J. Agr. Sci. Tech. (2014) Vol. 16: 1455-1466

Relationship between Soil Productivity and Erodibility in Rainfed Wheat Lands in Northwestern Iran

A. R. Vaezi[1*], and H. A. Bahrami[2]

ABSTRACT

Soil erosion by water is the main factor of land degradation, particularly in semi-arid regions where soil productivity is usually low and lowering soil quality can severely decrease crops yields. This study was done in an area of 900 km^2 in the semi-arid agricultural region of Hashtroud in northwestern Iran to determine the relationship between soil productivity and soil erodibility. Wheat grain yield (WGY) and soil erodibility factor (K) were measured separately at 108 plots in 36 dry-farming lands under natural rainfall conditions for a two-year period from March 2005 to March 2007. Based on the results, significant differences were observed among the lands in *WGY* ($P< 0.001$) and *K* ($P< 0.001$). These differences were attributed to variations of soil properties among the lands. There was a negative relationship between WGY and K ($R^2= 0.77$). Multiple regression analysis indicated that both WGY and K were significantly related to aggregate stability and infiltration rate, with a determination coefficient (R^2) of 0.74 and 0.90, respectively. Organic matter and calcium carbonate equivalent were the most effective soil properties that enhanced both aggregate stability and infiltration rate. The study revealed that soils with a lower percentage of water-stable aggregates and a lower infiltration rate also tended to have a higher susceptibility to erosion and a lower potential for crop production.

Keywords: Semi-arid region, Soil properties, Water erosion, Wheat grain yield.

INTRODUCTION

Soil productivity is defined as the capacity of a soil to produce a certain level of crop yield according to a specified system of management (Soil Science Society of America, 1997). It can be affected by various factors that may degrade or improve soil properties. Soil degradation is the temporary or permanent lowering of the productive capacity of soil, or its potential in relation to environmental management (Pieri *et al.*, 1995**;** Khormali *et al.,* 2009). Thus, assessment of soil productivity by determination of crop yield can be used as a direct means to evaluate features of soil degradation (Shresthaa *et al.,* 2004). Soil degradation is an important problem in cultivated lands, particularly in arid and semi-arid areas (Chikhaoui *et al.*, 2005; Shahriari *et al.,* 2011**;** Ayoubi *et al.,* 2012) due to its impacts on the sustainability of agricultural production (Atis, 2006).

Soil erosion has long been recognized as an important physical factor in reducing soil productivity (Fenton *et al.*, 2005; Afshar *et al.,* 2010). It is both the most visible and the most widespread factor of soil degradation (Erenstein, 1999). Soil erosion by water (water erosion) affects agricultural productivity in a number of ways, either directly or indirectly. It diminishes soil

[1] Department of Soil Science, Faculty of Agriculture, University of Zanjan, P. O. Box: 45371-38791, Zanjan, Islamic Republic of Iran.
[*] Corresponding author: e-mail: vaezi.alireza@gmail.com
[2] Department of Soil Science, Faculty of Agriculture, Tarbiat Modares University, Tehran, Islamic Republic of Iran.

productivity by reducing topsoil depth (Lal *et al.*, 2000); availability of water (Bossio *et al.,* 2010); nutrients (Li *et al.*, 2013) and organic matter (Fenton *et al.*, 2005), as well as by restricting rooting depth. Many studies have been done on the effect of soil erosion on crop yield and soil productivity (Bakker *et al.,* 2005; Wang *et al.*, 2009; Li *et al.*, 2012). A review of the related studies indicates that erosion reduces productivity on average by about 4% for each 10 cm of soil lost (Bakker *et al.,* 2004). A range of indirect methods have been used to quantify the effects of erosion on productivity including those involving the influences of past erosion on yield compared with productivity of un-eroded areas (Olson *et al.,* 1994; Bakker *et al.,* 2004). There is a lack of information that links the physical measures of soils susceptibility to water erosion to soil productivity, particularly in the semi-arid regions.

Soil erodibility is one of the factors affecting erosion, which can be considered as a physical measure to assess the degree of soils vulnerability to erosion (Chikhaoui *et al.*, 2005). In the universal soil loss equation (USLE) and its revised version (Renard *et al.,* 1991), the factor *K* expresses soil susceptibility to the processes of sheet and rill erosion. The inherent properties of soil play a major role in the ability of water to detach and transport its particles. The *K* collects the majority of soil properties and, for that reason, it has been one of the most common methods applied to evaluate erosion risks (Pérez-Rodríguez *et al.,* 2007). The evaluation of *K* may be difficult because it requires data collected over the long-term (Moebius-Clune *et al.*, 2011). However, this work is essential for making effective management decisions for agricultural lands.

