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Soil erodibility indices under different land uses in lower Shiwaliks

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Abstract: A field experiment was conducted to evaluate soil erodibility indices in relation to runoff and soil loss in the submontaneous tract (30º 40' to 32º 30' N and 75º 30' to 76º 40' E) of Punjab (India). Study was conducted under natural and simulated rainfall conditions at four locations under four land uses at each location *viz.*, barren, cultivated, grassland and forest land use. Values of dispersion ratio, clay ratio (CR), and modified clay ratio (MCR) were observed to be the highest at Ballowal Saunkhri II, erosion ratio was highest at Saleran, whereas, water stable aggregates (WSA) were highest at Kokowal Majari location. Among different land uses these indices were in the order of barren = cultivated > grassland > forest. However, WSA followed the opposite trend. Higher positive correlation of CR and MCR was observed with soil loss except for WSA index where the values were highly negative. WSA and MCR were observed to be better indices of soil erodibility.

Resumen: Por medio de un experimento de campo se evaluaron índices de erodabilidad del suelo en relación con la escorrentía superficial y la pérdida de suelo en el trecho submontano (30º 40' a 32º 30' N y 75º 30' a 76º 40' E) de Punjab (India). El estudio se realizó en condiciones de precipitación natural y simulada en cuatro localidades y bajo cuatro usos del suelo en cada localidad, a saber: suelo desnudo, uso como campo de cultivo, como pastizal o como bosque. Se observó que los valores de cociente de dispersión, cociente de arcilla (CR), y cociente de arcilla modificado (MCR) alzanzaron sus máximos en Ballowal Saunkhri II, el cociente de erosión tuvo su máximo en Saleran, mientras que los agregados estables de agua (WSA) tuvieron su máximo en la localidad de Kokowal Majari. Entre los diferentes usos del suelo los índices tuvieron el siguiente orden: desnudo = cultivado > pastizal > bosque. No obstante, los WSA mostraron la tendencia opuesta. Se observó una mayor correlación positiva de CR y MCR con la pérdida de suelo excepto para el índice WSA, para el que los valores fueron muy negativos. Se encontró que los WSA y el MCR son mejores índice de erodabilidad del suelo.

Resumo: Uma experimentação de campo foi conduzida para avaliar os índices de erodibilidade do solo em relação ao escorrimento e perda de solo num trecho submontano (30º 40' a 32º 30' N e 75º 30' a 76º 40' E) no Punjab (Índia). O estudo foi conduzido sob condições naturais e de chuva simulada em quatro locais sujeitos a quatro usos do solo em cada local, ou seja, terreno limpo, cultivado, pastagem e floresta. Os valores da razão de dispersão, razão de argila (CR), e razão modificada de argila (MCR) foram observados serem mais altos em Ballowal Saunkhri II, o ratio de erosão foi mais elevado em Saleran, enquanto que os agregados estáveis de água (WSA) foram mais elevados em Kokowal Majari. Entre os diferentes usos do solo o posicionamento destes índices foram: solo nu = cultivado > pastagem > floresta. Contudo, WSA seguiu um tendência oposta. Observou-se uma correlação positiva alta do CR e MCR com a perda de solo excepto para o índice WSA onde os valores foram fortemente negativos. WSA e MCR foram observados serem os melhores índices da erodibilidade do solo.

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Key words: Land use, natural rainfall, runoff, simulated rainfall, soil erodibility, soil loss.

Introduction

Soil erosion by water is a serious problem in the submontaneous tract of Punjab. At present about 0.47 m ha of land in the region is suffering from the problem of soil erosion. This region lies between 30º 40' to 32º 30' N latitude and 75º 30' to 76º 40' E longitude. The region along with the foothills of the Shiwaliks is comprised of undulating terrains and soils are structurally very poor.

