practices, found that particulate-C accounted for 88.9 to 94.4% of the total-C in runoff. However, the movement of exchangeable bases down the slope was mainly in soluble form. In the case of Na, it accounted for 74% (bare) to 98% (*Leonotis*), for K 70% (*Sida*) to 89% (*Cassia* and *Ageratum*), and in the case of Ca

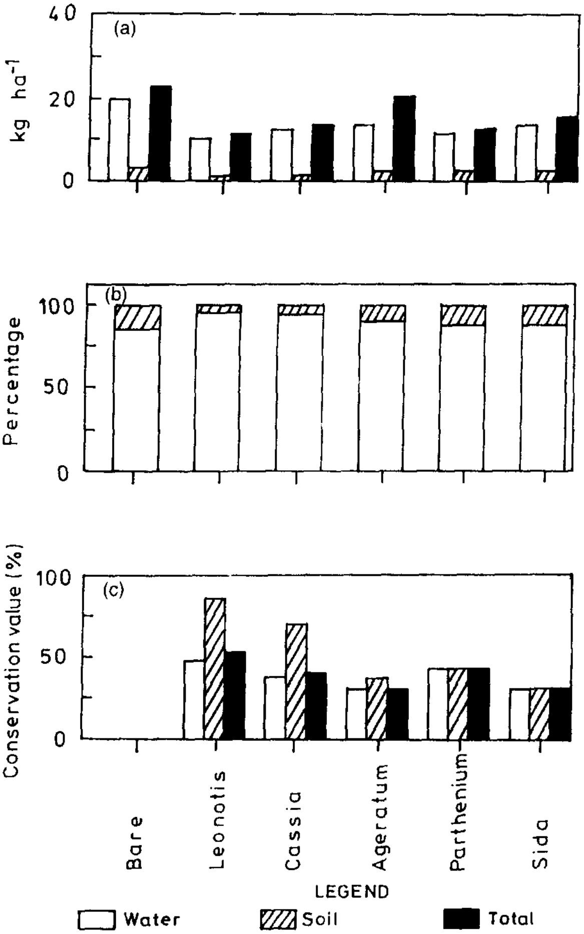

Fig. 4. (a) Sodium movement, (b) percent share of water and soil in its movement, and (c) conservation value of five different plant species in response to 42.5 mm simulated rainfall at 30 cm h^{-1} rain intensity.

from 87% (bare) to 96% (*Leonotis*) of the total load in runoff of the respective nutrients (Figs. 2–4). This may be attributed to greater availability of nutrients in soil solution.

3.4. Nutrient conservation

White and Williams (1977) reported that nutrient transport in surface runoff was significantly related to the amounts of water and soil loss and that 50–70% variation in the data was due to these factors alone. Unexplained variation was partially attributed to cover, growth and stage of decomposition resulting in difference in the leachate from different stands.

For organic-C, *Leonotis* showed maximum overall conservation value (83%) which resulted from minimum loss value (3.6 kg ha^{-1}) of the nutrients across the slope (Fig.

Table 2

Nutrient concentrations (±S.E.) in runoff water and eroded sediments from different vegetation and bare stands in response to 42.5 mm simulated rainfall at 30 cm h^{-1}

Variables	Bare	*Leonotis*	*Cassia*	*Ageratum*	*Parthenium*	*Sida*
Organic carbon						
Water borne (mg l^{-1})	11.5±0.75	9.9±0.58	14.3±0.75	12.1±0.58	13.2±0.58	12.1±0.52
Sediment bound (%)	0.3±0.02	0.2±0.01	0.5±0.02	0.2±0.01	0.3±0.01	0.3±0.03
Flow weighted (mg l^{-1})	67.3	21.5	58.3	40.3	53.7	57.7
Exchangeable sodium						
Water borne (mg l^{-1})	29±1.5	33±2.0	30±2.6	14±0.88	35±1.4	31±1.4
Sediment bound (μg g^{-1})	554±7.5	115±2.6	548±4.9	140±3.7	537±6.6	279±2.9
Flow weighted (mg l^{-1})	39.3	33.7	34.8	16.0	42.2	35.2
Exchangeable potassium						
Water borne (mg l^{-1})	13±1.4	8.4±0.2	19±0.6	14±1.4	16±0.9	4.8±0.1
Sediment bound (μg g^{-1})	196±4.3	266±4.0	280±2.6	140±3.7	271±5.2	116±3.2
Flow weighted (mg l^{-1})	16.6	9.9	21.5	16.0	19.6	6.6
Exchangeable calcium						
Water borne (mg l^{-1})	19± 0.87	62±1.73	57±1.73	74± 2.9	45± 1.73	52± 1.15
Sediment bound (μg g^{-1})	468±11.5	412±6. 4	464±6.9	687±13.2	485±10.4	502±13.8
Flow weighted (mg l^{-1})	27.7	64.4	23.0	83.7	51.5	59.6

Flow weighted: (water borne + sediment bound) per litre.

