ALEXANDRIA
SCIENCE EXCHANGE JOURNAL

VOL. 31 JULY- SEPTEMBER 2010

Application of WEPP-K Index for Erodibility Estimation of Red Mediterranean Soils, Libya

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ABSTRACT

Due to the increased importance of soil degradation investigation in the Libyan Mediterranean region, soil erodibility-related data is extremely needed. In the present study interrill soil erodibility (Ki) and interrill detachment rate (Di) were estimated using WEPP-formulae. In order to apply the formula, soil properties such as soil texture parameters, organic matter content, exchangeable calcium and saturated hydraulic conductivity (Ks) were measured. The calculated values of erodibility (Ki) ranged between 2.25 x 10^5 to 5.39 x 10^5 kg.s.m^{-4}. Multiple regression analysis showed that soil texture parameters, Ks and exchangeable Ca^{+2} explained about 92% of the interrill detachment rate. The slope factor also played an important role in the soil detachment process. The comparison between the used WEPP-Ki and the soil instability indicators showed that WEPP-Ki equation need to be reconsidered and should include more factors that affect soil structure stability under the Libyan Mediterranean conditions.

INTRODUCTION

Soil loss by erosion is affected by factors such as: rainfall characteristics, slope percentage and length, plant cover and land management, in addition to the inherent soil properties that determine soil erodibility. Soils exist under similar environmental conditions can have varied amounts of soil loss depending on the variation of particular soil properties, i.e. due to differences in "soil erodibility". Soil erodibility is "a function of complex interactions of a considerable number of its physical and chemical properties which frequently vary within a standard texture class" (Wischmeier and Smith, 1978). Middleton (1930) was the first to set up an index of erodibility. He showed that soils could be distinguished as "erodible" and "non-erodible" on the basis of the ease with which the soil would disperse. It is generally accepted that soil erosion will increase with a high erodibility; while under similar conditions soils with low erodibility will have lower soil erosion (Hudson, 1995).

It has been established in the literature that soil erodibility represents the effect of soil properties and soil profile characteristics on soil loss by erosion, the soil erodibility factor (K), as used in USLE (Universal Soil Loss Equation) and RUSLE (Revised Universal Soil Loss Equation), can be calculated using different formulae employing different packages of soil parameters. Several formulae had been suggested as erodibility indices, for instance, the Clay Ratio. The dispersion ratio and aggregate stability were also used as indices of erodibility by Adams *et al* (1958). Wischmeier and Mannering (1969) used a function of fifteen soil properties and their interactions as an empirical expression of soil erodibility, and Wischmeier *et al* (1971) later modified the formula to include only five soil parameters.

The USLE and RUSLE have been widely used for agricultural fields, WEPP (Water Erosion Prediction Project) is a physically based model developed in the USA by the USDA-ARS agencies as replacement for the empirical models. WEPP can be applied in wider range of scales and land uses (Yu and Rosewell, 2001). In addition, WEPP model can also be applied for individual storms to estimate runoff and soil loss distribution and amount during these events (Morgan, 1996). Unlike USLE and RUSLE sediment movement in small channels is simulated in the WEPP model (Renschler and Harbor, 2002). One of the changes in soil erodibility factor was separating the erodibility values in WEPP model for rill and interrill erosion, while in USLE model the erodibility factor represents the effect of rill and interrill erosion together (Sheridan et al, 2000). Beside rainfall intensity and slope factor, interrill erodibility (Ki) was used in WEPP to calculate interrill detachment rate. Generally, the WEPP model requires two erodibility values for each soil under investigation to allow the estimation of soil loss, interrill erodibility (Ki) and rill erodibility (Kr). Alternatively, WEPP model can calculate Ki and Kr using regression

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Received June12, 2010, Accepted July 24, 2010

equations based on soil texture parameters and organic matter (Romero et al, 2007).

Several empirical indices have been used in the region of Al Jabal al Akhdar to estimate soil erodibility (GEFLI, 1975; Gebril, 1995; Aburas et al, 2000). However, physically based models such as WEPP have never been used before in this region according to the author`s knowledge. The promising application of WEPP-K index in several parts of the Mediterranean region has encouraged its use in the region of Al Jabal al Akhdar. The objective of this study is to improve soil loss prediction by applying this index. In addition, the investigation of erosion-related soil degradation which is an important environmental issue in the region of study will also be benefited from this improvement.

