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NOTE

CLAY ENRICHMENT RATIO IN SEDIMENT FROM A SMALL AGRICULTURAL WATERSHED IN IRAN

S. AMIN AND SH. RAJAEE[1]

Department of Irrigation, College of Agriculture, Shiraz University, Shiraz, I.R. Iran.

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ABSTRACT

Soil erosion begins with detachment and transportation of soil particles from surface soil layers. In the evaluation of soil erosion, usually the volume or the weight of the soil losses is calculated, but the physical properties of the sediment are less often considered. Due to the selectivity of erosion process the clay particles are much more in the sediments than in the original soils. For estimating the clay enrichment ratio (CER) in the sediment resulting from erosion, a 4.83 ha watershed with a surface soil of silt loam texture was selected in the north-west of the College of Agriculture, Shiraz, Iran. Suspended sediment resulting from eight independent precipitation events was sampled and their particle size distribution was determined. The average CER for the selected rainfall events was 2.3 with a range of 1.5 to 3.1. No significant relation was found between CER and the properties of the precipitation and runoff such as magnitude, average, and maximum rainfall intensities. The following relation between CER and the suspended solid in runoff from the watershed was obtained, $CER=59\ (SS_a)^{-0.465}$, ($R^2=0.91$), where, SS_a is the average sediment concentration in suspension, mg l^{-1}. This equation shows that the CER decreases with an increase in the sediment concentration.

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1. Associate Professor and former Graduate Student, respectively.

Key words: Agricultural watershed, Clay enrichment ratio, Iran, Sediment.

تحقیقات کشاورزی ایران

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نسبت افزایش رس در رسوبات خروجی از حوضه آبخیز کوچک کشاورزی در ایران

سیف اله امین وشاهپوررجایی

به ترتیب دانشیار و دانشجوی پیشین کارشناسی ارشد بخش آبیاری دانشکده کشاورزی دانشگاه شیراز، شیراز، جمهوری اسلامی ایران.

چکیده

فرسایش خاک با کنده شدن و انتقال ذرات خاک از رویه خاک سطحی آغاز می شود. معمولا در ارزیابی این پدیده حجم و وزن خاک فرسایش یافته محاسبه و ارایه می گردد لیکن خصوصیات فیزیکی مواد منتقل شده کمتر مورد توجه قرار می گیرد. با توجه به این که فرسایش خاک پدیده ای است که ذرات خاک را مانند غربال الک نموده، ذرات ریز را منتقل و درشت دانه ها را بر جای می گذارد، بنابراین می توان انتظار داشت که ذرات رس در رسوبات حاصل از فرسایش بیشتر از خاک مادری سطح حوضه آبخیز باشد. برای تخمین CER (غنای ذرات رس در مواد رسوبی) حاصل از فرسایش، حوضه آبخیزی با مساحت ۴/۸۳ هکتار در دانشکده کشاورزی دانشگاه شیراز انتخاب و از رسوبات حاصل از هشت بارندگی منفرد در خلال هر بارندگی نمونه برداری و توزیع ذرات نمونه ها تعیین گردید. میانگین CER

برای بارندگی های مزبور ۲/۳ و محدوده مقادیر آن ها ۱/۵ تا ۳/۱ بود. رابطه معنی داری بین CER و خصوصیات بارندگی مانند مقدار، میانگین و حداکثر شدت بارندگی به دست نیامد. اما رابطه $CER=59(Ss_a)^{-0.465}$ بین CER و SSa ، میانگین مواد معلق در سیلاب (میلی گرم در لیتر) از حوضه آبخیز مورد مطالعه با ضریب تبیین (R^2) ۰/۹۱ به دست آمد. معادله مزبور نشان می دهد که مقدار CER با افزایش فرسایش خاک و اضافه شدن مواد معلق در سیلاب کاهش می یابد. همچنین با داشتن میانگین مواد معلق رسوبات حاصل از فرسایش خاک می توان مقدار رس آن ها را به دست آورد.