1). Its movement down from the slope was 1.4 (*Sida*) to 6 (*Leonotis*) times lower than the movement from the bare stand. Minimum organic-C movement in particulate form (2 kg ha^{-1}) and in soluble form (1.6 kg ha^{-1}) was also from *Leonotis* stand. Consequently, it showed a maximum conservation value of 89% and 59% in two forms, respectively. This high C_v is caused by low concentration of the nutrients in particulate form (0.2%) and in soluble form (9.1 mg l^{-1}) along with low water runoff volume (16 mm) as well as soil loss quantity (93 g m^{-2}) from the stand. Low concentrations of nutrients in runoff water (Table 2) may be attributed to the insoluble nature of organic-C in water (Daji, 1985), as well as the poor interaction between the following raindrops and the surface soil particle due to better ground cover conditions (Table 1). Low concentrations of particulate forms are largely due to fast mineralization of nutrients under a better moisture regime (12%) of the stand. As a result, there was low nutrient availability for transport adsorbed to soil particles. The low quantity of water runoff and soil loss from the stand is due to the better soil binding property of the extensive root (4.67×10^5 m^{-2}) of *Leonotis* (Table 1) along with efficient reduction in raindrop energy by littermass (51 g m^{-2}) present on soil surface. The multi-layered (3–6 layered) canopy cover (98%), whose cushioning effect was further increased when the plants became lodged under the initial impact of simulated rain, protected the ground more closely. Reduction in sheer stress of runoff by the small diversion and detention reservoirs formed by plant residues (Foster and Meyer, 1977) further help to reduce raindrop energy. This led to increased flow depth on the plot surface which acted as a protective cushion against raindrop impact and caused high infiltration, low water runoff

Table 3

Stepwise multiple regression equation relating fine root, canopy, litter and soil antecedent moisture content with runoff variables in relation to selected riparian weeds (the squared multiple correlation coefficient (R^2) are also shown)

Variable	Equation	R^2
Water movement	32.5 − 3.32 fr	0.96^{*}
Water conservation value	− 1.5 + 10.36 fr	0.96^{*}
Soil movement	589.3 − 96.74 fr	0.90^{*}
	588.9 − 108.0 fr + 1.5 amc	0.95
Soil conservation value	0.66 + 16.2 fr	0.90^{*}
	0.71 + 18.1 fr − 0.26 amc	0.95^{*}
Organic carbon		
Total movement	22.4 − 3.51 fr	0.92^{*}
	21.1 − 4.09 fr + 0.04 lt	0.97^{***}
	21.6 − 3.43 fr − 0.05 cy + 0.05 lt	0.99^{**}
Overall conservation value	− 3.50 + 16.14 fr	0.92^{*}
	2.60 + 18.83 fr − 0.17 lt	0.98^{***}
	0.57 + 15.84 fr + 0.22 cy − 0.23 lt	0.99^{**}
Movement through soil	18.5 − 3.13 fr	0.94^{*}
	17.52 − 3.58 fr + 0.03 lt	0.98^{***}
	17.89 − 3.03 fr − 0.04 cy + 0.03 lt	0.99^{**}
Sediment bound conservation value	− 3.21 + 17.47 fr	0.94^{*}
	2.59 + 20.03 fr − 0.17 lt	0.98^{***}
	0.59 + 17.08 fr + 0.23 cy − 0.22 lt	0.99^{**}
Movement through water	3.90 − 0.38 fr	0.74^{**}
	3.59 − 0.52 fr + 0.01 lt	0.94^{**}
Water borne conservation value	0.72 + 10.51 fr	0.72^{**}
	3.01 + 14.52 fr − 0.26 lt	0.94^{**}
Sodium		
Total movement	12.96 − 1.75 fr	0.74^{**}
Overall conservation value	− 3.95 + 14.12 fr	0.74^{**}
Movement through soil	3.03 − 0.60 fr	0.83^{*}
Sediment bound conservation value	7.2 + 18.70 fr	0.83
Movement through water	N.S.	
Water borne conservation value	N.S.	
Calcium		
Total movement	23.06 − 0.11 cy	0.90^{*}
Overall conservation value	− 1.17 + 0.49 cy	0.90^{*}
Movement through soil	2.78 − 0.42 fr	0.71^{**}
Sediment bound conservation value	0.65 + 15.05 fr	0.71^{**}
Movement through water	19.08 − 0.08 cy	0.90^{*}
Water borne conservation value	− 0.41 + 0.48 cy	0.90^{*}
Potassium		
Total movement	5.50 − 0.03 cy	0.58^{***}
Overall conservation value	− 1.90 + 0.62 cy	0.58^{***}
Movement through soil	1.17 − 0.01 cy	0.71^{**}
Sediment bound conservation value	− 1.54 + 0.73 cy	0.71^{**}
Movement through water	N.S.	
Water borne conservation value	N.S.	

