

## Resource conservation, productivity, soil fertility and economics under rain-fed Pearl millet at different slopes of reclaimed Yamuna ravine

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### ABSTRACT

Soil erosion poses a major threat to the sustainability of rain-fed agriculture on reclaimed ravine lands. A long-term field study (2010–2016) was conducted to quantify the effects of runoff and soil loss on soil fertility, productivity, and economic viability of pearl millet mono-cropping on reclaimed Yamuna ravines. Standard runoff plots (38.88 m<sup>2</sup>) were established on 0.5, 1.0, 2.0, and 3.0% slopes and equipped with multi-slot divisors and runoff collection systems. The study period received an average annual rainfall of 529.8 mm (range: 172.2–797.2 mm), resulting in large inter-annual variability; no runoff, soil loss, or crop yield occurred during the drought years 2014 and 2015. Mean annual runoff and soil loss increased 4.26- and 5.45-fold, respectively, as slope increased from 0.5% to 3.0%. Correspondingly, pearl millet grain and stover yields declined by 37.1% and 31.1%, leading to sharp reductions in gross return, net return, and benefit–cost ratio. Significant depletion of soil organic carbon, available phosphorus, and potassium was observed at 2 and 3% slopes, along with increases in soil pH and electrical conductivity. The results indicate that pearl millet mono-cropping on steeper reclaimed ravine slopes is increasingly erosion-prone, economically risky, and unsustainable without effective soil and water conservation measures.

**Key words:** Economics, runoff, soil loss, soil fertility, reclaimed ravines

### INTRODUCTION

The semi-arid Agra region, characterized by sandy loam soils with low organic carbon (0.18–0.20%), erratic rainfall, high potential evapotranspiration, and severe water erosion, is dominated by traditional rain-fed mono-cropping of pearl millet on the U-shaped Yamuna ravine lands. During normal rainfall years, farmers typically apply about 100 kg urea ha<sup>-1</sup> in two split top dressings, whereas fertilizer application is often avoided under uncertain rainfall due to high risk of crop failure and poor economic returns. Across-slope furrowing (*gurr*) between pearl millet rows (45–60 cm) is occasionally practiced to control weeds and enhance in situ moisture conservation, thereby reducing runoff and soil loss (Yadav *et al.*, 2004). However, cultivation on sloping ravine beds without adherence to recommended agronomic practices may accelerate soil degradation and undermine long-term productivity (Zhao *et al.*, 2012). Despite the inherently low fertility of the light-textured ravine soils, the long-term impacts of continuous pearl millet cultivation on soil productivity remain largely unquantified.

Moreover, conventional approaches that simulate erosion by removing fixed depths of topsoil inadequately reflect field conditions, as natural erosion is a gradual process accompanied by residue recycling and progressive changes in soil structure and fertility. Although erosion-induced declines in agricultural productivity are well documented (Kraaijvanger and Veldkamp, 2015; Erol *et al.*, 2015; Musinguzi *et al.*, 2015), empirical evidence from semi-arid, degraded Indian ravine ecosystems is scarce.

Therefore, the present study was conducted to quantify the relationship between soil erosion and pearl millet productivity, with particular emphasis on soil fertility dynamics and economic feasibility under the rain-fed agro-ecosystem of reclaimed Yamuna ravines.

### MATERIAL AND METHODS

The study was conducted on standard runoff plots measuring 1.83 × 21.25 m (38.88 m<sup>2</sup>) laid at four land slopes, namely 0.5, 1.0, 2.0, and 3.0%. Each plot was fitted with a multi-slot divisor (number of slots to be specified), and runoff from one representative slot was

routed into three interconnected collection tanks with dead storage capacities of  $1.0 \times 0.9 \times 0.6 \text{ m}^3$ ,  $1.0 \times 0.9 \times 0.5 \text{ m}^3$ , and  $1.0 \times 0.9 \times 0.5 \text{ m}^3$ , respectively. The experiment was carried out at the Research Farm of the ICAR–Indian Institute of Soil and Water Conservation, Research Centre, Chhalesar, Agra, India ( $27^{\circ}10' \text{ N}$ ,  $78^{\circ}02' \text{ E}$ ; 168 m above mean sea level). The experimental soil was a reclaimed, shallow Yamuna ravine soil with sandy loam texture, and the selected slopes were representative of the prevailing slope conditions of shallow ravines in the region.