INTRODUCTION

In 1980, more than 56,000,000 ha (about one third) of the surface soil layers in Iran have been subjected to water erosion rates of >10 tons ha^{-1} y^{-1} (10). Since erosion is recognized as a selective process (1, 4, 7, 14, 17, 18), when there is enough energy for detachment and transportation of the soil particles, it will selectively carry fine materials and leave the coarse grains as deposited sediment. This selective process applies to all three stages (detachment, transportation, and sedimentation) of soil erosion (4). Sharpley's research (14) in 1980 revealed that the percentage of <0.2 mm particles in the runoff is greater than the <0.2 mm fraction of surface soil layers; thus the runoff is enriched with clay relative to the eroded soil. This leads to the concept of clay enrichment ratio which is the ratio of clay particles in the suspended sediment and the surface layer of the soils of a watershed (CER).

In the evaluation of soil erosion, the total volume of the lost soil is usually calculated, but the physical properties of the detached materials resulting from erosion are less often considered. The washout, transport, and deposition of these eroded materials are influenced by physical properties of the sediment (e.g., particle size distribution, sediment density, etc.) (8, 9, 13, 20). The clay particles in the sediments, due to having electrical charge and high specific surface, can carry plant nutrients and organomineral pollutants (5). Accordingly, when agricultural soils erode, the amount of the plant nutrients in the sediments transported from watersheds is greater than that of the main soil (6). Therefore, due to the importance of clay particles in transportation of plant nutrients, agricultural chemicals, and pollutant agents the clay fraction in the sediments from the watersheds need to be precisely determined.

The main objective of this research was to evaluate the CER of the sediments resulting from the soil erosion from a small agricultural watershed.

MATERIALS AND METHODS

The experimental site was a small (4.83 ha) agricultural watershed located in the Bajgah valley in the northwest of the Agricultural College in Shiraz, Iran (Fig. 1). The watershed has an average gradient

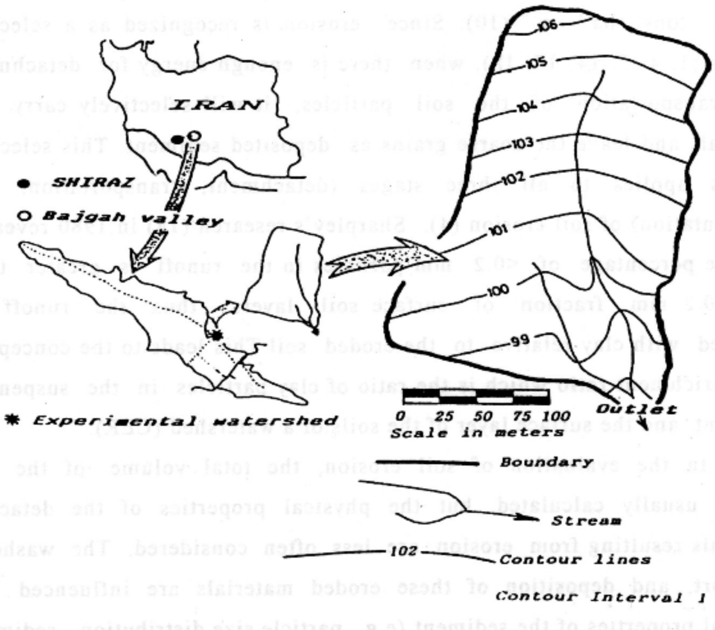

Fig. 1. Location of the experimental watershed in Bajgah valley in the north of Shiraz. Adapted from Amin *et al.* (2).

of 2.2% with minimum and maximum gradients of about 1.7 and 3.3%, respectively.

The catchment time of concentration is very short (15 min) due to its small size (11). Precipitation occurs primarily from November to May each year with the greatest frequency (the greatest number of storms per month) during February. The average rainfall of the valley is 400 mm yr^{-1} and the rainfall events fit the B distribution pattern (2, 11). Two soil series occur within the watershed: 1) Kuye-Asatid-loamy-skeletal over fragmental, carbonatic, mesic, Fluventic, Xerothents-lies in the upper portion of the watershed; and 2) Ramjerdi- fine, mixed, mesic, Fluventic, Haploxerepts-clay loam in the lower protion (16). Some properties of the soils are shown in Table 1. Composite samples of the surface soil were collected and analyzed for particle size distribution using the pipette method (3).

