Developing A Nomograph For Estimating Erodibility Factor Of Calcareous Soils In North West Of Iran

A. R. Vaezi, H. A. Bahrami, S. H. R. Sadeghi, M. H. Mahdian

Abstract— In the USLE model, the soil erodibility factor (K) is measured using the average rate of soil loss from the unit plot per the unit of rainfall erosivity factor. This factor can also be estimated by the USLE nomograph on the basis of some measurable soil properties. The USLE nomograph has been developed based on field measurements of soil loss in soils of the semi-humid regions in USA, where soils are uncalcareous with low values of carbonates (lime). In semi-arid regions' soils, carbonates are identified as important factors influencing the soil structure stability. Thus, the application of the USLE nomograph in semi-arid regions' soils may lead to inaccurate assessment of the K factor. Therefore, semi-arid regions' soils need a new nomograph to reliably estimate this factor. A 900 km^2 agricultural area in a semi-arid region of northwestern Iran was selected for the research, whose soils had about 12.7% lime. The K factor was measured under natural rainfall events in 36 unit plots from March 2005 to March 2007 and estimated using the USLE nomograph based on soil properties. The results showed that the nomograph-based estimates were 8.77 times more than the measured values. The measured K factor significantly ($p<0.001$, $R^2=0.923$) related to coarse sand, lime, aggregate stability and soil. Therefore, these four variables develop a new nomograph for estimating the K factor in the semi-arid regions' soils.

Keywords— Iran, New nomograph, Semi-arid region, Soil erodibility factor.

I. INTRODUCTION

SOIL erosion is a serious environmental problem threatening the future development of agriculture and societies. It is not only a major factor responsible for the long-

A. R. Vaezi is with the Department of Soil Sciences, Agriculture Faculty, Zanjan University, Zanjan, 45371-38111, Iran, (corresponding author to provide phone: +98-9144230426; fax: +98241-51283202; e-mail: vaezi.alireza@gmail.com).

H. A. Bahrami, Department of Soil Sciences, Agriculture Faculty, Tarbiat Modares University, Tehran, 14115-336, Iran (e-mail: bahramih@modares.ac.ir).

S. H. R. Sadeghi is Department of Watershed Management, Natural Resources and Marine Sciences College, Tarbiat Modares University, Noor, 46417, Iran (e-mail: shrsadeghi@yahoo.com).

M. H. Mahdian is Organization of Extension, Education and Research, Agriculture Ministry, Tehran, 1113-19395, Iran (e-mail: mahdian_1338@yahoo.com).

term degradation of land quality, but also a major source of non-point water pollution. Increased attention to these concerns has led to improved measures for erosion control and a superior comprehension in soil erosion mechanics and soil loss prediction (Lei et al., 2008). Almost 39 percent of Iran (642797 km^2) is located in semi-arid regions, with an annual precipitation ranged from 200 to 500 mm (Alizadeh, 2003). Soil erosion is an important environmental problem in these regions, particularly in the north west, where calcareous soils are mostly utilized to crop production under dry-farming condition. In this region, soil erosion varies between 8 to 16 t ha^{-1} per year (Mahdian, 2005). Quantification of soil loss is one of the greatest challenges in natural resources and environmental planning (Bhuyan et al., 2002). Proper evaluation of main erosional factors in area of interest is the first step in the choice of an effective strategy to reduce soil erosion (Rejman et al., 1998). Erosion prediction models can help address long-range land management planning under natural and agricultural conditions.

Soil loss is commonly predicted using the universal soil loss equation (USLE) based on rainfall erosivity, soil erodibility, slope steepness and length, cover management, and support practices factors (Wischmeier and Smith, 1978). Soil erodibility expresses the resistance of soil particles to both detachment and transport by raindrop impact and runoff (Renard et al., 1997). This factor is the integrated effect of processes that regulate rainfall acceptance and the resistance of the soil to particle detachment and sequent transport. These processes are influenced by soil properties, such as particle size distribution, structural stability, organic matter, soil chemistry and water transmission characteristics (Lal, 1994).

For the USLE, the concept of soil erodibility was introduced as the K factor, which is defined as the average rate of soil loss per unit of rainfall erosivity index from a unit plot (Zhang et al., 2004). A unit plot is defined as a ploughed-continuous fallow land having a uniform 9% slope steepness and 22.1 m length. In different unit plots located in an area that receive the same rainfall events, soil loss is only related to the soil erodibility factor (Wischmeier and Smith, 1978). As direct determination of the K factor requires long-term measurements of soil loss, which is costly and time-consuming, a few techniques have been developed to estimate the K factor values from readily available data on soil properties (Zhang et

al., 2008). To estimate the K factor in the USLE , soil erodibility nomograph was previously developed in the early 1970s (Wischmeier et al., 1971). The USLE nomograph has obtained from the field measurements of soil loss in lands of the semi-humid regions in the USA, where soils are mostly uncalcareous with low values of lime (Rafahi, 1996). The factors considered in the K factor estimation in the USLE nomograph consist of soil particles (% sand, % silt, % very fine sand and silt, and % clay), % organic matter, soil structure code and soil permeability class (Wischmeier et al., 1971; Wischmeier and Smith, 1978).

Different studies have been conducted to determine factors influencing soil erodibility (the K factor) in the world, which some have been inspired by the USLE nomograph. Some studies show that the K factor is related to soil properties, who affect on the structure stability and soil permeability (Gupta, 2002; Hoyous, 2005; Summer, 2007). Some indicate the direct effect of soil particles (Veihe, 2002; Santos et al., 2003; Zhang et al., 2004), organic matter (Evrendliek et al., 2004; Rodriguez et al., 2006), exchangeable potassium (Auerswald et al., 2007), and iron oxides (Rhoton et al., 1998) on the K-factor. Some studies have also focused on the influence of polyvalent cations, especially Ca^{2+}, on the flocculation of colloids, structural stability, and the soil resistance to water erosion (Orts et al., 2000; Charman and Murphy, 2000).