Pearl millet (*Pennisetum glaucum* L.) was grown as a rain-fed crop during the rainy seasons from 2010 to 2016. The crop was sown across the slope on contour lines at 45 cm row spacing with the onset of the monsoon, generally during the first week of July ( $27^{\text{th}}$ – $28^{\text{th}}$  standard meteorological week). No organic manure or basal fertilizers were applied; however, nitrogen was supplied through top dressing of  $100 \text{ kg urea ha}^{-1}$  in two equal splits at the knee-high and flowering stages. The crop was harvested in the second week of September ( $37^{\text{th}}$  standard meteorological week). Soil samples were collected from 0–15 and 15–30 cm depths before sowing in 2010 and after harvest in 2016 and analyzed for pH, electrical conductivity (EC), organic carbon, and available N, P, and K using standard analytical procedures. During the crop period, the site received an average annual rainfall of 529.8 mm, ranging from 172.2 mm in 2015 to 797.2 mm in 2016. The average number of rainy days was 23, varying from 14 in 2014 to 32 in 2012. The average maximum daily rainfall was 80.2 mm, with a range of 26.0 mm in 2011 to 133.8 mm in 2016.

Runoff from each plot was estimated by multiplying the runoff volume collected from a single slot by the total number of slots and expressed as  $\text{ha mm}$  for each runoff-generating event. Seasonal runoff was calculated by summing runoff from all such events during the crop period. Soil loss was determined by collecting three 100-ml subsamples from the thoroughly stirred runoff water for each event, oven drying, and weighing the sediment. The average sediment concentration ( $\text{g } 100 \text{ ml}^{-1}$ ) was multiplied by total runoff volume to estimate soil loss ( $\text{kg ha}^{-1}$ ) for each event, and seasonal soil loss was obtained by summation.

Grain and stover yields were estimated by harvesting  $1 \text{ m}^2$  quadrats from the upper, middle, and lower sections of each plot. Harvested biomass was sun-dried, weighed, threshed, and cleaned to determine grain yield, which was expressed in  $\text{g m}^{-2}$  and converted to  $\text{kg ha}^{-1}$ . Stover yield was calculated by subtracting grain yield from total biological yield. Economic analysis was performed annually using prevailing market prices of inputs, labour, and grain and stover outputs, standardized to 2016 price levels.

## RESULTS AND DISCUSSION

### Runoff and soil loss

The mean data (Table 1) clearly indicate that both runoff and soil loss increased with increasing land slope. Runoff increased from 17.41 mm at 0.5% slope to 74.10 mm at 3.0% slope, while soil loss increased from  $409.6 \text{ kg ha}^{-1}$  to  $2231.4 \text{ kg ha}^{-1}$  over the same slope gradient. This trend, however, was not observed during the drought years of 2014 and 2015, when no runoff or soil loss occurred across all slopes (Table 1; Fig. 1). Inter-annual variations in runoff and soil loss at a given slope were primarily governed by differences in total rainfall, rainfall intensity, number of runoff-generating events, crop cover and growth stage at the time of rainfall, degree of soil saturation, and slope-dependent variations in soil infiltration capacity resulting from differences in soil structure, aggregation, and physical condition. Among the study years, minimum runoff (19.1 mm at 0.5% to 69.2 mm at 3.0%) and soil loss ( $465 \text{ kg ha}^{-1}$  at 0.5% and  $1957 \text{ kg ha}^{-1}$  at 3.0%) were recorded in 2011, coinciding with the lowest rainfall during the crop period (352.5 mm received over 23 rainy days; Table 4).