MATERIALS AND METHODS

Al Jabal al Akhdar region (where this study was conducted) is located at the north east of Libya between the Mediterranean coast and Sahara desert (longitude 20° to 30° E, latitude 32° to 33° N) (Figure 1). Although it represents less than 2% of the total area of Libya, the region is the most climatically favoured part of the country with an annual rainfall range of about 400 to 500 mm falling mainly in the period from October to April.

To achieve the objective of this study, six main sites were selected. Three of the sites were sub-divided into more sub-sites making the total number of sites 10. Soil samples were collected from the soil surface (0–15cm) of each site. The Red Mediterranean soil Terra Rossa (equivalent to Rhodoxeralfs according to the US Soil Taxonomy (Soil Survey Staff, 1999)) is predominate soil type in the area (Bin-Mahmoud, 1995) and represent the most soils under investigation in the present study (Figure,2).

4The laboratory measurements of soil properties:

A. Soil particle size analysis: Particle size distribution was determined by the pipette method as described by Sheldrick and Wang (1993). A set of sieves was used to separate the oven-dried sand fractions into different classes according to the USDA sand sizes as follows: very fine sand (0.05-0.10mm), fine sand (0.10-0.25mm), medium sand (0.25-0.5mm), coarse sand (0.5-1.0mm) and very coarse sand (1-2mm).

B. Saturated hydraulic conductivity: The constant-head method according to Mohanty *et al* (1994) was used to measure hydraulic conductivity of saturated soil samples using constant volume cylinder samples (soil cores).

C. Organic matter: The soil organic matter content was determined by the modified Walkely-Black method and as described by Nelson and Sommers (1996).

D. Exchangeable calcium: Ammonium acetate (1N NH_4OAc) was used to replace exchangeable ions, and standard EDTA solution was used for titration, as described in Black et al (1965).

E. Instability of soil aggregates: the index was determined using wet sieving as described by Ekwue (1984).

Figure 1. Aljabal Alkhdar region, north east Libya (the source: www.infoplease.com/atalas

Figure 2. Soil map of the study area shows the study sites (the map does not show Gandola site which is located about 20 km to the south of Masa) the source: Selkhoze Prom Export (1980)

Prediction of soil erodibility:

Interrill erodibility (Ki) in WEPP model was estimated using soil texture parameters: Ki (kg s m^{-4}) = 6, 054,000 – 55, 130 Clay (%) for soils with < 30% sand (Duiker et al, 2001).

Consequently, interrill detachment (Di) can be calculated with the following formula:

Di = Ki I^2 (Lane et al, 1992). Or, Di = Ki I^2 S_f (Flanagan and Nearing, 1995)

Where, Di = interrill detachment rate (kg s^{-1} m^{-2}), Ki = interrill erodibility (kg s m^{-4}), I = rainfall intensity (m s^{-1}) and S_f = slope factor.

S_f slope factor (dimensionless) = 1.05 – 0.85 exp $^{(-0.85 \sin [\Theta])}$, Where, Θ is expressed in degrees.

Unfortunately detailed rainfall data for the study area is not available in the literature to calculate rainfall intensity for each site. Since all sites are placed in an area of 40 km diameter, values of rainfall intensity obtained by Aburas (1997) for some locations within this area were used.

To analyze the relation between WEPP-Di values and soil properties, correlation and regression analyses were used. Best subsets regression in the statistical software Minitab 15 were used to find out the best predictors of soil erodibility using initial set of soil properties.