The literature review reveals that the soil erodibility has been influenced by each factor which affects the structure stability and the soil permeability. However, most soils located in semi-arid regions, dissimilar to humid and semi-humid region soils, are calcareous/ limy formed from calcium carbonates in the forms of calcite and aragonite minerals. So, calcium is indicated as an important factor influencing the structure stability and erodibility in these soils (Bronick and Lal, 2005; Vaezi, et al., 2008). For this reason, the application of the USLE nomograph in the semi-arid regions may lead to inaccurate assessment of the K factor (Rafahi, 1996). Therefore, it is essential to evaluate the USLE nomograph and to develop a new nomograph to estimate the K factor in the calcareous soils. In this reason, the study was carried out based on the field-measurements of soil loss under natural rainfall events in calcareous soils of a semi-arid region in Iran.

II. MATERIALS AND METHODS

A. Study Area

The study was conducted in the Hashtrood Township, located in the East Azarbijan Province, northwestern Iran. The study zone was 900 km^2 in area located between 37° 18' 49" - 37° 35' 0" latitude, and 46° 46' 5"- 47° 6' 5" longtitude. The climate is semi-arid, with an average annual precipitation of 322 mm and a mean annual temperature of 13°C. Soils are mainly clay loam and calcareous (limy), which are mostly located in 5-15% slopes and usually are utilized as dry farming for wheat production (Hakimi, 1986).
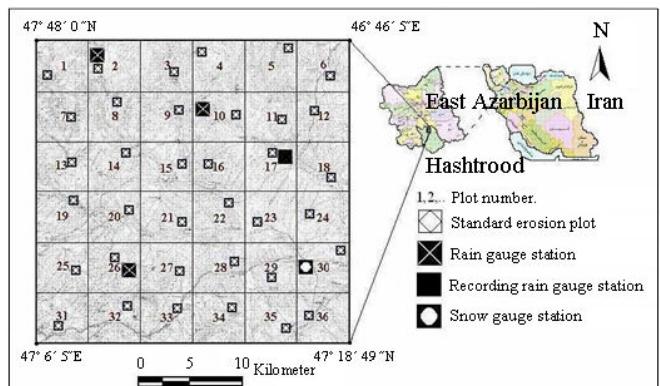

Figure1. Location of the study area.

B. Field Study

The study area consisted of 36 grids with a dimension of 5 km × 5 km (Fig. 1) containing three unit plots with 1.83-m wide and 22.1-m long and 1.2-m spacing. To installation of the plots in each grid, a dry-farming land under the fallow condition located in a uniform southern slope of 9% was specialized according to the USLE criteria (Wischmeier and Smith, 1978). Immediately after plowing in the slope direction, the land was harrowed to provide a smooth uniform on early March 2005. To avoid adjustment for residue cover and plant canopy effects, the plots were maintained in a bare condition by herbicide treatment. At the lower parts of the plots, runoff-collecting equipments consisting of gutter pipes, pipes and 70-liter tanks were established (Rejman et al, 1998).

Soil loss measurements under natural rainfall events was performed for a 2-year period from March 2005 to March 2007. In order to measure the soil loss of each event, the total runoff-sediment volume of each plot's tank was measured. Based on the Guy's (1975) suggestion, after mixing thoroughly its content, a uniform sample was taken, filtered, dried and weighed to determine the sediment concentration. The soil loss in each rainstorm was calculated through multiplying the total tank's contents volume by the sediment concentration (Zhang et al., 2004). The annual soil loss was summated for total events of the first and second study years.

C. Determining Rainfall Erosivity Factor

The rainfall spatial distribution was investigated in four locations of the study area (Fig. 1). Three standard rain gauge stations installed in the grids 2, 10 and 26, and an automatic recording rain gauge station located in grid 17 were used to measure manually the rain height after each event. The spatial homogeneity of the rainfalls in different events causing runoff-sediment was evaluated in the stations using Duncan's parametric test. Data of the automatic recording rain gauge was also used to determine rainfall intensities. The rainfall kinetic energy was then computed using the following equation (Wischmeier and Smith, 1978):

$$KE = 210.3 + 87\log_{10}I \qquad (i)$$

where I is the rainfall intensity (cm h^{-1}) and KE is the kinetic

energy per unit area in unit of rain height (J m^2 cm^{-1}). The kinetic energy (E) was then computed through multiplying the KE by the rain height (cm). The rainfall erosivity index (EI_{30}) for each rainfall event with a duration time higher than 30 minute was then obtained by multiplying the rainfall energy (E) by I_{30} (the maximum 30-minute intensity in cm h^{-1}). The annual rainfall erosivity factor or R (MJ mm ha^{-1} h^{-1}) was ultimately calculated by the summation of the EI_{30} values of different rainfall events occurred in the first and second years.

D. Measurement And Estimation Of The K Factor

The K factor in the unit of t h MJ^{-1} mm^{-1} was measured using the mean annual soil loss (t ha^{-1}) per the unit of average annual rainfall erosivity factor R (MJ mm ha^{-1} h^{-1}). The mean annual K factor of each grid was obtained from averaging the annual K factor of its three unit plots. The K factor for each plot was also estimated using the USLE nomograph in order to compare with the measured K factor. The following multi-regression equation was applied to estimate the K factor value in each plot (Wischmeier and Smith, 1978):

$$K=2.8\times10^{-7}M^{1.14}(12-a)+4.3\times10^{-3}(b-2)+3.3\times10^{-3}(c-3) \qquad (ii)$$

where K is soil erodibility factor in t h MJ^{-1} mm^{-1}, M is [(100-% clay) × (% very fine sand + % silt)], a is % organic matter, b is soil structure code and c is profile permeability class.