Maximum runoff at 0.5 and 1.0% slopes (30.0 and 59.3 mm, respectively) occurred in 2012, when 719.4 mm rainfall was received over 32 events. In contrast, the highest runoff at 2.0 and 3.0% slopes (34.4 and 125.0 mm, respectively) was observed in 2010, despite a lower seasonal rainfall of 456.6 mm received over 26 days. This highlights the critical role of antecedent soil moisture conditions, surface or plough-sole saturation, rainfall intensity, and crop canopy development in regulating runoff

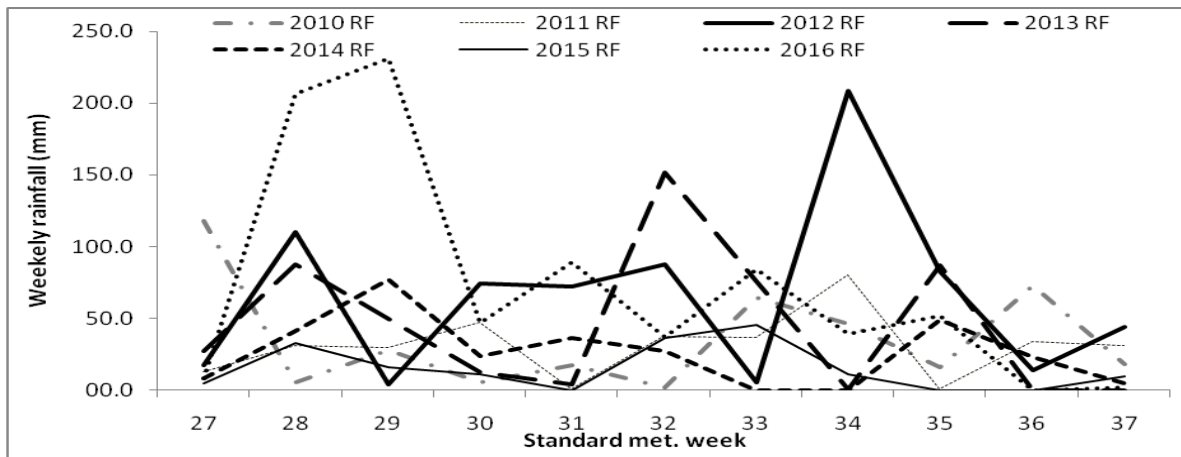


Fig.1: Rainfall (mm) during different standard met weeks during crop period

generation and in situ rainwater conservation. Weekly rainfall distribution further revealed that a high-intensity rainfall event of 117.8 mm during the early crop stage in 2010 resulted in elevated runoff and soil loss (Fig. 1). Minimum soil loss at 0.5 and 1.0% slopes (422 and 950 kg ha<sup>-1</sup>, respectively) was recorded in 2010, whereas at 2.0 and 3.0% slopes the lowest soil loss (1445 and 1957 kg ha<sup>-1</sup>, respectively)

occurred in 2011, corresponding with fewer rainfall events exceeding 25 mm h<sup>-1</sup>. Conversely, maximum soil loss at 0.5 and 1.0% slopes (709 and 1607 kg ha<sup>-1</sup>, respectively) was recorded in 2012, while at 2.0 and 3.0% slopes the highest soil loss (3355 and 4537 kg ha<sup>-1</sup>, respectively) occurred in 2016, associated with 797.2 mm rainfall over 29 days and 11 high-intensity (>25 mm h<sup>-1</sup>) rainfall events.

Table 1: Runoff (mm) and soil loss (kg ha<sup>-1</sup>) under rain-fed pearl millet at varying land slopes of Yamuna ravine

Land slope	2010	2011	2012	2013	2014	2015	2016	Total	Average
Runoff									
0.5%	26.0	19.1	30.0	26.0	-	-	20.8	121.87	17.41
1.0%	59.0	35.4	59.3	50.7	-	-	41.1	245.49	35.07
2.0%	84.4	49.9	81.5	74.4	-	-	78.1	368.30	52.61
3.0%	125.0	69.2	118.8	97.0	-	-	108.7	518.7	74.10
Mean	73.6	43.9	72.4	62.0	-	-	62.2	-	44.8
Soil loss									
0.5%	422	465	709	604	-	-	667	2867	409.6
1.0%	950	1003	1607	1466	-	-	1370	6396	913.7
2.0%	1567	1445	2785	2178	-	-	3355	13508	1929.7
3.0%	2328	1957	3678	3120	-	-	4537	15620	2231.4
Mean	1317	1218	2195	1842	-	-	2482	-	1371