Soil erosion by water is also a major environmental problem in many areas of Iran that threatens the sustainability of agricultural lands. Annually, about 500 million tons of soil is removed from about 15 Mha of agricultural lands (Samani *et al.,* 2009). East-Azarbijan Province is one of the most susceptible areas to water erosion in northwestern Iran. This area has a semi-arid climate with a mean annual precipitation of about 300 mm. Farming is mainly performed under rainfed conditions and water is the main factor limiting productivity (Agriculture and Economic Service of Iran, 2009). Cultivation in slope direction is the most important factor accelerating erosion, particularly in rainfed wheat lands.

The importance of studying the response of crop yield to soil erosion for assessment of the vulnerability of agricultural lands to erosion has been reported by other authors (Lal, 1983; Marathianou *et al.,* 2000). Nevertheless, there is a need to relate soil productivity to *K*. This is vital, particularly in semi-arid regions, where soil erosion can play an important role in lowering the soil productivity. Limited studies have been done on the relationship between crop yield and soil erosion in Iran. These studies have mostly focused on predicting crop yield using soil properties (Norouzi *et al.,* 2010)**;** the effect of erosion on crop yield (Mehdizadeh *et al.,* 2013) and cost-estimation of soil and water degradation (Samani *et al.,* 2009). In their study, it was assumed that (i) *WGY* under rainfed conditions can be related to *K*, and (ii) these two variables may be affected by the same soil properties. Therefore, the main objectives of the present study were to build upon these hypotheses by determining the relationship between *WGY* and *K* and by identifying soil properties influencing those variables in dry lands of a semi-arid region in northwestern Iran.

MATERIALS AND METHODS

Study Area

The study area was located in an agricultural region (30×30 km), between 37° 18' 39" - 37° 35' 0" N latitude, and 46° 46' 5"- 47° 6' 5" E longitude in the Hashtroud township, East-Azarbijan Province, northwestern Iran (Figure 1). The region has

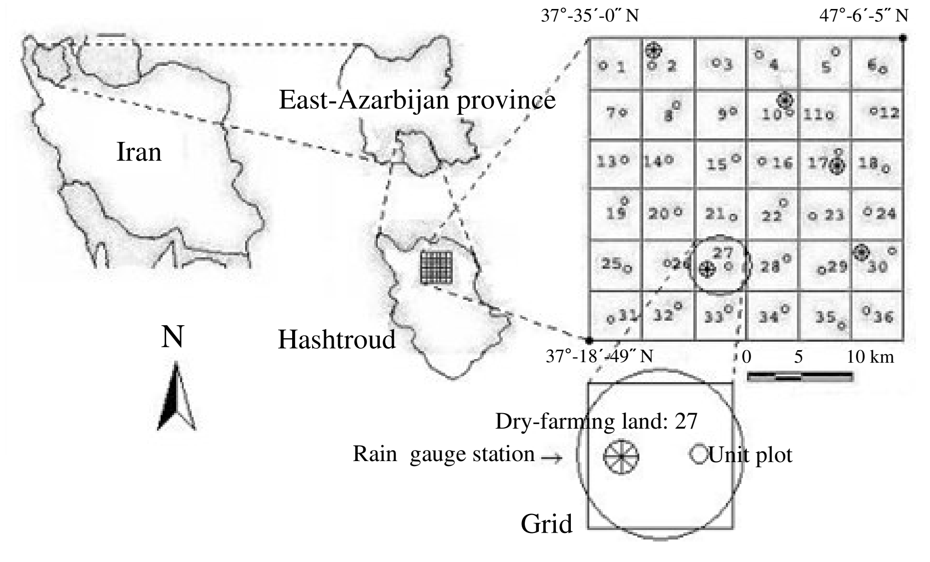

Figure 1. Location of the study area and the grids used for field experiments in northwestern Iran.

a semi-arid climate with an average annual precipitation of 322 mm. Most of the rainfalls occur during spring (from January to June) and autumn (from October to December). The mean annual temperature is 13°C. Elevation varies from 1,360 m to 1,700 m above sea level. Soil depth is generally in the range of 1.3 to 1.7 m. Soils are classified as Typic Calcic Xerepts according to the Soil Taxonomy classification system (Soil Survey Staff, 2010). Field crops such as wheat are most commonly planted on slopes of 5-15% (Hakimi, 1986). In order to determine WGY and K, thirty-six grids with dimensions of 5×5 km were considered on the slope map of the area. After field observations, a rainfed farmland in fallow condition located in a uniform slope of 9% was selected in each grid to install standard plots according to the USLE criteria (Wischmeier and Smith, 1978). The lands had historically identical conditions in tillage practices and field management (fallowing, fertilization, etc.). Immediately after plowing, the plots were harrowed to provide a smooth and uniform surface on early March 2005. Although measurements of yield on eroding lands have been used to assess the effect of soil erosion on productivity (Bakker *et al.,* 2004), in this study, *WGY* and *K* were determined separately in two sites (crop site and erosion site) covering an area of 200 m^2 with 10 m spacing in each land. Three plots with 22.1 m length and 1.83 m width, and 1.2 buffer bed were installed in each site according to the field measurements. Overall, field experiments were done in 216 plots (36×2×3) for a 2-year period (from March 2005 to March 2007