Table 1. Mean values of some soil properties (0-15cm) of all sites under investigation*

Sites	Clay %	Silt+Very fine sand (%)	Saturated hydraulic conductivity (cm.min^{-1})	Organic matter (%)	Exchangeable calcium (cmol$^+$ kg^{-1} soil)
Elbieda 1	18.5	70.9	0.44	3.31	9.60
Elbieda 2	35.7	60.8	0.26	2.28	11.66
Elwosita 1	23.3	74.9	0.55	1.70	10.03
Elwosita 2	40.7	54.8	0.42	3.46	18.55
Elwosita 3	66.6	31.9	0.40	3.24	22.65
Alhamama 1	53.8	42.8	0.81	4.00	12.70
Alhamama 2	68.8	30.5	0.50	2.96	16.60
Masa	17.8	67.3	0.35	1.78	9.53
Alhania	12.1	85.2	0.69	2.42	12.10
Gandola	17.1	59.6	1.26	3.79	n.d.

*All soils under investigation contain less than 30% of sand.

RESULTS AND DISCUSSION

The influence of soil properties and slope factor on soil resistance to erosion:

Data in Table (1) summarise the mean values of the studied soil properties, while Table (2) shows Ki values of all sites under investigation. Calculated Ki values ranged from 2.25 x 10^5 to 5.39 x 10^5 ($kg.s.m^{-4}$). The values are comparable to those reported by Duiker et al (2001) where data ranges from 1.48 x 10^5 to 6.99 x 10^5 ($kg.s.m^{-4}$) for Spanish Mediterranean soils. Soil erodibility values in the present study were relatively different; accordingly soils will have varied response to the water erosion factors. The highest calculated Ki value (5.39 x 10^5 $kg.s.m^{-4}$) was found in Alhania soil which is characterized by the lowest clay content and the highest content of silt + very fine sand. In contrast, the lowest Ki value (2.25 x 10^5 $kg.s.m^{-4}$) was found in Alhamama soil which is characterized by the highest clay content and the lowest content of silt + very fine sand. These results are expected since the erodibility (Ki) equation depends on the clay content. The effect of soil texture on soil susceptibility to erosion is obvious in these soils. Clay is an effective bonding and aggregating factor, thus soil would have greater stability and larger aggregate size as a result of having higher clay content. In general well aggregated clay soil will support fast water movement throughout the soil layers. Zhang et al (2004) found a significant relation between soil erodibility and clay content,in which soils with higher clay content were less erodible.

Table (2) shows the calculated interrill detachment rate (Di). Since all sites are located in an area of 40 km diameter, one value of rainfall intensity was used. Thus Di values of the studied sites were differentiated by their erodibility (Ki) and slope factor (S_f) values. The minimum Di value was found in Alhamama 2 soil which is regarded as the least erodible.

The order of Di values did not follow that of the Ki values. Alhania soil (the highest value of Ki) was less detachable than Gandola soil. This can be explained by the fact that Gandola soil is located on steeper slope (10°) compared to Alhania soil which is located on slight slope (3°). Since soil detachment rate (Di) values were affected by the slope factor S_f which was used within the Di calculations. The influence of slope on soil erosion is evident as can be seen in Figure (3) which showed significant relation between slope and the detachment rate. On steeper slopes more splash downhill, more runoff and faster flow occur (Hudson, 1995) and consequently more soil loss.

The statistical relation between measured soil parameters and detachment rate (Di):

Multiple regression analysis (Table 3) showed low r^2 values between Di and the individual soil parameters, except clay percentage. However, r^2 was improved when the relation between Di and sets of more than one soil parameter were tested. In addition to the direct effect of soil particles, saturated hydraulic conductivity and exchangeable calcium could also contribute to the soil detachability process.

From Table (3) soil texture parameters, Ks and Ca^{+2} explained about 92% of the interrill detachment process. The influence of clay and silt + very fine sand is described above, while the exchangeable Ca^{+2} may decrease soil susceptibility to erosion and improve resistance by encouraging flocculation of soil colloids. Another stabilizing factor in the Mediterranean soils is the content of finely divided carbonates (Duiker et al, 2001). However, in this study soil content of calcium carbonates was not measured. In south western Kenya, Macharia et al (1997) investigated the effect of chemical properties on soil erodibility and found that 78% of the variations in soil loss were explained by exchangeable Ca and K; CEC; organic matter and EC.