The experimental watershed was under fallow during the course of this study subjected to more erosion and runoff. Surface run-off was measured manually (12) in 15 cm and 22 cm Parshall flumes in series at the outlet of the watershed for control and checking of the accuracy of the watershed run-off flow rates. During a storm event at the outlet the grab sediment samples were collected in the polyethylene bottles wath 10 min intervals and transported to the laboratory where they were filtered and made ready for particle-size distribution analysis (3).

RESULTS AND DISCUSSION

Determination of CER of the transported sediments requires information on clay content of both surface soil of the watershed and the suspended solids in the runoff. Table 1 shows the dominant soil texture of the surface soils of the watershed was silt loam using the soil texture diagram proposed by Shirazi and Boersma (15).

To evaluate the CER of sediments in this watershed, suspended solids from eight runoff events during November and December 1994 and in February 1995 were sampled and analyzed. The particle size distribution for the suspended solids along with the corresponding CER values are

Table 1. Soil type, area, and physical, properties of the soils of the experimental watershed†.

Soil type	Area %	Horizon depth, cm	Infiltration capacity, mm hr^{-1}	Field capacity $cm^3\ cm^{-3}$	Soil erodibility factor, K, 0.01ton/ac*ac/ (ton-ft*h)/in	Total porosity $cm^3\ cm^{-3}$	Particle size Distribution %				Soil texture
							Clay	Fine silt	Coarse silt	Sand	
Kuy-e- Asatid	66	0-20	4.5	0.28	0.45	0.45	13	7	40	40	Sandy loam
		20-25		0.23	------	0.41	24	7	29	40	
Ramjerdi	34	0.20	8.3	0.29	0.44	0.44	29	5	41	24	Clay loam
		20.25		0.25		0.40	38	5	34	23	

† Columns 2 to 6 obtained from Amin (2) and other columns obtained from Solhi (16).

presented in Table 2 for each sampled event. The dominant texture of the suspended solids was silty clay using the procedure proposed by Shirazi and Boersma (15). The CER values ranged from 1.5 to 3.1 with minimum and maximum values occurring during the storm events of 19 December 1994 and 5 February 1995, respectively. The maximum suspended solid concentration during these two events were 5682 mg l^{-1} and 1995 mg l^{-1}, respectively. The results show that when the sediment transport capacity of the runoff flow increases the coarser particles become more detached and transported. Consequently, the percentage of the fine particles (e.g., clay) decreases and corresponding CER also decreases.

Table 2. Particle size distribution of the sediment and corresponding CER values.

Date	Particle size distribution			Geometric mean diameter	Geometric standard deviation	Soil texture†	Clay enrichment ratio (CER)
	sand	silt	clay				
	(%)			(× 1000, mm)			
1994							
Nov. 8	1.8	39.1	59.1	4.1	5.7	11§	2.4
16	0.5	31.1	68.4	3.0	4.8	12	2.7
17	0.7	29.2	70.1	2.7	4.8	12	2.8
Dec. 19	0.8	22.8	76.4	2.2	4.4	11	3.1
20	0.9	29.2	70.1	6.7	4.8		2.8
1995						9	
Feb. 5	1.0	60.7	38.3	7.7	5.2	11	1.5
6	0.3	44.9	54.8	4.4	5.2	12	2.2
7	1.0	40.7	58.3	4.0	5.5		2.3
Mean	1.9	40.6	57.5	4.4	5.1	11	2.3

† Using Shirazi and Boersma (15).

§ 9 = silty caly loam, 11=silty clay, and 12= clay.

Average CER from our experimental watershed was calculated to be 2.3, which is very close to values reported by other researchers conducting studies in watersheds and in field experimental plots (17, 18, 19). The CER reported are 2.18 and 2.4 for the watershed with the same soil conditions of ours (17) and experimental field plots (18), respectively.