Determination of Wheat Grain Yield

Traditionally, wheat is the main crop in the area and is planted in two different times under rainfed conditions: early autumn (October) and early spring (March). Since winter wheat is widely planted in the area and measuring *K* under snow condition could be very difficult, spring wheat was selected for cultivation in the crop sites. It was planted in three plots in each farm right after plowing in March. The Sardary variety, that is normally grown for bread-making, was planted at the depth of about 4-6 cm, with row spacing of 20 cm and plant spacing of 5 cm. Chemical fertilizers were not applied to any of the crop plots in an attempt to create the same condition with those of erosion site. Length of the growing period was about four months and on July 25, wheat samples were randomly taken from an area of 1 m^2 from three locations in each plot. Mean annual WGY was calculated for each land from average of yield values of the three plots (t ha^{-1}) for a two-year period.

Determination of the Soil Erodibility Factor (K)

To determine K, after installation of three plots in the erosion site, plots were surrounded using soil ridges 30 cm in height. Runoff-collecting equipment consisting of gutter pipes, pipes and 70-liter tanks were established at the lower parts of the plots. To avoid adjustment for residue cover and effects of plant canopy, plots were maintained in a bare condition. The total volume of runoff-sediment was determined from each tank after each rainfall event resulting in soil loss. After mixing contents of the tank thoroughly, a uniform sample was taken, filtered, dried and weighed to determine the concentration of sediment (Guy, 1975). Soil loss in each rainstorm was calculated through multiplying the total volume of contents by the sediment concentration (Zhang *et al.*, 2004). Value of *K* for each plot (t h MJ^{-1} mm^{-1}) was determined using annual soil loss (t ha^{-1} yr^{-1}) per unit of the rainfall erosivity factor (R). The mean *K* of each land was obtained from averaging annual *K* values in three plots for a two-year period. The *R* (MJ mm ha^{-1} h^{-1} yr^{-1}) was calculated by the summation of the erosivity index (EI_{30}) of rainfalls for each year (Wischmeier and Smith, 1978). The spatial distribution of rainfalls was investigated in five stations throughout the area (Figure 1). Four standard rain gauge stations were located in the grids 2, 10, 27, and 30, with an automatic recording gauge station in grid 17 were used to measure depth of rainfalls. Data collected from the recording gauge station was also used to determine EI_{30}.

Measurement of Soil Properties

To identify the soil properties influencing *K* and *WGY*, soil samples (0-30 cm depth) were taken randomly from three locations in each plot, before plowing. The samples were mixed together and a representative sample was provided and passed through a 2 mm sieve. Particle size distribution of coarse sand (0.1-2 mm), very fine sand (0.05-0.1 mm), silt and clay was determined by the pipette method (SSEW, 1982). Gravel (2-8 mm) was determined using the weighting method (Gee and Bauder, 1980). Soil pH and *EC* were measured by a pH meter and an EC meter, respectively. Total organic carbon was measured by the Walkley–Black wet dichromate oxidation method (Nelson and Sommer 1982). Calcium carbonate equivalent was measured using the titration method (Goh *et al.*, 1993). Total nitrogen (TN) was determined using a Kjeldahl digester after treatment with H_2SO_4 (Jones, 2001). Soil phosphorus was determined by extraction with sodium bicarbonate (Olsen *et al.*, 1954). Soil exchangeable potassium was determined using a flame photometer after extraction with ammonium-acetate (Black *et al.*, 1965). Aggregate stability was determined using the wet-sieving method and calculated as mean weight diameter (MWD) (Angers and Mehuys, 1993). Bulk density was determined using a core sampler (Blake and Hartge, 1986) with 5 cm diameter and 6 cm height. Soil infiltration rate was determined based on the final infiltration rate (K_s) using a double-ring infiltrometer (Bouwer, 1986) with four to six replications in each land at the end of the dry season.