Table 2. Calculated interrill erodibility WEPP-Ki (10^5 $kg.s.m^{-4}$) and interrill detachment rate WEPP-Di ($kg.m^{-2}.s^{-1}$)*

Sites	WEPP-Ki	Slope factor (Sf)	WEPP-Di
Elbieda 1	5.03	0.32	0.00017
Elbieda 2	4.08	0.21	0.00009
Elwosita 1	4.77	0.29	0.00014
Elwosita 2	3.81	0.21	0.00008
Elwosita 3	2.38	0.22	0.00006
Alhamama 1	3.07	0.28	0.00009
Alhamama 2	2.25	0.21	0.00005
Masa	5.07	0.26	0.00014
Alhania	5.39	0.24	0.00013
Gandola	5.11	0.32	0.00017

*Di values in this table only represent the rainy season (October to March) when the average rainfall intensity is applied in the WEPP-Di formula.

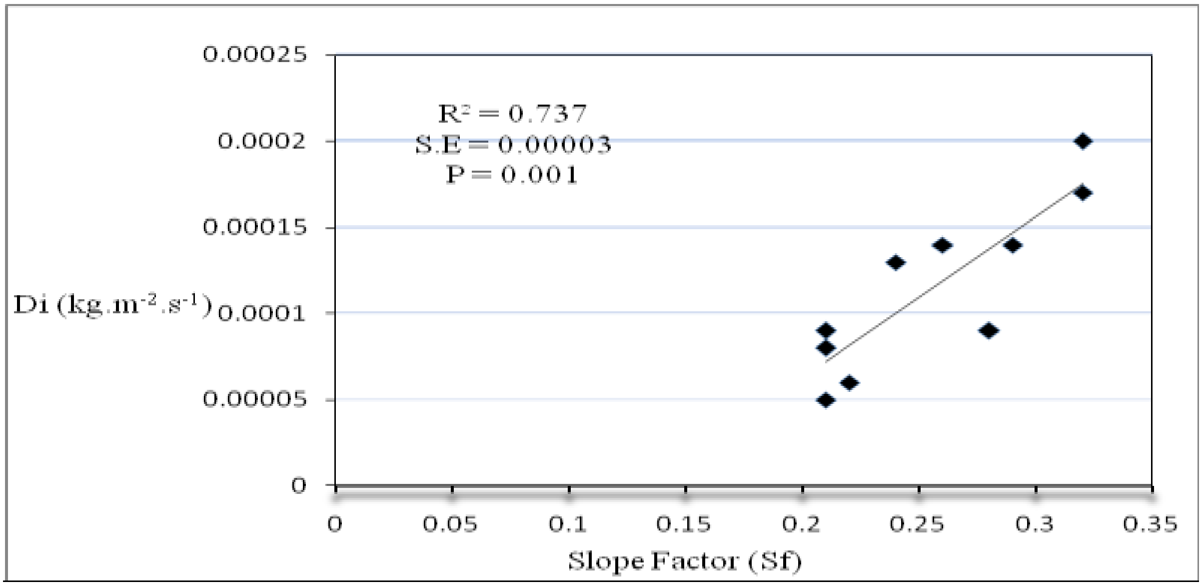

Figure 3. The relation between slope factors (S_f) and soil detachment rate(Di)

Table 3. Coefficient of determination (r^2), standard error (S.E) and level of significance between interrill detachment rate (WEPP-Di) and soil parameters, according to the multistep regression analyses

Soil parameters	r^2	Significance	S.E
Clay	0.75	**	0.00002
Silt + Very fine sand (Si + Vfs)	0.49	*	0.00003
Saturated Hydraulic Conductivity (Ks)	0.28	Ns	0.00004
Exchangeable Calcium (Ca^{+2})	0.48	*	0.00004
Clay + (Si + Vfs)	0.89	**	0.00002
Clay + (Si + Vfs) + Ca^{+2}	0.89	**	0.00002
Clay + (Si + Vfs) + Ca^{+2} + Ks	0.92	**	0.00002

*, **, ns: significant at the 0.05 and 0.01 probability levels and non significant, respectively

Comparison of the calculated erodibility (Ki) against the instability index:

The aggregate stability test has been applied to indicate change in soil resistance to erosion and may provide an early warning before soil is degraded. Since aggregate stability indirectly reflects the combined effects of soil properties, parent material, climate characteristics, vegetation and land use, it can be a good indicator for soil erodibility estimation (Cerda, 2000). A comparison was carried out between calculated WEPP-Ki and instability index obtained by wet sieving. According to the values of the two tested indictors, Alhania soil was the most erodible. Results (Table 4) indicated inconsistency between the orders of the values of both indicators. This can be explained by the fact that some soil properties that may influence the stability of soil structure were not considered in the used WEPP-Ki formula. Several environmental factors could affect the accuracy of WEPP-Ki formula to estimate soil erodibility. For more accurate estimation extra soil parameters need to be taken into account (Yao *et al*, 2004). Several studies pointed out the effect of clay mineral type and content of oxides. Vanelsland *et al* (1987) reported that amounts of kaolinitic clay and the content of free iron oxides significantly affect aggregate stability. Under the Libyan Mediterranean conditions, the study of Selkoz Brom Export (1980) showed that the soil content of kaolinitic clay was varied according to the soil types. Clay mineral type, in addition to other parameters such as labile carbon and hydraulic soil properties can add more understanding of the factors that affect soil structure stability and might lead to considerable improvement in the erodibility measurement.

CONCLUSIONS

The maximum interrill erodibility (Ki) values were corresponded to soils characterized by the lowest clay content and the highest content of silt + very fine sand, while the minimum Ki values were corresponded to soils characterized by the highest clay content and the lowest

Table 4. comparison of WEPP-Ki values (10^5 kg.s.m^{-4}) with the instability index (g.min^{-1})*

Sites	Instability index	WEPP-Ki
Alhania	0.57	5.39
Elwosita 1	0.23	4.77
Masa	0.22	5.07
Gandola	0.10	5.11

*The instability index values were not determined for the other six sites.

content of silt + very fine sand. Multiple regression analysis showed that soil texture parameters, saturated hydraulic conductivity and exchangeable calcium explained about 92% of the interrill detachment process. Slope factor also played an important role and contributed to the detachment rate. The comparison between WEPP-Ki and soil instability indicators showed general inconsistency. The study can conclude that extra soil parameters need to be considered in the WEPP-Ki formula to improve accuracy in soil erodibility estimation of the Red Mediterranean soils in Libya.

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الملخص العربي

تطبيق معادلة WEPP-K لتقدير إنجرافية بعض ترب البحر المتوسط الحمراء، ليبيا

مراد ميلاد أبوراس

نظرا للأهمية المتزايدة لأبحاث تدهور التربة فى الأقليم الشمالي الشرقي من ليبيا، فأنه من الضروري توفير المعلومات ذات العلاقة بقابلية التربة للإنجراف. تهدف الدراسة الحالية لتقدير قابلية التربة للإنجراف (Ki) ومعدل فصل حبيبات التربة (Di) بإستخدام معادلة WEPP، لتحقيق هذا الهدف تم تقدير بعض الخصائص الضرورية لتطبيق هذه المعادلة، تضمنت هذه الخصائص كل من مؤشرات قوام التربة والمادة العضوية والكالسيوم المتبادل والتوصيل الهيدروليكي المشبع. أوضحت النتائج أن قابلية التربة للإنجراف (Ki) قد تراوحت مابين 2.25×10^5 و 5.39×10^5 كجم.ثانية.متر$^{-4}$. إحصائيا وحسب نتائج تحليل الإنحدار فإن مؤشرات قوام التربة والتوصيل الهيدروليكي المشبع والكالسيوم المتبادل فسرت حوالي 92% من الإختلافات في معدل فصل التربة. كما بينت المقارنة بين معادلة WEPP-Ki المستخدمة في هذه الدراسة ودليل عدم ثباتية التربة أهمية إعادة النظر في المعادلة المذكورة والتي يجب ان تتضمن مستقبلا خصائص وعوامل أخرى ذات أهمية بالغة في التأثير على ثباتية بناء التربة تحت ظروف أقليم البحر المتوسط بليبيا.