E. Determination Of Soil Physicochemical Properties

To determine soil physicochemical properties, soil samples (0-30 cm depth) were taken randomly from three locations within each plot before plowing. Then, the samples of each plot were mixed together and a representative sample was provided. After being dried, the soil samples were grounded to pass a 2 mm sieve and stored in sealed polyethylene bags in a cool and dry place until the chemical analysis in the laboratory. The particle size distribution consisted of coarse sand (0.1-2 mm), very fine sand (0.05-0.1 mm), silt (0.002-0.05) and clay (<0.002 mm) was determined by the Robinson's pipette method (SSEW, 1982). Gravel (2-8 mm) was determined using the weighting method (Gee and Bauder, 1980). The total soil organic carbon was measured by the Walkley–Black wet dichromate oxidation method (Nelson and Somers, 1982) and converted to organic matter through multiplying it by 1.724. To determine lime amount, the total neutralizing value (TNV) on the basis of calcium carbonate was measured using acid acetic volume consumed to neutralizing carbonates (Goh et al., 1993). The available potassium content was also measured with the ammonium acetate extraction method (Knudsen et al., 1982). The soil structure was determined based on the size and shape of aggregates according to the Wischmeier and Smith's (1978) procedure. The aggregate stability was determined using the wet-sieving method based on the mean weight diameter (MWD) as proposed by Angers and Mehuys (1993). The water-stable aggregates were determined by placing 100 g aggregates with diameter larger than six mm on the top of sieves set and moved up to down in a water cylinder for one minute. The soil permeability was determined in the field based on the final infiltration rate for each study plot by measuring the one-dimensional water flow into the soil per unit time by double-ring infiltrometer (Bouwer, H. 1986) at four to six replications. The infiltration measurements were carried out at the end of the dry season (in July 2005) in order to exclude the influence of different initial moisture contents as described by Turner and Summer (1978). The soil structure code and profile permeability class were obtained from the National Soils Handbook, No. 430 (USDA, 1983).

F. Development Of A Soil Erodibility Nomograph

The soil physicochemical properties and K factor data were evaluated for normality using the Kolmogorov-Smirnov test prior to the regression analysis and the K factor modeling. The bivariate relationships between the K factor and physicochemical soil properties were determined using the Pearson's correlation (Soka and Rohlf, 1981) to determine the soil properties influencing the K factor. The principal component analysis (PCA) was, in this respect, used to extract a small number of factors explaining most variance observed in the correlated soil properties (Jollife, 1986). A stepwise multiple regression analysis was utilized to formulate an equation to estimate the K factor from the soil properties factors, which finally led to developing a new nomograph.

III. RESULTS

A. Rainfall Erosivity Factor

During the 2-year study period, out of 97 rainfall events, 41 rainstorms produced runoff and sediment (soil loss) at the unit plots. Table 1 shows the characteristics of the natural rainfalls events led to soil loss in the plots from March 2005 to March 2007. The rainfall erosivity index (EI_{30}) varied from 1.077 to 73.402 MJ mm ha^{-1} h^{-1}, with an average of 14.658 MJ mm ha^{-1} h^{-1}. The mean annual erosivity factor (R) was also identified to be 334.543 MJ mm ha^{-1} h^{-1} year^{-1}. The mean height of rainfalls causing sediment in the rain gauge stations located in grids 2, 10, 17 and 30 were 7.22, 6.59, 6.98 and 6.84 mm respectively. The analysis of variance test (Table 2) showed that there was no significant difference among the rainstorms values of the different rain gauge stations (F= 0.027, P-value= 0.994). Therefore, the spatial rainstorm distribution was uniform and the soil loss at the plots was directly depended on the soil erodibility factor.

Table 1. Characteristics of the natural rainstorms led to soil loss at the plots between March 2005 and March 2007

Rainfall characteristic	Mean	St. D.
Duration (h)	1.80	1.54
Height (mm)	4.13	4.14
Intensity (mm.h^{-1})	2.76	2.55
I_{30} (mm.h^{-1})	4.88	4.99
EI_{30} index (MJ.mm.ha^{-1}.h^{-1})	6.76	13.78

Table 2. Analysis of variance test of the rainstorms height values of the different rain stations

	Mean	St. D.	F	P-value
Station 1	7.15	5.01		
Station 2	6.77	4.89	0.027	0.994
Station 3	6.98	4.95		
Station 4	7.08	4.84		

B. Soil Properties

According to Table 3, soil textures were mainly clay loam having 36.7% sand, 31.6% silt and 32.0% clay. Soils had low organic matter (about 1.1%) and were calcareous (limy) with about 13% calcium carbonate equivalent (TNV). The gravel and potassium amounts were 10% and 315 mg.kg^{-1}, respectively. The water-aggregate stability of the soils was very low and the mean weight diameter value ranged between 0.27 and 1.91 mm. Aggregates were mainly granular with a mean diameter of 5 mm and so were categorized in the structure code 3. The soil permeability value varied between 1.4 and 5.8 cm h^{-1}. The soils were mainly classified in the permeability group 2. Statistical distributions of the different soil properties were normal.