Statistical Analysis

In order to determine spatial homogeneity of the rainfalls, differences in rainfall depths among the stations were analyzed using one-way ANOVA. Differences of *WGY* and *K* among the lands were analyzed using Duncan's parametric test. Relationship between *WGY* and *K* was quantified using different functions (linear, etc.) and the best relationship was obtained based on the highest determination coefficient (R^2). Soil properties affecting *WGY* and *K* were extracted using the Pearson's correlation coefficient (r). A stepwise multiple linear regression analysis was applied to develop a relationship between *WGY* and *K*, and soil properties. All data were assessed for normality using the Kolmogorov-Smirnov test before analysis. SPSS 18 software was used in all statistical analysis.

RESULTS AND DISCUSSION

Soil Properties

Total soils of the lands were grouped into five classes as follows: clay loam (23), loam (9), sandy clay loam (2), silty clay loam (1), and sandy loam (1). As shown in Table 1, the soils were calcareous with an average of 12.7% calcium carbonate equivalent. Amount of organic matter in the soils was low (1.1% on average). Soil pH varied from 7.3 to 8.2. Soil electrical conductivity varied among the soils from 0.32 to 2.19 dS m^{-1}. The soils had very low amounts of nitrogen (about 0.1%), while that of potassium was relatively high (314.7 mg kg^{-1} on average). The aggregates were relatively unstable with a *MWD* ranging from 0.27 to 1.91. Values of K_s varied widely from 1.4 to 5.8 cm h^{-1} in the area.

Rainfall Erosivity Factor

The rainfall erosivity factor (R) was calculated to be 334.543 MJ mm ha^{-1} h^{-1} year^{-1} in the area. Out of 97 rainfall events, 41 rainstorms led to soil loss at the erosion plots. The mean depth of rainstorms in the rain gauge stations located in grids 2, 10, 17, 27 and 30 were 7.15, 6.77, 6.98, 7.08 and 6.82 mm, respectively. Analysis of variance (Table 2) showed no significant difference among stations in rainstorms depth (F= 0.027, P-value= 0.994). Thus, spatial

Table 1. Soil properties in the study area.

Soil variable	Min	Max	Mean	Standard deviation
Coarse sand (%)	9.90	29.40	18.9	5.2
Very fine sand (%)	12.60	25.80	17.8	3.2
Silt (%)	20.2	44.8	31.6	7.1
Clay (%)	20.8	42.2	32.0	5.7
Gravel (%)	5.3	14.8	9.9	2.4
Organic matter (%)	0.7	2.1	1.1	0.2
Equivalent calcium carbonates (%)	4.1	23.7	12.7	5.2
pH	7.3	8.2	7.8	0.2
EC (dS m^{-1})	0.3	2.2	0.8	0.3
Total nitrogen (%)	0.1	0.2	1.0	0.1
Phosphorous (mg kg^{-1})	2.8	14.4	7.7	2.7
Potassium (mg kg^{-1})	237.4	390.5	314.7	25.4
Bulk density (g cm^{-3})	1.0	1.7	1.4	0.2
MWD (mm)	0.3	1.9	1.13	0.44
K_s (cm h^{-1})	1.4	5.8	3.5	1.2

Table 2. Analysis of variance for the rainstorms depth values of the different rain stations.

Location of the rain gauge station	Mean	F	P-value
Grid 2	7.15	0.027	0.994
Grid 10	6.77		
Grid 17	6.98		
Grid 27	7.08		
Grid 30	6.82		

distribution of rainstorms depth was uniform and, in consequence, variation of soil loss in different lands could be directly related to *K*.

Relationship between *WGY* and *K*

Mean *WGY* varied widely among the lands from 0.801 to 3.484 t ha^{-1} (Table 3). Sandy loam and silty clay loam were identified as having the lowest and the highest WGY (0.801 and 3.316 t ha^{-1}, respectively) among the soil textures. Values of *K* ranged from 0.002 t h MJ^{-1} mm^{-1} in silty clay loam to 0.007 t h MJ^{-1} mm^{-1} in sandy loam (Table 3). Significant differences were observed among the lands in *WGY* and *K* (P< 0.001) (Table 4). These differences could be attributed to variation of soil properties among the lands.

A significant negative relationship was observed between *WGY* and *K* (R^2= 0.77, P< 0.001) (Figure 2). Regarding the relatively high dependency between the two variables, there may be some soil properties that declined *K* and in turn improved soil productivity. This result is different from that of other research, which showed that soil degradation and deterioration of soil properties led to lower soil productivity (den Biggelaar *et al.*, 2004; Ye and Van Ranst, 2009) and higher rate of soil erosion.