Soil erosion depends on the erosivity of the rainfall and erodibility of soil. The soil erodibility depends primarily on the physical characteristics of the soils *viz.*, nature and amount of soil aggregates, organic matter content and particle size distribution. These physical characteristics of soils are much affected by the land use. Soil erodibility can be evaluated by using runoff plots, which is quite expensive, time consuming and is not feasible at all places. It can also be estimated using nomograph developed by Wischmeier *et al.* (1971) but it may not be applicable in many situations (Rejman *et al.* 1999). Another way to estimate soil erodibility is by using various soil erodibility indices based on soil characteristics. Erodibility indices like dispersion ratio (Middleton 1930), clay ratio (Buoyoucos 1935), modified clay ratio (Kumar *et al.* 1995) and erosion ratio (Lugo-Lopez 1969) have been employed by different workers to assess the soil erodibility. However, very little information is available on the erodibility indices for the soils of submontaneous tract of Punjab particularly under different land uses and in relation to runoff and soil loss (Khera & Kahlon 2005). The present study was undertaken to evaluate various soil erodibility indices under different land uses and their relationship with runoff and soil loss.

Materials and methods

The study area, lying between 30º40' to 32º30' latitude and 75º30' to 76º40' longitude belongs to the ecologically fragile agro-economic zone that poses serious land degradation and environmental problems. Field experiment under natural rainfall conditions was conducted at Zonal Research Station for Kandi area at Ballowal Saunkhri, Nawanshahr (Punjab) at two locations differing in soil physical properties (Table 1) and under four land uses *viz.*, barren, cultivated, grass and forest land use with three replications in each. In the case of barren land use, soils, which were left uncultivated because of undulating terrain or because of very poor soil fertility and had more stones, were selected. The vegetation was negligible on these soils. In cultivated land use, maize - wheat crop rotation was being followed and experimentation was done during the months of June to September after removing whatever vegetation was there. In the case of grassland land use, *Cordia dichotoma* (Casma), *Chrysopogas fulvus*, *Eulaliopsis binata* (Bhabbar grass), *Heteropogon contortus* and *Saccharum munja* (kanah) are the prevalent species. In the case of forest land use; *Acacia catechu* (khair), *Dalbergia sisso* (shisham), *Salmalia malabarioum* (simal), *Terminalia bellerica* (Bahera), *Terminalia chebula* (harar) and *Mangifera indica* (mango) are the main tree species. *Jatropha* sp. (jabblota) and *Indigofera* sp. (kothi) are the main shrubs.

Plots measuring 5.0 m x 1.5 m were prepared and the average slope of the plots was kept at 4 %. Plots were cleared from vegetation and were tilled along the slope and bunds were made on all the sides. An outlet made from galvanized iron sheet was fixed to channelize the flow of runoff from plots to the iron containers of 200 litres capacity fixed on the lower end of each plot. After each rainstorm, depth of runoff in drums was measured using meter rod and was converted to runoff volume. Amount of rainfall received during a rainstorm was deducted from the runoff depth before converting it to runoff volume. A representative sample of 2 litres of runoff suspension was taken in PVC containers from each drum after shaking the contents of the drum thoroughly with iron rod and was dried to

Table 1. Basic soil characteristics of experimental sites.

Location	Land use	Sand (%)	Silt (%)	Clay (%)	OC (%)	MWD (mm)	IR (cm h^{-1})	MOR (N cm^{-1})	Db (mg m^{-3})
Ballowal Saunkhri – I	Barren	81	12	8	0.34	0.38	6.5	2.8	1.46
	Cultivated	68	22	11	0.36	0.43	1.6	5.4	1.43
	Grassland	80	12	8	0.41	0.66	7.7	1.3	1.49
	Forest	81	12	8	1.18	0.82	9.2	1.5	1.11
	Mean	77	14	9	0.57	0.57	6.3	2.8	1.37
Ballowal Saunkhri –II	Barren	85	11	4	0.31	0.33	11.4	1.2	1.45
	Cultivated	84	10	6	0.33	0.33	9.8	1.4	1.44
	Grassland	81	13	6	0.57	0.78	8.6	2.3	1.43
	Forest	77	16	8	1.52	0.96	12.4	2.3	1.24
	Mean	82	12	6	0.68	0.60	10.6	1.8	1.39
Kokowal Majari	Barren	42	34	24	0.49	1.48	0.5	4.3	1.48
	Cultivated	41	33	25	0.49	1.59	0.3	4.6	1.37
	Grassland	41	37	22	0.74	1.73	1.2	5.8	1.34
	Forest	42	35	23	1.27	1.75	1.5	6.0	1.30
	Mean	42	35	24	0.75	1.64	0.9	5.2	1.37
Saleran	Barren	84	10	6	0.32	0.84	10.9	1.3	1.46
	Cultivated	83	12	5	0.32	0.91	11.5	1.4	1.44
	Grassland	83	10	7	0.47	1.00	12.7	1.5	1.42
	Forest	82	10	8	1.65	0.98	12.9	1.7	1.43
	Mean	83	10	7	0.69	0.93	12.0	1.5	1.44