Table 3. Mean and standard error of soil properties in the study area

Variable	Mean	S.D.
Sand (%)	36.7	6.9
Coarse sand (%)	18.9	5.2
Very fine sand (%)	17.8	3.2
Silt (%)	31.6	7.1
Clay (%)	32.0	5.7
Gravel (%)	9.9	2.4
Organic matter (%)	1.08	0.25
TNV/lime (%)	12.7	5.2
Potassium (mg.kg^{-1})	314.7	25.4
Structure stability, MWD (mm)	1.13	0.44
Permeability (cm.h^{-1})	3.5	1.2

C. Soil Loss And Erodibility Factor

The mean annual value of soil loss measured in the plots varied from 0.674 to 2.431 t ha^{-1}, with an average of 1.516 t ha^{-1} (Table 4). The mean measured values of the K factor ranged between 0.002032 and 0.007172 t h MJ^{-1}mm^{-1} with an average of 0.004447 t h MJ^{-1} mm^{-1}. The nomograph-based estimated K values were also between 0.025371 and 0.049233 t h MJ^{-1} mm^{-1} with an average of 0.035988 t h MJ^{-1} mm^{-1}. The measured and estimated K data tended to be normally distributed (Fig. 2). According to Table 4, the nomograph-based estimates were 8.77 times higher than the measured values on average. Difference between the estimated and measure K factor was statistically significant and correlation between the two was relatively low with an R^2 of 0.21 (Fig. 3).

In fact the estimated K factor value explained only 21 percent of the measured K factor value variations in the study soils. These results revealed that using the USLE nomograph is lead to an overestimation of the K factor.

Table 4. Mean annual soil loss and measured K factor values in the study plots from March 2005 t0 March 2007

Plot No.	Soil loss (t.ha^{-1})	K factor (t.h.MJ^{-1}.mm^{-1})	Plot No.	Soil loss (t.ha^{-1})	K factor (t.h.MJ^{-1}.mm^{-1})	Plot No.	Soil loss (t.ha^{-1})	K factor (t.h.MJ^{-1}.mm^{-1})
1	2.431349	0.007172	13	2.357626	0.006573	25	2.192917	0.006023
2	2.096989	0.00586	14	1.731074	0.004933	26	0.963799	0.002733
3	2.352918	0.006873	15	1.732319	0.005307	27	0.841642	0.00254
4	1.475604	0.004495	16	0.722483	0.002595	28	2.165491	0.006078
5	2.110446	0.006227	17	0.825921	0.002376	29	1.559563	0.004538
6	0.736642	0.002468	18	1.755493	0.005099	30	1.76484	0.004938
7	1.13111	0.004039	19	2.034308	0.00576	31	1.349734	0.00407
8	1.039198	0.003063	20	1.490839	0.004698	32	0.673654	0.002032
9	1.612573	0.004773	21	0.870596	0.002559	33	1.314344	0.003589
10	1.950224	0.005628	22	1.235089	0.003849	34	1.27276	0.00368
11	1.714406	0.004889	23	1.74544	0.005019	35	1.531927	0.004365
12	0.905605	0.002838	24	1.469572	0.004276	36	1.444244	0.004136

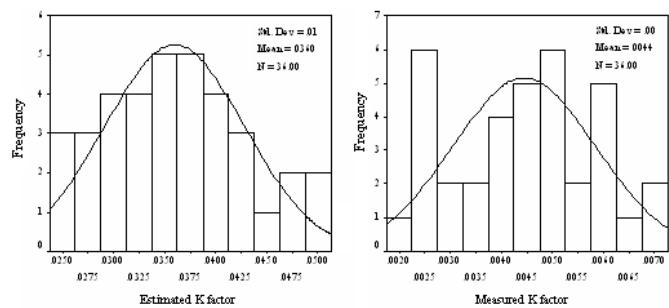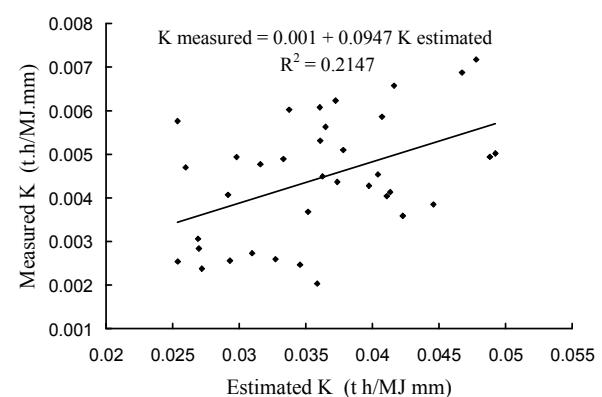Figure 2. Statistical distribution of the estimated (A) and measured (B) K factor data.

Figure 3. Relationship between the measured and estimated soil erodibility factor (K) in the study area.

D. Relationship Between The K Factor And Soil Properties

Table 5 shows the correlation matrix of the measured K factor and soil properties in the study area. The K factor significantly correlated with coarse sand (p < 0.01), very fine

sand ($p < 0.01$), silt ($p < 0.01$), clay ($p < 0.05$), organic matter ($p < 0.01$), TNV ($p < 0.01$), aggregate stability ($p < 0.001$) and soil permeability ($p < 0.001$). Coarse sand, organic matter, aggregate stability and soil permeability were negatively associated with the soil erodibility, whereas very fine sand and silt were positively related to it. A significant correlation was also indicated between some soil properties, such as very fine sand and clay with the aggregate stability; and coarse sand and organic matter with the soil permeability.