### Grain and stover yield

Data (Table 2) indicate that out of different years, 2014 and 2015 were beset with crop failures due to a low total rainfall (<300 mm) and least number of rainy days (14-15) which hatched droughts of variable duration and intensity (Table 4 and Fig. 1) The year 2015 was beset with two droughts of 18 days duration (in 36<sup>th</sup> and 37<sup>th</sup> met. week) while pearl millet crop faced two droughts of 15 and 16 days duration in 2014 (33<sup>rd</sup> and 34<sup>th</sup> met.

week). Average grain and stover yield of pearl millet registered a decreasing trend on increase in land slope from 0.5% (1684 and 4794 kg ha<sup>-1</sup>, respectively) to 3% (1059 and 3305 kg ha<sup>-1</sup>, respectively) (Table 2). This can be ascribed to less runoff or more *in situ* conservation of rain water in soil at less sloping land higher runoff, soil and nutrient loss and less conservation of rainwater *in situ* in soil at higher land slopes. Thus, pearl millet cropping gradually becomes unsustainable and risky with increase in land slope on reclaimed Yamuna ravines due to

Table 2: Grain and stover yield of rain-fed pearl millet ( $\text{kg ha}^{-1}$ ) at varying slopes of Yamuna ravine

Land slope	Grain yield								Total	Average
	2010	2011	2012	2013	2014	2015	2016			
0.5%	2400	2484	2558	2574	-	-	1772	11788	1684	
1.0%	2100	2136	2228	2240	-	-	1431	10135	1448	
2.0%	1800	1962	1928	2132	-	-	1163	8985	1284	
3.0%	1600	1552	1603	1685	-	-	974	7414	1059	
Mean	1975	2034	2079	2158	-	-	1335	-	1369	
	Stover yield									
0.5%	7406	7426	7546	7594	-	-	3589	33561	4794	
1.0%	6069	5551	5589	5780	-	-	4639	27628	3947	
2.0%	5374	5352	5456	5863	-	-	3772	25817	3688	
3.0%	3520	5129	5236	5392	-	-	3858	23135	3305	
Mean	5592	5865	5957	6157	-	-	3965	-	3934	

higher runoff and soil and nutrient loss (Table 1, 2 and 4). It is established that rate of crop yield reduction increases exponentially with level of soil erosion on account of variations in rooting depth limitations, deterioration of soil structure, decrease in plant available water and

nutrient reserves in soil and decrease in soil organic matter level (Zhao *et al.*, 2012, Lal and Moldenhauer, 1987). Further, when rainfall is not adequate during critical stages of plant development, soil moisture storage becomes a yield determine factor (Miller *et al.*, 1985).

Table 3: Average gross return, net return and benefit: cost ratio under rain-fed pearl millet at varying slopes of Yamuna ravine at prevailing market price of 2016 (Average 2010-16)

Land slope	Gross return ( $\text{Rs ha}^{-1}$ )	Net return ( $\text{Rs ha}^{-1}$ )	Benefit: cost ratio
0.5%	34135	22544	2.94
1.0%	29089	17498	2.51
2.0%	26076	14485	2.25
3.0%	19784	10311	1.89
Mean	27801	16210	2.40

Pearl millet grain  $\text{Rs } 1600 \text{ q}^{-1}$  and stover  $\text{Rs } 150 \text{ q}^{-1}$ . Cost of cultivation (at 2016 prices)  $\text{Rs } 14877 \text{ ha}^{-1}$  in normal years and  $\text{Rs } 3377 \text{ ha}^{-1}$  under abnormal years/crop failure