OC = Organic carbon, MWD = Mean weight diameter, IR = Infiltration rate, MOR = Modulus of rupture, Db = Bulk density

calculate soil loss. Drums were emptied and cleaned after each rainstorm manually and plots tilled and cultivated again. The observations were recorded for 11 rainstorms during the years 2003 and 2004. The duration of rainstorms varied from 45 to 375 minutes, the amount varied from 14.2 to 96.0 mm and maximum intensity varied from 18.4 to 76.0 mm h^{-1}.

Field experiment was conducted under simulated rainfall conditions at four locations i.e. Ballowal Saunkhri-I, Ballowal Saunkhri-II, Kokowal Majari and Saleran in submontaneous tract of Punjab (India) differing in soil physical properties and under four land uses *viz.*, barren, cultivated, grass and forest land use with three replications in each.

Physical characteristics of soils of four locations under different land uses are presented in Table 1. Coarse sand content was highest at Ballowal Saunkhri-II location (51.4%) followed by Ballowal Saunkhri-I (42.5%), Saleran (40.0%) and Kokowal Majari (9.5%), whereas, fine sand content was highest at Saleran (45.5%) followed by Ballowal Saunkhri-I (34.9%), Kokowal Majari (32.0%) and Ballowal Saunkhri-II (30.2%). Silt and clay contents were the highest at Kokowal Majari (34.9% and 23.6%, respectively) and lowest at Saleran (10.2%) and Ballowal Saunkhri-II (6.0%). At Kokowal Majari, the highest values of modulus of rupture (5.2 N cm^{-2}) were observed which could be attributed to the higher clay content at this location. Among different land uses, forest soils had the lowest bulk density (1.27 mg m^{-3}), which may be ascribed to higher organic carbon content (1.41%) under this land use.

Plots measuring 2.5 m x 1.5 m were prepared and the average slope of the plots was kept at 4 %. Plots were cleared from vegetation and were tilled along the slope and bunds were made on all the sides. An outlet made from galvanized iron sheet was fixed to channelize the flow of runoff from plots to the runoff collecting containers fixed on the lower end in each plot. Micro-sprinkler based rainfall simulator was fabricated and calibrated and the simulated rainfall of 75 mm h^{-1} intensity was applied *in-situ*. Runoff volume was measured after each storm. The containers were emptied and cleaned after each storm. To estimate the soil loss, the representative samples of soil water suspension were taken in plastic bottles of 2 litre capacity after the completion of each run. The suspension was oven-dried to calculate soil loss from the experimental plots. Various soil erodibility indices were calculated (Table 2) and the correlation analysis was carried out to relate these indices with runoff and soil loss.

Results and discussion

Soil erodibility indices

Various soil erodibility indices derived from soil physical properties have been tabulated in Table 3. Among different locations, dispersion ratio (DR) was observed to be the highest for Ballowal Saunkhri-II (0.80) location. Whereas, among different land uses it was the lowest under forest land use (0.62).

The values of clay ratio (CR) and modified clay ratio (MCR) were the highest at Ballowal Saunkhri-II (16.7 and 14.3) and the lowest at Kokowal Majari (3.3 and 3.1), respectively. Erosion ratio (ER) was the highest at Saleran (1.13) whereas at other locations it ranged between 0.54 to 0.97. Among different land uses it was in the order of barren (0.97) > cultivated (0.84) > grassland (0.74) > forest (0.63). Dabral *et al.* (2001) also observed low value of erosion ratio in the forest soils compared to other land uses. The MCRs were higher than CRs, which may be because of inclusion of organic matter in the denominator in case of MCRs. In general, grassland and forest soils had lower values of DR, MCR and ER. Percentage of water stable aggregates > 2 mm (WSA) was the highest at Kokowal Majari followed by Ballowal Saunkhri-I, Ballowal Saunkhri-II and Saleran. Among different land uses, the percentage of WSA was in the order of forest > grassland > cultivated > barren soils.