The relationship between CER and precipitation and runoff characteristics, such as rate and depth, average and maximum concentration of suspended solids in runoff were evaluated by the regression analysis, the results of which did not show any significant relation. The relationship between CER and average suspended load is shown in Fig. 2. The relationships between CER and average (SS_a) and maximum (SS_a) concentrations of suspended solids in runoff are shown by Eq. [1] and [2], respectively:

$$\log (CER) = 1.77 - 0.465 \log (SS_a) \qquad R^2=0.91; \qquad [1]$$

$$\log (CER) = 2.54 - 0.604 \log (SS_{max}) \qquad R^2=0.93; \qquad [2]$$

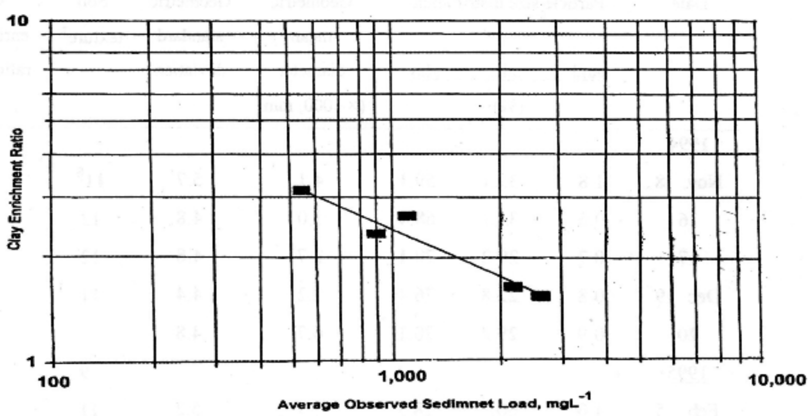

Fig. 2. Relationship between clay enrichment ratio (CER) and the observed average sediment loads for five storm events.

Since the average value of suspended sediment concentration is commonly available and is usually reported in the literature, this parameter can be used to calculate CER. Eqs. [1] and [2] show that the CER decreases with an increase in suspension concentration.

The highest maximum concentrations of suspended load in watershed runoff is related to the precipitation events of 20 December 1994 and 5 February 1995 (5400 mg l^{-1} and 5682 mg l^{-1}, respectively). One reason for those high sediment discharges may be the severe cold and the freezing surface soil conditions during sampling. Prior to these precipitation events the surface soil expands and constricts nocturnally and soil aggregates scatter on the surface. Therefore, they could be easily transported by the overland flow and would increase sediment concentration in run-off.

Table 3. Properties of the storm, runoff events, and related CER values.

Date	Rainfall				Runoff		Suspended load		CER
	Depth	Duration	Intensity (mm hr^{-1}) mean	max.	Depth mm	Max. mm hr^{-1}	Mean mg l^{-1}	Max. mg l^{-1}	
1994									
Nov. 8	26.9	320	5.77	9.0	7.6	5.01	--	3950	2.4
16	19.5	560	2.25	6.0	5.1	3.63	1081	2400	2.7
17	46.8	620	4.47	9.0	26.9	6.00	--	2800	2.8
Dec. 19	20.8	800	2.67	6.0	6.5	0.61	536	1955	3.1
20	15.8	500	3.63	6.0	5.9	5.60	2149	5400	1.6
1995									
Feb. 5	34.5	600	3.43	7.5	12.2	2.87	2676	5682	1.5
6	56.4	1260	3.30	7.5	20.6	4.06	--	3200	2.2
7	31.3	740	3.05	6.0	8.6	3.20	901	2282	2.3

CONCLUSIONS

The quality of surface and groundwater deteriorates by the presence of suspended clay particles. Because of the importance of clay particles in attraction and transportation of plant nutrients and pollutants such as pesticides and other agricultural chemicals, CER should be determined. The CER is a property of the eroded materials based on the presence of clay particles in them and the corresponding values in the soil surface layers of a watershed. In this study, the CER of sediment in the runoff from eight storm events were analyzed. The results of the regression analysis showed that the clay enrichment ratio is inversely related to the average concentration of the suspended sediment. The equation which governs the relationship is:

$$CER = 59\,(SS_a)^{-0.465} \qquad R^2=0.91 \qquad [3]$$

This equation shows that due to the selectivity of erosion process, high overland flow rates would have more transport capacity. Therefore, the suspended sediments will become coarser in texture with higher overland flows rates. For low rate conditions, the percentage of clay-sized particles sizes will increase. This study showed that in our experimental watershed, the average CER was 2.3 which is close to the range reported by other researchers. Soil erosion should be minimized because the colloidal materials are the most valuable particles which control soil fertility, CEC of the soil, and other soil-water relationship properties.

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