### Rainfall, resource conservation and pearl millet yield over and above different slopes

The rainfall trend during crop period depicted a wide variation and high aberration in rainy days (14 in 2014 to 32 in 2012), total rainfall (172.9 mm in 2015 to 797.2 mm in 2016), maximum daily rainfall (26.0 mm in 2011 to 133.8 mm in 2016) and rainfall events exceeding 25 mm daily rain (3 in 2011 to 11 in 2016) (Table 4). Rainfall amount, intensity and interval directly inter-link with favorable or adverseness in rainfall distribution and thereby crop yields due to differences in availability of soil moisture to crop plants, occurrence of droughts and resource conservation (runoff and soil loss). Among different years, 2012 (maximum rainy days 32 and 2<sup>nd</sup> maximum rainfall 719.4 mm) was also beset with 2<sup>nd</sup> highest runoff (72.4 mm), soil loss (2195  $\text{kg ha}^{-1}$ ), grain (2079  $\text{kg ha}^{-1}$ ) and stover (5957  $\text{kg ha}^{-1}$ ) yield of pearl millet (Table 1 and 2 and Fig 1).

The year 2016 having maximum rainfall of 797.2 mm was though beset with the highest soil loss (2482  $\text{kg ha}^{-1}$ ) but it generated near to lowest runoff (62.2 mm) and lowest grain (1335  $\text{kg ha}^{-1}$ ) and stover (3965  $\text{kg ha}^{-1}$ ) yield of pearl millet which can be ascribed to the highest events of daily rainfall exceeding 25 mm (11) that led to maximum soil loss (2482  $\text{kg ha}^{-1}$ ) but runoff depended on degree of un-saturation of soil which is well explained by rainfall interval (Fig. 1 and Table 1). In fact, a weekly rainfall of 206.3 and 230.9 mm during 28<sup>th</sup> and 29<sup>th</sup> standard met. week was recorded in 2016 when crop was in a very early stage (7-10 days) having more exposed soil surface which was not only more conducive to water erosion or soil loss in one side but also sowing and plowing on contours retarded the runoff by virtue of storage of rainwater in furrows and

Table 4: Number of rainy days, total rainfall during crop period (mm) and maximum daily rainfall (mm) during pearl-millet crop

Year	Number of rainy days	Total rainfall during crop period (mm)	Maximum daily rainfall (mm)	Rainfall events >25 mm day <sup>-1</sup>
2010	26	456.6	60.8	6
2011	23	352.5	26.0	3
2012	32	719.4	110.9	10
2013	23	665.9	121.9	09
2014	14	293.4	74.0	04
2015	15	172.9	34.0	02
2016	29	797.2	133.8	11
Average	23	529.8	80.2	6.71

ridge obstacles of furrows variably stopped rain water from going out of field as runoff which created excessive soil moisture that was harmful to crop plants and more plant mortality on other side especially on 0.5 and 1% land slope. This is why lowest pearl millet yield was recorded in 2016. However, the highest grain and stover yield of pearl millet (2158 and 6157 kg ha<sup>-1</sup>, respectively) was recorded in 2013 due to a well distributed rainfall (23 rainy days and 665.9 mm rainfall) (Table 2 and Fig. 1). Thus, runoff registered a different trend reaching to maximum in 2010 (73.6 mm at 456.6 mm rain). The runoff in 2012 (72.4 mm) at a rainfall of 719.4 mm was only slightly lower than 2010 again due to higher degree of un-saturation of soil as revealed by rainfall interval but also due to more ground cover at time of high intensity rain. Minimum soil loss (1218 kg ha<sup>-1</sup>) was

evident in 2011 when rainfall was also minimum (352.5 mm). However, the highest runoff (73.6 mm) was recorded in the year 2010 when rainfall was 2<sup>nd</sup> minimum (456.6 mm in 26 rainy days) due to a high intensity rain of 117.8 mm in 27<sup>th</sup> standard met. week and rainfall one after another in a short span in 33<sup>rd</sup>, 34<sup>th</sup> and 36<sup>th</sup> standard met. weeks (Fig. 1). As such, data conclude that soil loss increased with increasing rainfall and vice versa but runoff did not show a linear relationship with rainfall but it rather depended on intensity of rains, ground cover at time of high intensity rains and degree of un-saturation of soil at time of rainfall. It can be therefore, otherwise concluded that maintenance of sufficient soil moisture for optimum growth and yield throughout the pearl millet growing period was an important factor.