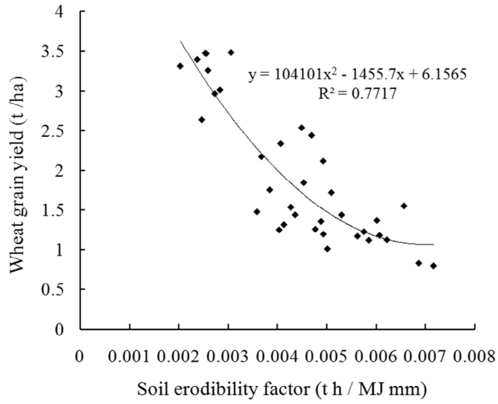

Figure 2. Relationship between *WGY* and *K* in the study area for a 2-year period.

Soil Properties Influencing *WGY* and *K*

Results of correlation analysis indicated that *WGY* and *K* were significantly correlated with the content of coarse sand, very fine sand, silt, clay, organic matter, and calcium carbonate equivalent as well as pH, *MWD*, and K_S (Table 5). Some soil properties that considerably declined the value of *K* (coarse sand, very fine sand, silt, clay, organic matter, calcium carbonate equivalent, pH, aggregate stability, and permeability) positively affected *WGY*. Value of *K* was strongly increased by increasing very fine sand and silt particles. Nitrogen was the only factor affecting *WGY* and soil fertility (Liebig *et al*., 2006), and was determined as having no significant correlation with *K*. Research by Norouzi *et al.* (2010) in a semi-arid region showed that *WGY* under rainfed conditions was mostly affected by soil total nitrogen. Although *EC* is usually an important index in assessments of soil productivity in rainfed wheat production (Yong *et al*., 2009), there was no considerable correlation between *WGY* and *EC*.

Table 3. Statistical descriptive of WGY and K in thirty six lands for a 2-year period.

Variable	Min	Max	Mean	Standard deviation
Wheat grain yield (t ha^{-1})	0.801	3.484	1.938	0.868
Soil erodibility factor (t h MJ^{-1} mm^{-1})	0.002	0.007	0.004	0.001

Table 4. Analysis of variance of the *WGY* and the *K* in rainfed lands.

Variable	Sum of squares	df	Mean Square	F	Significant level
Wheat grain yield	5.71×10^{7}	35	1631653.08	71.41	0.000
Soil erodibility factor	2.00×10^{-4}	35	1.00×10^{-5}	68.74	0.000

Table 5. Correlation matrix of soil properties, soil erodibility factor and wheat grain yield in the study soils.[a]

	CS[a]	VFS[b]	Si[c]	Cl[d]	Gr[e]	OM[f]	CCe[g]	BD	MWD[h]	K_s[i]	N[j]	P[k]	K[l]	pH	EC	K[m]	WGY[n]
CS	1																
VFS	0.22	1															
Si	-0.74***	-0.20	1														
Cl	-0.18	-0.50**	-0.40*	1													
Gr	0.03	-0.07	0.02	-0.06	1												
OM	0.27	-0.31*	-0.23	0.21	0.16	1											
CCe	-0.01	-0.56***	0.17	0.03	-0.03	0.05	1										
BD	0.26	0.31	0.11	-0.59**	-0.01	-0.33*	0.04	1									
MWD	-0.17	-0.67***	-0.12	0.70***	-0.09	0.29*	0.48**	-0.44**	1								
K_s	0.76***	-0.05	-0.55***	-0.07	0.09	0.54**	0.29*	0.14	0.13	1							
N	0.06	-0.16	-0.09	0.24	0.13	0.60**	-0.24	-0.06	0.22	0.11	1						
P	-0.03	0.16	0.25	-0.34*	-0.13	0.11	-0.30	-0.09	-0.33*	-0.01	0.31	1					
K	-0.07	-0.05	-0.18	0.31*	0.09	0.06	-0.09	-0.18	0.22	0.08	-0.07	-0.11	1				
pH	0.10	-0.50**	-0.21	0.44**	-0.02	0.06	0.47**	-0.07	0.56**	0.26	-0.08	-0.54**	0.19	1			
EC	-0.33*	-0.19	0.41*	-0.11	-0.07	0.03	0.36*	0.11	0.24	-0.14	-0.04	-0.07	-0.17	-0.03	1		
K	-0.49**	0.43**	0.46**	-0.31*	-0.13	-0.54**	-0.55**	0.14	-0.64***	-0.78***	-0.18	0.23	-0.16	-0.57 **	-0.06	1	
WGY	0.50**	-0.38**	-0.63**	0.51**	0.06	0.68**	0.31*	-0.23	0.60***	0.69***	0.29*	-0.20	0.17	0.44**	-0.04	-0.84***	1

[a] CS: Coarse Sand; VFS: Very Fine Sand; Si: Silt; Cl: Clay; Gr: Gravel; OM: Organic matter; CCe: Calcium Carbonate equivalent; BD: Bulk Density; MWD: Mean Weight-Diameter (Aggregate stability); K_s: Final infiltration rate; N: Nitrogen; P: Phosphorous, K: Potassium; K: Soil erodibility factor; WGY: Wheat Grain Wield.