According to the criterion of Middleton (1930); soils having dispersion ratio > 0.15 and erosion ratio > 0.10 are erodible in nature. So, the soils were found to be highly erodible under all land uses using above criteria. Kukal *et al.* (1993) observed that the soils under forest land use were more stable as compared to the soils under cultivation and they ascribed it to the higher organic carbon content resulting in more stability of soil aggregates. The soils under forest cover had higher water retention, infiltration rate and lower dispersion and erosion ratios. Khera & Kahlon (2005) also observed that forest soils and grassland soils had lower values of dispersion and erosion ratios as compared to bare and arable soils. Bryan (1968) favoured aggregate stability as the most efficient index of soil erodibility. He used the proporation of water stable aggregates > 0.5 mm in the soil as indicator of soil quality. Kukal & Kaur (2003) also observed that content of water stable aggregates was more reliable index of erodibility of soils. Sharma & Bhatia (2003) concluded that both ER and DR are equally good indices of soil erodibility. Whereas, Mukhi (1988) while studying vertisol soils of Karnatka observed that ER was better index of soil erodibility than DR.

Relationship of erodibility indices with runoff and soil loss

Runoff was observed to be negatively correlated with all the indices of soil erodibility.

Table 2. Calculation of various soil erodibility indices.

Erodibility index		Calculation
Dispersion Ratio (DR)	=	[(% silt + % clay) in undispersed soil]/[(% silt + % clay) after dispersion of soil in water]
Clay Ratio (CR)	=	(% sand + % silt) / % clay
Modified Clay Ratio (MCR)	=	(% sand + % silt) / (% clay + % organic matter)
Erosion Ratio (ER)	=	DR / (colloidal content / moisture equivalent ratio)
Water Stable Aggregates (WSA)	=	% of soil aggregates > 2.0 mm after wet sieving

Table 3. Soil erodibility indices at four locations under different land uses.

Land use	Ballowal Saunkhri-I	Ballowal Saunkhri-II	Kokowal Majari	Saleran	Mean
		Dispersion Ratio			
Barren	0.59	0.88	0.56	0.80	0.71
Cultivated	0.56	0.86	0.59	0.78	0.70
Grassland	0.60	0.78	0.59	0.70	0.67
Forest	0.53	0.68	0.57	0.70	0.62
Mean	0.57	0.80	0.58	0.75	
CD (0.05)	Location = 0.02, Land use = 0.02, Location x Land Use = 0.04				
		Clay Ratio			
Barren	12.0	24.0	3.2	16.8	14.0
Cultivated	7.7	15.2	3.0	18.3	11.1
Grassland	11.6	15.9	3.6	13.2	11.1
Forest	11.6	11.6	3.3	10.9	9.4
Mean	10.7	16.7	3.3	14.8	
CD (0.05)	Location = 0.75, Land use = 0.86, Location x Land Use = 1.50				
		Modified Clay Ratio			
Barren	11.1	21.2	3.0	15.3	12.7
Cultivated	7.5	13.9	2.9	16.5	10.2
Grassland	10.6	13.6	3.4	11.8	9.9
Forest	9.2	8.7	3.1	9.6	7.6
Mean	9.6	14.3	3.1	13.3	
CD (0.05)	Location = 0.61, Land use = 0.81, Location x Land Use = 1.22				
		Erosion Ratio			
Barren	0.60	1.58	0.50	1.21	0.97
Cultivated	0.47	0.99	0.48	1.44	0.84
Grassland	0.56	0.80	0.62	1.00	0.74
Forest	0.58	0.50	0.58	0.87	0.63
Mean	0.55	0.97	0.54	1.13	
CD (0.05)	Location = 0.06, Land use = 0.04, Location x Land Use = 0.11				
		WSA (%)			
Barren	2.12	2.09	35.25	3.21	10.67
Cultivated	5.35	3.89	38.63	5.37	13.31
Grassland	14.51	12.92	41.81	10.04	19.82
Forest	18.83	19.11	46.07	16.27	25.07
Mean	10.20	9.50	40.44	8.72	
CD (0.05)	Location = 1.28, Land use = 1.93, Location x Land Use = 3.15				

The correlation coefficient (r) was the highest with CR (-0.84), followed by MCR (-0.81), DR (-0.80), ER (-0.70) and WSA (0.69). All these correlation values were significant at 1% level of significance.