Table 5. Correlation matrix of the measured K factor and soil properties in the study area

	CS[a]	VFS[b]	Silt	Clay	Gravel	OM[c]	TNV[d]	Potas.[e]	MWD[f]	Per[g]	K[h]
Sand											
CS	1										
VFS	0.224	1									
Silt	-0.742 ***	-0.197	1								
Clay	-0.179	-0.500***	-0.400*	1							
Gravel	0.028	-0.007	0.024	-0.058	1						
OM	0.268	-0.207	-0.228	0.208	0.165	1					
TNV	-0.001	-0.558***	0.174	0.028	-0.030	0.046	1				
Potas.	-0.072	-0.046	-0.177	0.309*	0.093	0.059	-0.092	1			
MWD	-0.175	-0.670***	-0.123	0.705***	-0.091	0.293*	0.481 ***	0.217	1		
Per.	0.761***	-0.047	-0.553 ***	-0.069	0.091	0.541 ***	0.295*	0.080	0.134	1	
K	-0.496***	0.435***	0.459***	-0.307*	-0.131	-0.545***	-0.549***	-0.160	-0.637***	-0.784 ***	1

[a] CS: Coarse sand; [b] VFS: Very fine sand; [c] OM: Organic matter; [d] TNV: Total neutralized carbonates (lime); [e] Potas.: Potassium; [f] MWD: Mean weight diameter of water stable aggregates; [g] Per.: Permeability (final infiltration rate); [h] K: Measured K factor

The soil properties influencing the K factor including coarse sand, very fine sand, silt, clay, organic matter, TNV (lime), the aggregate stability and the soil permeability were analyzed using the PCA to extract a small number of main factors. Table 6 shows the rotated component loadings using the PCA. For each component, only the variables with absolute loading values greater or equal to 0.7 were considered for interpreting the retained component. A three-component model best summarized the dataset explaining 82.5% of total soil variance (TSV). The first component (PC1) associated with 34.7% of the TSV presenting strong positive loadings on soil permeability and coarse sand, as well as a strong negative loading on silt. Organic matter also showed a good correlation with the first component, but it was lower than 0.7. The second component (PC2) accounted for 31.5% of the TSV and dominantly targeted clay and aggregate stability. Very fine sand also presented a negatively moderate association with this component, but it was more related to component three. The third component (PC3) explained 16.3% of the TSV and mainly contained the TNV (lime) and very fine sand. Thus, coarse sand, very fine sand, clay, TNV, aggregate stability and soil permeability were the main factors explained soil properties in the study area.

The multiple regression analysis of the K factor and the main soil factors showed that the K factor was only significantly ($p < 0.001$, $R^2 = 92.3$) related to aggregate stability, soil permeability, TNV (lime) and coarse sand. According to Table 7, aggregate stability, soil permeability, TNV (lime) and coarse sand negatively affected the K factor. Aggregate stability and soil permeability were the most important factors determining the K factor value ($p < 0.001$, $R^2 = 90.3$).

Table 6. Rotated component loadings using the PCA

Soil property	PC1	PC2	PC3
Coarse sand	0.912	-0.211	-0.138
Very fine sand	0.080	-0.557	-0.710
Silt	-0.781	-0.340	0.428
Clay	0.018	0.978	-0.061
Organic matter	0.546	0.281	0.251
TNV (lime)	0.098	0.029	0.891
Aggregate stability	0.059	0.789	0.477
Soil permeability	0.919	-0.078	0.266
Variance explained (%)	34.7	31.5	16.3

Table 7. Multiple regression analysis of soil properties explaining the K factor

Factors[*]	Unstandardized coefficient	Standard error	Standardized Coefficient	t-value	p-level
Constant	0.00999	0.00037		27.353	0.000
CS	-4.9×10^{-5}	0.00002	-0.182	-2.091	0.045
TNV	-3.6×10^{-5}	0.00002	-0.137	-2.263	0.031
MWD[a]	-0.00167	0.00019	-0.531	-8.854	0.000
Per.[b]	-0.00064	0.00011	-0.534	-5.970	0.000

[*] CS: coarse sand, TNV: Total neutralized carbonates (lime); [a] MWD: Mean weight diameter of water-stable aggregates in mm; [b] Per.: Soil permeability based on final infiltration rate in cm h^{-1}.

Therefore, the following equation was extracted from the multiple regression analysis:

$$K \text{ factor} = 0.00999 - 4.9 \times 10^{-5}CS - 3.6 \times 10^{-5}TNV - 0.00167 MWD - 0.00064 Per \qquad (iii)$$

where the K factor is the soil erodibility factor in t h MJ^{-1} mm^{-1}, CS is coarse sand in percent, TNV is total neutralized carbonates as calcium carbonate equivalent (lime) in percent, MWD is the mean weight diameter of water-stable aggregates in mm, and Per is the soil permeability in cm h^{-1}.

As shown in Figure 4, a nomograph was developed according to the multi-regression equation (2) to easily estimate the K factor. In the nomograph, soil permeability is entered in the graph A on the basis of the final infiltration rate (cm h^{-1}), then it is contacted to the aggregate stability line based on the MWD (mm) and is linked to the vertical line on the right side of the graph. This contact point is the first estimation of the K factor in t h MJ^{-1} mm^{-1} with an $R^2 = 90.3\%$. If it is linked to the TNV (lime) line and is contacted to the horizontal line in graph B, the contact point will be the second estimation of the K factor with an $R^2 = 91.2\%$. By continuing this line and linking it to the coarse sand line in graph C, a new contact point is emerged, which is linked to the vertical line on the left side of the graph with an R^2 of 92.3%. This new point can propose a reliable estimation of the K factor in the study semi-arid area. The dash arrowed line in the nomograph (Fig. 4) indicates that the K factor is estimated 0.0046 t h MJ^{-1}mm^{-1}, when a soil sample has 2.58 cm h^{-1} permeability, 1 mm

aggregate stability in water, 24% TNV (lime) and 30% coarse sand.

Figure 4 (see at page 8)

IV. DISCUSSION

The results indicated that use of the USLE nomograph to estimate the K factor leads to over-estimating the K factor by a factor of 4.40 to 17.64 (8.77 on average). This result accords with Rejman et al (1998), Zhang et al. (2004), and Zhang et al. (2008), who found that the measured soil erodibility values were 6-10, 3.3-8.4, and 10.9-12.7 times smaller than values derived from the USLE nomograph, respectively. Our results also agree with previous findings of Vaezi et al. (2008) which showed that the measure value of the K-factor is significantly (p< 0.001) lower than that nomograph-estimated value by a factor of 8.35. The results of the study show the importance of developing a new reliable nomograph to estimate the K factor in the semi-arid regions.