***: Correlation significant at $P< 0.001$; **: Correlation significant at $P< 0.01$; *: Correlation significant at $P< 0.05$.

Based on the results, *K* had the highest correlation with *MWD* and K_s with a correlation coefficient (r) of 0.64 and 0.78, respectively. Some studies also showed that the aggregate stability is a critical component of soil erodibility as it controls soil dispersion, surface seal development, and thus the extent to which runoff occurs (Ries and Hirt, 2008; Rhoton and Duiker, 2008). Results on the negative effect of K_s on *K* accorded with Zehetner and Miller (2006) who found that the surface runoff and soil erodibility decreases by increasing the permeability. Results indicated that WGY was strongly correlated with *MWD* (r= 0.60) and K_s (r= 0.69). In general, soil structure is a significant factor affecting plant growth because it influences water movement and water retention, nutrient recycling, and root penetration (Lupwayi *et al.*, 2001). Favorable soil structure and high aggregate stability are important factors required to improve soil productivity, and decrease *K* (Bronick and Lal, 2005; Karchegani *et al.,* 2012). There was no significant correlation between *MWD* and *Ks* (r= 0.13) because it was determined in aggregate samples taken from soil surface, while K_s was measured on the basis of final infiltration rate. Soil infiltration rate (K_s) was an important soil factor in the soil productivity particularly in high intensity rainfalls, so that, with increasing it, water demand for the wheat growth was supplied during growth period.

Regression analysis indicated that both *WGY* and *K* were strongly related to *MWD* and K_s (R^2= 0.74, P< 0.001 and R^2= 0.90, P< 0.001, respectively) (Table 6). With an increase in *MWD* and K_S, value of *K* declined remarkably and, consequently, *WGY* and soils productivity improved. Both *MWD* and K_S were significantly affected by some independent soil properties including mineral particles (coarse sand, very fine sand, silt, and clay), organic matter, and calcium carbonate equivalent. The effective soil properties, except the content of very fine sand and silt, considerably enhanced either *MWD* or K_s, and in consequence remarkably decreased *K* and improved *WGY* in the area. Calcium carbonate equivalent (CCE) and organic matter were the most effective soil properties that improved both *MWD* and K_s. Calcium carbonate equivalent (CCE) increased Ca^{2+} in soil exchange phase and so stimulated flocculation of colloids and increased the *MWD* and decreased the *K* (Duiker *et al.*, 2001).

Organic matter was the only soil property influencing *K* and *WGY* that, contrary to the other effective soil properties, could be affected by soil and crop management. The role of soil organic matter as a factor affecting sustainability of eco-geomorphic systems has been well reported in some studies (Marqués *et al.*, 2005; Khormali *et al.,* 2009). The importance of organic matter in soil productivity springs from its effects on aggregation, structural stability, water retention, infiltration rate, and amount of available water for plant. At the same time, organic matter contributes to soil fertility by serving as a source of plant nutrients. Bonding, adsorption processes, and interactions with polyvalent cations explain why organic matter has often been found to be positively correlated to soil structure but negatively correlated to soil erosion (Sarah, 2006). Therefore, adding organic matter to the soils can be an effective management practice to improve physical properties, reduce soil erodibility, and enhance soil

Table 6. Regression analysis of the relationships between *K* and *WGY* [a], and *MWD* [b] and K_S [c] in the study area.

	Soil erodibility factor (K)			Wheat Grain Yield (WGY)		
Soil property	Coefficient	Std. error	Sig. level	Coefficient	Std. error	Sig. level
Constant	0.00940	0.00029	p< 0.001	-0.85762	0.29723	p< 0.01
MWD [a]	-0.00170	0.00017	p< 0.001	1.01786	0.17472	p< 0.001
K_s [b]	-0.00085	0.00007	p< 0.001	0.46062	0.06636	p< 0.001

[a] Wheat Grain Yield [b] Mean Weight-Diameter, [c] Final infiltration rate.

productivity in the area.