Soil loss on the other hand was observed to be positively correlated with all the erodibility indices except WSA. Correlation coefficient was the highest for MCR (0.78), followed by CR

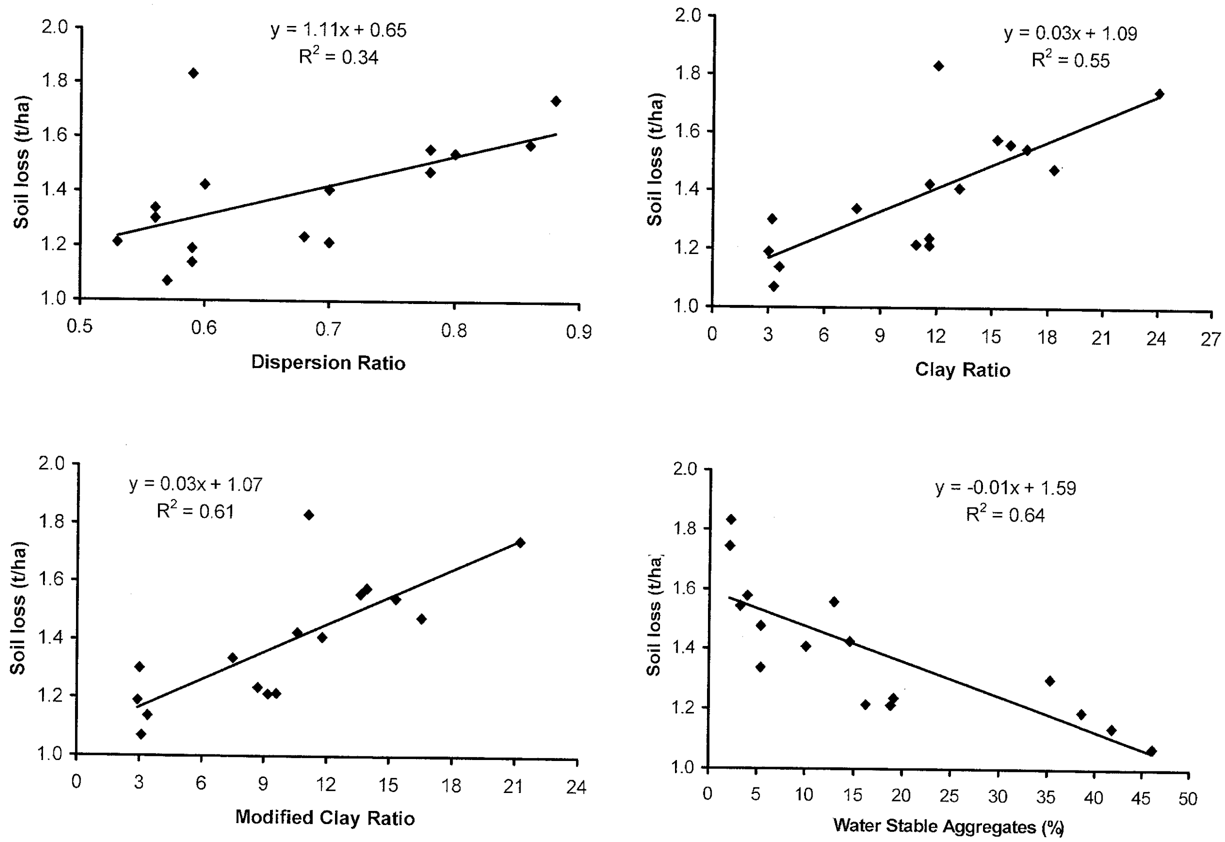

Fig. 1. Relationship of soil loss with various soil erodibility indices.

(0.74), DR (0.59) and ER (0.54). It was negatively but significantly correlated with WSA (-0.80). These correlations were significant at 1% level of signifance for WSA, MCR and CR and at 5% level of significance with DR and ER. Negative correlation of WSA index with soil loss indicates that higher the aggregation, lower is the soil loss.