The correlation matrix, principal component analysis (PCA) and multi-regression analysis revealed that the coarse sand, TNV (lime), aggregate stability and soil permeability can explain 92.3% of total variance of the K factor. The effect of coarse sand, TNV, aggregate stability and soil permeability on the K factor was negatively significant. Coarse sand effect on the K factor supports Santos et al. (2003), who have suggested that sand has an important role in increasing infiltration and decreasing soil erodibility. Negative effect of coarse sand on the aggregate stability also is in agreement with results obtained by Moreno-de and Heras (2009).

The effect of TNV on the K factor accords with the studies of Orts et al. (2000) and Charman and Murphy (2000), who identified that Ca^{2+} stimulates flocculation of soil colloids and increases the aggregate stability and soil resistance to erosion. The aggregate stability explanation confirms the report of Charman and Murphy (2000), suggesting soils with stable aggregates have a high resistance to erosion. Results on effect of the aggregate stability also agree with Rhoton et al., (2008) who reported that the aggregate stability is a critical component of soil erodibility since it controls soil dispersion, surface seal development, and thus the extent to which runoff occurs. Thus, the soil erodibility is inversely related to the aggregate stability. Despite positive influence of organic matter and clay on the aggregate stability agree with findings of McConnell (1989), Siegrist et al., (1998) and Moreno-de et al., (2009), regression analysis showed that their influences on the soil erodibility are not direct and can be explored by aggregate stability factor.

The negative effect of soil permeability on the K factor also accords with El-Assward and Abufaied (1994) YU et al. (2006), who found that the surface runoff and soil erodibility decrease by increasing soil permeability. In this study, approximately 90.3 % of the total variance of the K factor was determined by the aggregate stability and soil permeability. These two properties can state the effect of other soil properties to be very fine sand, clay and organic matter on the K factor. The importance of these two properties in estimating the K factor has also been showed in the studies of Gupta (2002) and Hoyos (2005). The study also indicated that TNV

(lime) is an important factor in estimating the K factor in the semi-arid regions. Therefore, in the semi-arid regions' soils with similar physio-chemical properties to the study soils', the K factor can reliably ($R^2 = 0.93$) be estimated using a new nomograph developed by the determinants of coarse sand, TNV, aggregate stability and soil permeability.

V. CONCLUSIONS

The use of the USLE nomograph method to estimate the K factor in the study soils leads to over-estimating the soil erodibility by a factor of 8.77. Therefore, this nomograph may inaccurately assess the K factor in semi-arid regions' soils. Despite the universal importance of the USLE nomograph, the semi-arid regions' soils need a new nomograph to estimate the K factor. For developing this new nomograph, the K factor measured in the standard plots was related to the physio-chemical soil properties. On account of this, the K factor can be estimated by an equation based on the coarse sand, TNV, aggregate stability and soil permeability. In the developed nomograph, TNV (lime) is identified to be a new property to determine the K factor. Moreover, the effect value of other three properties in the new nomograph is different from those in the USLE nomograph, but their effect direction are the same (negative). The soil properties such as organic matter and clay that positively affect on the aggregate stability or soil permeability may decline the K factor.

REFERENCES

[1] A. Alizadeh, "Applied Hydrology," 3rd ed. Asetan Ghodse Razavi Publication pp. 147-148, 2003.

[2] D. A. Angers and G. R. Mehuys, "Aggregate stability to water," In: Cartner, M.R. (Editor), Soil sampling and methods of analysis. Canadian Society of Soil Science. Lewis Publishers, Boca Raton, Canada pp. 651-657, 1993.

[3] K. Auerswald, M. Kainz, S. Angermüller and H. Steindl, "Influence of exchangeable potassium on soil erodibility," *Soil Use and Management* 12(3), 117-121, 1996.

[4] S. J. Bhuyan, P. K. Kalita, K. A. Janssen and P. L. Barnes, "Soil loss predictions with three erosion simulation models," *Environmental Modelling & Software* 17, 137–146, 2002.

[5] H. Bouwer, "Intake rate: Cylinder infiltrometer. In: Klutem A., Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods," Second addition, Agronomy, Soil Science Society of America, Inc., Madison, Wisconsin, USA, pp. 341-345, 1986.

[6] C. Bronick and R. Lal, "Soil structure and management: a review," *Geoderma* 124, 3 –22, 2005.

[7] P.E.V. Charman and B. W. Murphy, "Soils (their properties and management). 2nd ed. Land and Water Conservation," New South Wales, Oxford. pp. 206-212, 2000.

[8] R. M. El-Assward and A. F. Abufaied, "The erodibility of three Libyan soil types in relation to their physical and chemical properties," *Journal of Arid Environments* 26(2), 129-134, 1994.

[9] F. Evrendliek, I. Celik and S. Kilic, "Changes in soil organic carbon and other physical soil properties along adjacent Mediterranean forests,

grassland and cropland ecosystems," *Journal of Arid Environment* 59,743-752, 2004.

[10] G. W. Gee and J. W. Bauder, "Particle-size analysis," In: Klutem A., Methods of Soil analysis, Part 1, Physical And Mineralogical Methods, 2nd ed., AGRONOMY, Soil Science Society of America, Inc., Madison, Wisconsin, USA pp. 383-385, 1980.

[11] T. B Goh, R. J. St. Arnaud and A. R. Mermut, "Aggregate stability to water," In: Cartner, M.R. (Editor), Soil sampling and methods of analysis. Canadian Society of Soil Science. Lewis Publishers, Boca Raton, Canada, pp. 177-180, 1993.