Table 5: Changes in soil properties/fertility at 0-15 and 15-30 cm depth at different slopes under pearl millet crop

Year	Land slope (%)	Soil depth (cm)											
		0-15 cm		15-30 cm		0-15 cm		15-30 cm		0-15 cm		15-30 cm	
		pH		EC (dsm)		Organic carbon (%)		Available N (kg ha <sup>-1</sup> )		Available P (kg ha <sup>-1</sup> )		Available K (kg ha <sup>-1</sup> )	
2010	0.5	8.03	8.13	0.20	0.17	0.23	0.34	125.3	127.5	14.96	14.11	103.3	98.2
	1.0	8.11	8.21	0.21	0.20	0.36	0.25	140.2	117.0	15.41	14.25	112.8	101.7
	2.0	8.16	8.23	0.14	0.14	0.39	0.28	142.2	131.5	17.58	15.62	117.5	105.5
	3.0	8.16	8.25	0.16	0.14	0.41	0.35	123.2	121.0	13.60	12.94	118.5	117.2
Mean		8.12	8.21	0.18	0.16	0.35	0.31	132.73	124.25	15.39	14.23	113.02	105.65
2016	0.5	8.12	8.25	0.23	0.17	0.51	0.37	309.7	270.6	27.10	22.20	241.5	201.30
	1.0	8.11	8.28	0.24	0.20	0.48	0.34	295.1	261.7	26.85	21.52	264.5	226.83
	2.0	8.29	8.39	0.23	0.18	0.22	0.13	174.8	149.3	15.92	14.19	114.33	98.83
	3.0	8.33	8.45	0.25	0.20	0.18	0.13	125.9	108.6	11.32	9.57	67.0	58.67
Mean		8.21	8.34	0.24	0.19	0.35	0.24	226.38	197.55	20.30	16.87	171.83	146.41

### **Soil fertility and properties**

pH and EC recorded at 0-15 and 15-30 cm soil depth registered an increase in 2016 over 2010 at all the land slopes (Table 5). However, pH at 0-15 cm soil depth and EC at 15-30 cm layer at 1% runoff plot recorded exactly same values in 2010 and 2016 even after seven years of experimentation. This otherwise indicates that the concentration of salts at 15-30 cm soil layer at 1% runoff plot was maintained on account of existence of a delicate balance between the leaching of salts and bringing up of salts on soil surface by capillary action through evaporation under high summer temperature. Results further show that soil organic carbon level in 0-15 and 15-30 cm layers registered considerably higher values in 2016 than 2010 at 0.5 and 1% slopes while inverse results were recorded at 2 and 3% land slope. This clearly pin points on adverse effect of high runoff and soil loss at 2 or 3% land slopes which variably removed the valuable soil organic matter from top fertile plough sole depth. The higher soil organic carbon levels in 0-15 and 15-30 cm soil depth in 2016 over 2010 shows a soil organic carbon build up which can be ascribed to lower runoff and soil loss and contribution of more crop roots and traces/left overs at lower grades of slope up to 1% due to high growth and yield of pearl millet

on account of conservation of more rain/residual moisture in soil. Alike soil organic carbon, immobile/semi mobile nutrients like P and K also registered higher values in 2016 over their respective counterparts in 2010 both at 0.5 and 1% slopes. However, N registered higher values both in 0-15 and 15-30 cm soil layers in 2016 over their respective counterparts in 2010 at 0.5, 1.0 and 2.0% land slopes. Results thus advocate that traditional pearl millet cropping at sloping ravine lands should be restricted to 1% slope under existing level of management for sustainable crop yields and maintenance or improvement in soil fertility.

### **Economics**

Results (Table 3) show that traditional cropping of rain-fed pearl millet on sloping lands of Yamuna ravines is economical even at 3% land slope (average net return Rs. 10311 ha<sup>-1</sup> and benefit cost ratio 1.89). However, the average net return and benefit cost ratio registered a decreasing trend with increase in land slope and the highest average net return of Rs. 22544 ha<sup>-1</sup> and a benefit cost ratio of 2.94 was recorded at 0.5% land slope. This economic data sufficiently explain why farmers are growing pearl millet on sloping ravine lands in semi-arid Agra region since decades.

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