Kahlon & Khera (2000) observed that DR correlated with soil loss at low rainfall intensities. However, Kukal & Kaur (2003) observed that MWD and GMD were higher in pasture and forest soils and low in cropland and eroded lands but DR and ER were higher in forest and pasture lands. Therefore, DR and ER could not be relied upon while evaluating erodibility of soils. In this study also WSA ($r^2 = 0.64$) and MCR ($r^2 = 0.61$) explained > 60 % variability in soil loss data, whereas, DR ($r^2 = 0.34$) and ER ($r^2 = 0.30$) explained < 35% variability in soil loss data (Fig. 1). But in case of runoff CR ($r^2 = 0.71$), MCR ($r^2 = 0.66$) and DR ($r^2 = 0.65$) explained > 60 % variability in runoff data whereas, WSA ($r^2 = 0.47$) and ER ($r^2 = 0.50$) explained only about 50% variability in runoff data (Fig. 2). It thus appears that WSA and MCR are the better indices of soil erodibility.

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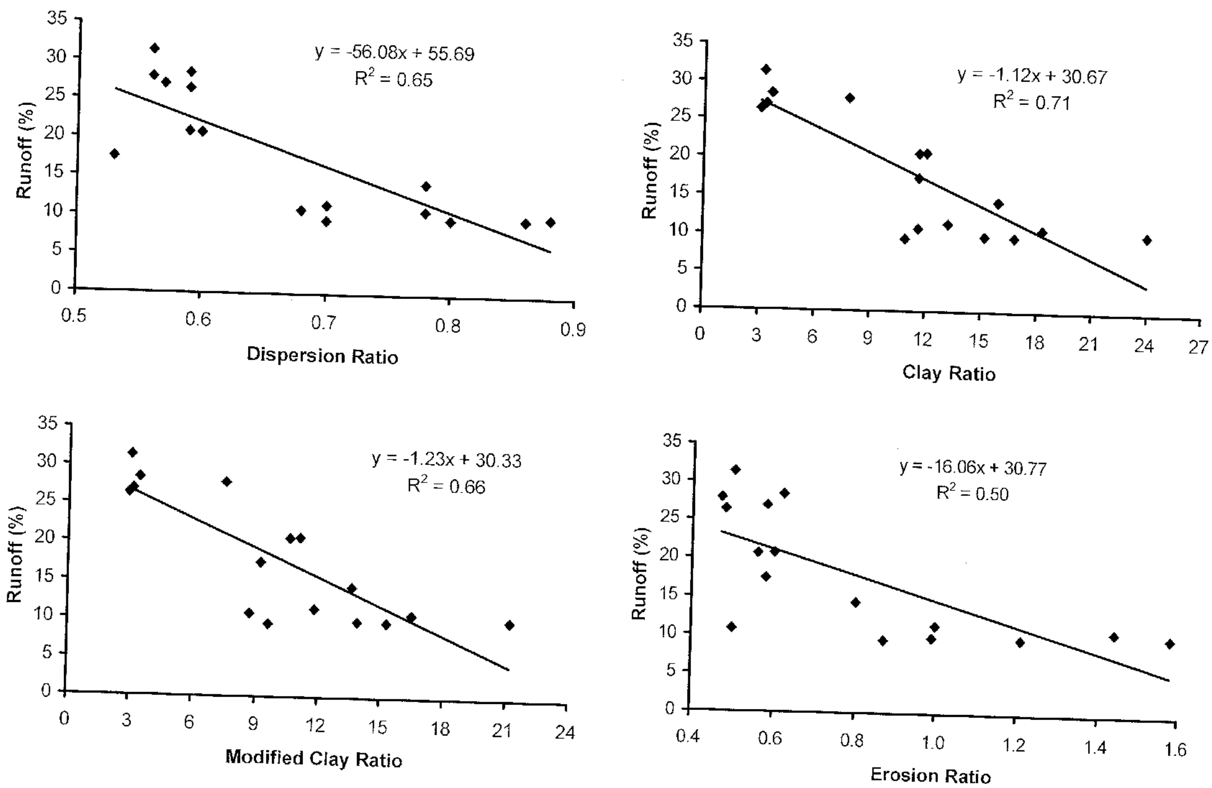

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