CONCLUSIONS

There were significant differences among the rainfed lands in *WGY* and *K*. These differences were associated with variations of soil properties among the lands. *WGY* and *K* had significant correlations with soil content of coarse sand, very fine sand, silt, clay, organic matter, and calcium carbonate equivalent, as well as pH, *MWD*, and K_s. Multiple regression analysis indicated that both *WGY* and *K* were significantly related to *MWD* and K_S with R^2 of 0.74 and 0.90, respectively. Organic matter and calcium carbonate equivalent improved both *MWD* and K_S and, consequently, decreased *K* and enhanced *WGY*. Therefore, maintaining crop residues and adding organic manures to soil can be an effective management practice to improve soil physical properties in order to reduce soil erodibility and enhance soil productivity in the area.

REFERENCES

1. Afshar, F. A., Ayoubi, S. and Jalalian, A. 2010. Soil Redistribution Rate and Its Relationship with Soil Organic Carbon and Total Nitrogen Using 137Cs Technique in a Cultivated Complex Hillslope in Western Iran. *J. Environ. Radioact.,* **101(8):** 606-14.
2. Agriculture and Economic Service of Iran. 2009. *Climate and Water Resources in East-Azarbijan Province.* Publisher?? Location?? PP. 3–5.
3. Angers, D. A. and Mehuys, G. R. 1993. Aggregate Stability to Water. In: "*Soil Sampling and Methods of Analysis*", (Ed.): Cartner, M. R.. Canadian Society of Soil Science, Lewis Publishers, Boca Raton, Canada, PP. 651–657.
4. Atis, A. 2006. Economic Impacts on Cotton Production due to Land Degradation in the Gediz Delta, Turkey. *Land Use Policy*, **23:** 181–186.
5. Ayoubi, S., Mokhtari Karchegani, P., Mosaddeghi, M. R. and Honarjoo, N. 2012, Soil Aggregation and Organic Carbon as Affected by Topography and Land Use Change in Western Iran. *Soil Till. Res.,* **121:** 18-26.
6. Bakker, M. M., Govers, G., Kosmas, C., Vanacker, V., Van Oost, K. and Rounsevell, M. 2005. Soil Erosion as a Driver of Land-use Change. *Agr. Ecosyst. Environ.*, **105:** 467–481.
7. Bakker, M. M., Govers, G. and Rounsevell, M. D. A. 2004. The Crop Productivity-erosion Relationship: An Analysis Based on Experimental Work. *Catena,* **57:** 55–76.
8. den Biggelaar, C., Lal, R., Wiebe, K. and Breneman, V. 2004. The Global Impact of Soil Erosion on Productivity. Absolute and Relative Erosion-induced Yield Losses. *Adv. Agron.,* **72:** 1–52.
9. Black, C. A., Evans, D. D., White, J. L., Ensminger, L. E. and Clark, F. E. 1965. Methods of Soil Analysis. Part 2. "*Chemical and Microbiological Properties*". American Society of Agronomy, Soil Science Society of America, Madison, Wisconsin, USA, *Agronomy Series No. 9*, 801 PP.
10. Blake, G. R. and Hartge, K. H. 1986. Bulk Density. Part 1. Physical and Mineralogical Methods. In: "*Methods of Soil Analysis*", (Ed.): Klutem, A.. 2nd Edition, ASA-SSSA, PP. 363–376.
11. Bossio, D., Geheb, K. and Critchley, W. 2010. Managing Water by Managing Land: Addressing Land Degradation to Improve Water Productivity and Rural livelihoods. *Agr. Water Manage*., **97:** 536–542.
12. Bouwer, H. 1986. Intake Rate: Cylinder Infiltrometer. Part 1. Physical and Mineralogical Methods. In: "*Methods of Soil Analysis*", (Ed.): Klutem, A.. 2nd Edition, American Society of Agronomy, Soil Science Society of America, Inc., Madison, Wisconsin, USA, PP. 341–345.
13. Bronick, C. J. and Lal, R. 2005. Soil Structure and Management: A Review. *Geoderma*, **124:** 3–22.
14. Chikhaoui, M., Bonn, F., Bokoye, A. I. and Merzouk, A. 2005. A Spectral Index for Land Degradation Mapping Using ASTER Data: Application to a Semi-arid Mediterranean Catchment. *Int. J. Appl. Earth Observ. Geoinfo*., **7:** 140–153.
15. Duiker, S. W., Flanagan, D. C. and Lal, R. 2001. Erodibility and Infiltration Characteristics of Five Major Soils of Southwest Spain. *Catena*, **45:** 103–121.