[12] O. P. Gupta, "Water in relation to soils and plants," Agrobios, India pp. 31-34, 2002.

[13] H. P. Guy, "Laboratory procedures of sediment measurement techniques," In: Anoni, V.A. (Editor), Sedimentation Engineering. Am. Soc. Civil Eng., New York, NY, USA, 1975.

[14] A. Hakimi, "The briefly study of soil science in Hashtrood," Soil and Water Research Institute, Agriculture Ministry, Iran, Research Report No. 767, 2-15, 1986.

[15] K. H. Harteg and R. Horn, "Die Physikalische Untersuchung von Böden: 2," Auflage. Ferdinand Enke Verlag, Stuttgart. In: Scholten, T. 1997. Hydrology and erodibility of the soils and saprolite cover of the Swaziland Middleveld. Soil *Technology* 11, 247-262, 1989.

[16] N. Hoyos, "Spatial modeling of soil erosion potential in a tropical watershed of the Colombian Andes," *Catena* 63, 85-108, 2005.

[17] I. Jollife, "Principal Component Analysis," Springer-Verlag, New York, 1986.

[18] D. Knudsen, G. A. Peterson and P. F. Pratt, "Lithium, sodium and potassium," pp. 225-246. In: A. L. Page et al. (Editors) Methods of soil analysis: Part 2. Chemical and microbiological properties. ASA Monograph Number 9, 1982.

[19] R. Lal, "Soil Erosion Research Methods," Soil and Water Conservation Society (Aunkeny), 3rd ed. St. Lucie Press, Delray Beach, 1994.

[20] T. W. Lei, Q. W. Zhang, L. J. Yan, J. Zhao and Y. H. Pan, "A rational method for estimating erodibility and critical shear stress of an eroding rill," *Geoderma* 144, 628–633, 2008.

[21] M. H. Mahdian, "Study of land degradation in Iran. Proceedings of the Third National Conference of Erosion & Sediment," Tehran, Iran pp. 226-231, 2005.

[22] S. G. McConnell, "Potential wind and water erodibility of four land-use systems in south-eastern Montana, USA," *Agriculture, Ecosystems & Environment, 25(2-3), 207-215,* 1989.

[23] Moreno-de, M. & Heras, L., "Development of soil physical structure and biological functionality in mining spoils affected by soil erosion in a Mediterranean-Continental environment," *Geoderma* 149(3-4), 249-256, 2009.

[24] D. W. Nelson and L. E. Sommer, "Total carbon, organic carbon, and organic matter," In: A.L. Page (ed.) Methods of Soil Analysis. 2nd ed. ASA Monogr. 9(2). Amer. Soc. Agron. Madison, WI. pp. 539-579, 1982.

[25] J. W. Orts, R. E. Sojka and G. M. Glenn, "Biopolymer additives to reduce erosion- induced soil losses during irrigation.," *Industrial Crops and Products* 11, 19-26, 2000.

[26] H. G. Rafahi, "Soil erosion by water and conservation," 1st ed. Tehran University Publication, pp. 141-147, 1996.

[27] J. Rejman, R. Turski, and J. Paluszek, "Spatial and temporal variability in erodibility of loess soil.," *Soil Tillage Res*. 46, 61-68, 1998.

[28] K. G. Renard, G. R. Foster, G. A. Weesies, D. K. McCool and D. C. Yoder, "Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE)," U.S. Department of Agriculture, Agriculture Handbook No. 703, pp. 404, 1997.

[29] R. R. Rodríguez, C. D. Arbelo, J. A. Guerra, M. J. S. Natario and C. M. Armas, "Organic carbon stocks and soil erodibility in Canary Islands Andosols," *Catena* 66, 228-235, 2006

[30] F. E. Rhoton and S. W. Duiker, "Erodibility of a soil drainage sequence in the loess uplands of Mississippi," *Catena* 75, 164-171, 2008.

[31] F. E. Rhoton, D. L. Lindbo and M. J. M. Romkens, "Iron oxides erodibility intractions for soils of the Memphis catena.," *Soil Sci. Soc. Am. J.* 62(3), 1693-1703, 1998.

[32] F. L. Santos, J. L. Reis, O. C. Martins, N. L. Castanheira and R. P. Serralheiro, "Comparative assessment of infiltration, runoff and erosion of sprinkler irrigated soils," *Biosystems Engineering* 86(3), 355-364, 2003.

[33] S. Siegrist, D. Schaub, L. Pfiffner and P. MaÈder, "Does organic agriculture reduce soil erodibility? The results of a long-term field study on loess in Switzerland,"*Agriculture, Ecosystems and Environment* 69, 253-264, 1998.

[34] R. R. Soka and F. J. Rohlf, "Biometery: The Principals and Practice of Statistics in Biological Research," W. H. Freeman, San Francisco, USA, 1981.

[35] SSEW, "Soil Survey Laboratory Methods," Technical Monographs No. 6. Harpenden, UK, 1982.

[36] R. M. Summer, ","1982. Field and laboratory studies on alpine soil erodibility, southern Rocky Mountains, Colorado. *Soil Use and Management* 7(3), 253-266.

[37] D. P. Turner and M. Summer, "The influence of initial soil water content on field measured infiltration rates," Water SA 4, 18-24, 1978.

[38] USDA, "National Soil Survey Handbook," No. 430. US Department of Agriculture, Washington, DC, 1983.

[39] A. R. Vaezi. S. H. R. Sadeghi, H. G. Bahrami and M. H. Mahdian, "Modeling the USLE K-factor for calcareous soils in northwestern Iran," *Geomorphology* 97, 414–423, 2008.

[40] A. Veihe, "The spatial variability of erodibility and its relation to soil types: a study from northern Ghana,"*Geoderma* 106, 101-120, 2002.