Table 4
Water runoff and soil erosion from different vegetation and bare stands and their conservation values (%) in response to 42.5 mm simulated rainfall at 30 cm h^{-1}

	Bare	*Leonotis*	*Cassia*	*Ageratum*	*Parthenium*	*Sida*
Water movement (mm)	32 ± 0.7	16 ± 0.9	21 ± 0.8	18 ± 0.6	24 ± 0.9	26 ± 1.3
Water conservation value (%)	0	50 ± 1.8	34 ± 1.1	44 ± 2.9	25 ± 1.4	19 ± 2.4
Soil movement (g m^{-2})	594 ± 5.2	93 ± 2.7	186 ± 4.6	254 ± 4.6	324 ± 4.4	395 ± 4.7
Soil conservation value (%)	0	84 ± 0.3	69 ± 0.58	57 ± 0.5	45 ± 0.33	33 ± 0.33

Values are means ± S.E.

and low soil loss quantity (Kumar et al., 1992b). On the other hand, maximum water runoff (32 mm) and soil loss (594 g m^{-2}) was observed from the bare plot. This is attributed to intense splashing and beating effects on the surface soil in the absence of vegetation that caused finer particles to come to the surface resulting in clogging and sealing of pore spaces (Romkens et al., 1986) and consequently high runoff values. On performing the stepwise multiple regression equation (Table 3) taking terminal rootlet number, littermass, canopy cover and soil moisture as independent variables, the role of roots in retarding runoff processes is amply reflected. Roots were found to explain 92% ($p < 0.01$) of the variation in total organic-C movement and its overall conservation value. Roots also explained 96% ($p < 0.01$) of the variation in soluble organic-C movement and its C_v and 90% ($p < 0.05$) for particulate organic-C movement and its C_v. Littermass present on surface soil was the second most important factor in runoff processes, explaining up to 22% ($p < 0.05$) of the variation in the conservation of soluble organic-C.

Minimum movement of Na (2.8 kg ha^{-1}) down the slope was from *Ageratum* stand; consequently it had a maximum overall conservation value (78%). Na loss from different vegetated stands was 1.2 (*Parthenium*) to 4.5 times (*Ageratum*) lower than the loss from the bare stand. In the case of soluble fraction, although water runoff was minimum from *Leonotis*, *Ageratum* showed a maximum conservation value largely because of the low concentration (14 mg l^{-1}) of Na in the runoff water from the stand which caused minimum loss of nutrient and consequently higher C_v (73%). This may be attributed to a rapid uptake of the nutrient by plants since nutrients held by negatively charged clay and organic particles are readily available for uptake by the plants (Conyers and McLean, 1969). However, the particulate fraction maximum C_v (97%) was observed in the case of *Leonotis* which is determined by both the low quantity of soil and the low concentration (0.11 $\mu g\ g^{-1}$) of Na in the eroded soil. This finding is clear from the data given in Table 3 where 74% ($p < 0.05$) of the variation in total nutrient movement and its overall C_v and 83% ($p < 0.01$) in case of movement of

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Notes to table 3:
* $p < 0.01$; ** $p < 0.05$; *** N.S.
fr = fine root; cy = canopy; lt = litter; amc = antecedent soil moisture content.
Total movement = Movement of nutrient through sediment and water together.
Overall conservation value = water borne + sediment bound taken together.

particulate fraction and its C_v, are explained by roots. For soluble fraction the relationship was insignificant.

Leonotis had maximum C_v (Fig. 3) for the particulate fraction of K due to minimum loss value of the nutrient from the stand which in turn was determined mainly by the low (Table 4) soil loss quantity (93 g m^{-2}) as compared to other vegetated stands. But in case of soluble K, maximum C_v was observed for *Sida*, although water runoff was minimum from the *Leonotis* stand. Evidently, the K loss in soluble form was determined largely by the low concentration (4.8 mg l^{-1}) of the nutrient (Table 2) and not by the runoff volume. This may be due to high leaching losses of the nutrient since it is very feebly adsorbed to clay micelle. Leaching has been attributed as the principal mechanism of K loss to hydrologic cycle (Duvigneaud and de Emet Denaeyer, 1970). Maximum overall K – C_v (71%) was obtained for *Leonotis*. From Table 3, it is evident that canopy cover played a major role (71%; $p < 0.05$) in regulating the movement of particulate fraction across the riparian slope and its conservation by the vegetation. Canopy cover also played a greater role (58%) in regulating runoff processes for total loss of K and its overall C_v.

Again for Ca, *Leonotis* had maximum overall C_v (52%) followed by *Parthenium* (43%). Loss of the nutrient from different vegetated stands was 1.4 (*Sida*) to 2.1 (*Leonotis*) times lower than that from the bare stand (Fig. 4). It resulted mainly from the low quantity of soil movement and runoff water from the *Leonotis* stand accompanied with a low concentration (Table 2) of the nutrient in particulate form (412 $\mu g\ g^{-1}$). This may be attributed to high wash of nutrient in runoff water (62 mg l^{-1}), leaving small fractions for transport in particulate form. From the stepwise multiple regression equation (Table 3), it is evident that canopy cover explained 90% ($p < 0.01$) variation for soluble and overall C_v. However, for particulate fraction, roots played a greater role than the canopy in explaining 71% ($p < 0.05$) of the variability in its movement and conservation value.

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