[41] W. H. Wischmeier, C. B. Johnson and B. V. Cross, "A soil erodibility nomograph for farmland and construction sites," *J. Soil Water Conserv.* 26, 189-193, 1971.

[42] W. H. Wischmeier and D. D. Smith, "Predicting rainfall erosion losses: a guide to conservation planning," Agriculture Handbook No. 537. US Department of Agriculture, Washington DC., pp. 13-27, 1978.

[43] D. -S. YU, X. -Z. Shi and D. C. Weindorf, "Relationship between permeability and erodibility of cultivarted Acrisols and Cambisols in subtropical China," *Soil Science Society of China* 16, 304-311, 2006.

[44] K. Zhang, S. Li, W. Peng and B. Yu, "Erodibility of agricultural soils and loess plateau of China.," *Soil Tillage Res.* 76, 157-165, 2004.

[45] K. L. Zhang, A. P. Shu, X. L. Xu, Q. K. Yang and B.Yu, "Soil erodibility and its estimation for agricultural soils in China," *Journal of Arid Environments* 11, 1-10, 2008.

Procedure: in the graph A enter soil permeability and contact to aggregate stability line, and then link it to vertical line in the right part of the graph. This contact point is the first estimation of the USLE-K factor in t h $MJ^{-1}mm^{-1}$. If link it to TNV line in graph B and then contact to horizontal line, contact point will be the second estimation of K. If continue this line and link to coarse sand line in graph C and then link it to vertical line in the left part of the graph, this point will show final estimation of the K factor in t h $MJ^{-1}mm^{-1}$. It can be interpolated between the drawn lines if necessary. The broken arrowed line indicates the procedure for a soil sample having 2.58 cm h^{-1} permeability, 1 mm aggregate stability in water, 24% TNV and 30% coarse sand. K factor = 0.0046 t h $MJ^{-1}mm^{-1}$.
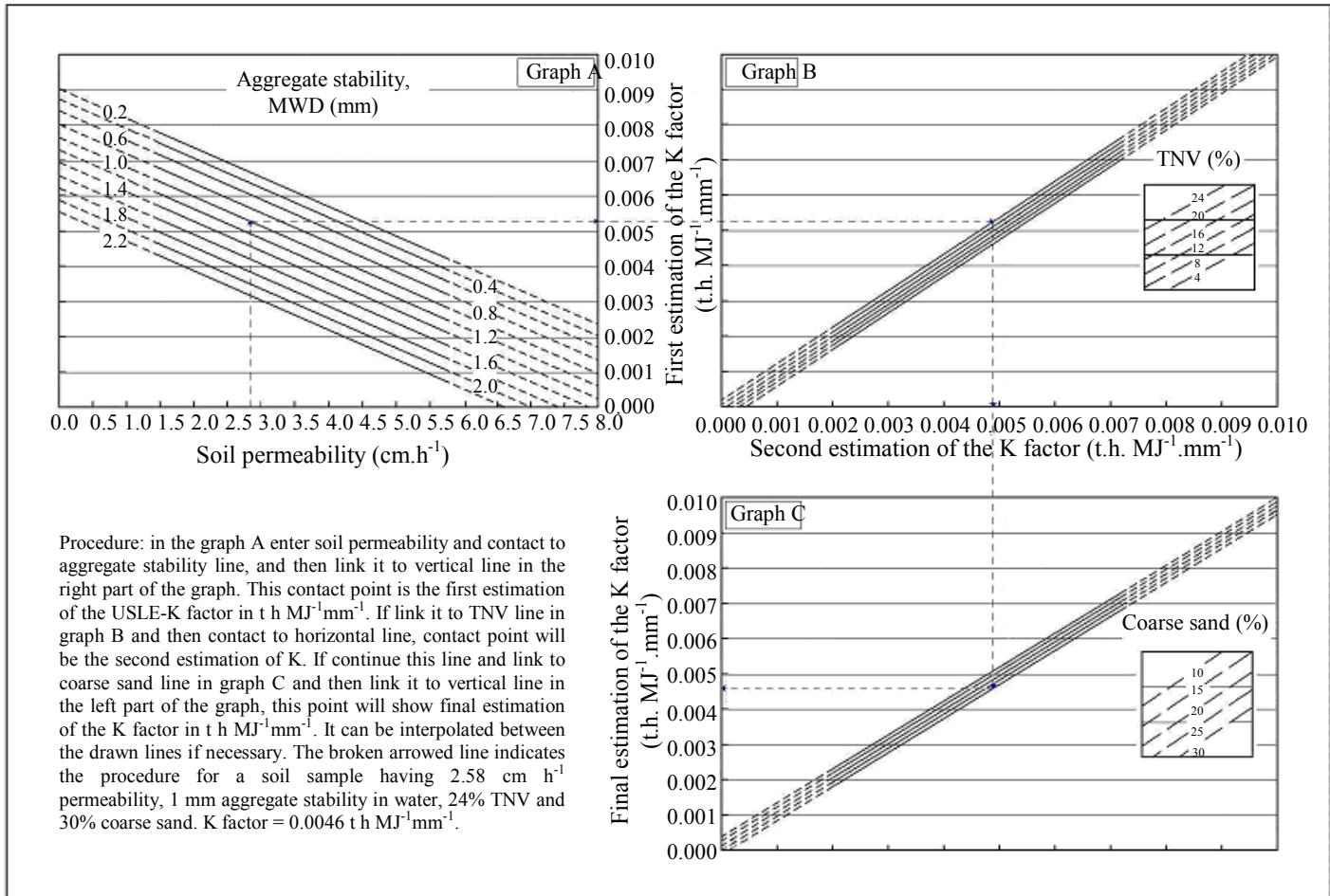
Figure 4. Soil erodibility factor K nomograph in the study soils of semi-arid region.