16. Erenstein, O. C. A. 1999. The Economics of Soil Conservation in Developing Countries: The Case of Crop Residue Mulching. Ph.D. Thesis, Wageningen University, Wageningen, The Netherland.
17. Fentonm T. E., Kazemim, M. and Lauterbach-Barrettm, M. A. 2005. Erosional Impact on Organic Matter Content and Productivity of Selected Iowa Soils. *Soil Till. Res.*, **81:** 163–171.
18. Gee, G. W. and Bauder, J. W. 1980. Particle-size Analysis. Part 1. Physical and Mineralogical Methods. In: "*Methods of Soil Analysis*", (Ed.): Klutem, A.. 2nd Edition, American Society of Agronomy, Soil Science Society of America, Inc., Madison, Wisconsin, USA, PP. 383–385.
19. Goh, T. B., Arnaud, R. J. St. and Mermut, A. R. 1993. Aggregate Stability to Water. In: "*Soil Sampling and Methods of Analysis*", (Ed.): Cartner, M. R.. Canadian Society of Soil Science, Lewis Publishers, Boca Raton, Canada, PP. 177–180.
20. Guy, H. P. 1975. Laboratory Procedures of Sediment Measurement Techniques. In: "*Sedimentation Engineering*", (Ed.): Anoni, V. A.. Am. Soc. Civil Eng., New York, NY, USA, PP.184.
21. Hakimi, A. 1986. The Briefly Study of Soil Science in Hashtrood. Soil and Water Research Institute, Agriculture Ministry, Iran, *Res. Report*, **767:** 2–15. (in Persian)
22. Jones, J. B. 2001. *Laboratory guide for conducting soil tests and plant analysis*. CRC Press, Corporate Blvd. Boca Raton, New York, P. 203.
23. Karchegani, P., Ayoubi, S., Mosaddeghi, M. R. and Honarjoo, N. 2012. Soil Organic Carbon Pools in Particle-size Fractions as Affected by Slope Gradient and Land Use Change in Hilly Regions, Western Iran. *J. Mountain Sci.,* **9:** 87-95.
24. Khormali, F., Ajami, M., Ayoubi, S., Srinivasarao, Ch. and Wani, S. P. 2009. Role of Deforestation and Hillslope Position on Soil Quality Attributes of Loess-derived Soils in Golestan Province, Iran. *Agr. Ecosyst. Environ.*, **134:** 178–189.
25. Lal, R., Ahmadi, M. and Bajracharya, R. M. 2000. Erosional Impacts on Soil Properties and Corn Yield on Alfisols in Central Ohio. *Land Degrad. Dve.*, **11:** 575–585.
26. Lal, R. 1983. Soil Erosion in the Humid Tropics with Particular Reference to Agricultural Land Development and Soil Management. *Proceedings of the Hamburg Symposium in Hydrology of Humid Tropical Regions with Particular Reference to the Hydrological Effects of Agriculture and Forestry Practice*, August 1983, IAHS' Publ. No. 140.
27. Li, X., Zheng, J., Li, X., Tan, H., Pan, Y. and Wei, Y. 2013. Responses of Runoff, Sedimentation, and Induced Nutrient Loss to Vegetation Change in the Tengger Desert, Northern China. *Aust. J. Soil Res.*, **51(1):** 1–9.
28. Li, Z., Jie, J., Shuhan, D. and Gangcai. 2012. A Quantification of the Effects of Erosion on the Productivity of Purpole Soils. *J. Mt. Sci.* **9:** 96–104.
29. Liebig, M. A., Gross, J. R., Kronberg, S. L., Hanson, J. D., Frank, A. B. and Phillips, R. L. 2006. Soil Response to Long-term Grazing in the Northern Great Plains of North America. *Agr. Ecosyst. Environ.*, **115:** 270–276.
30. Lupwayi, N. Z., Arshad, M. A., Rice, W. A. and Clayton, G. W. 2001. Bacterial Diversity in Water-stable Aggregates of Soils under Conventional and Zero Tillage Management. *Appl. Soil Ecol,* **16:** 251– 261.
31. Marathianou, M., Kosmas, C., Gerontidis, S. and Detsis, V. 2000. Land Use Evolution and Degradation in Lesvos (Greece): A Historical Approach. *Land Degrad. Dev.,* **11:** 63–73.
32. Marqués, M. J., Jiménez, L., Pérez-Rodríguez, R., GarcÍa-Ormaechea, S. and Bienes, R. 2005. Reducing Water Erosion in a Gypsic Soil by Combined Use of Organic Amendment and Shrub Revegetation. *Land Degrad. Dve.*, **16:** 339–350.
33. Mehdizadeh, B., Asadi1, H., Shabanpour, M. and Ghadiri, H. 2013. Impact of Erosion and Tillage on the Productivity and Quality of Selected Semiarid Soils of Iran. *Int. Agrophys.,* **27:** 291–297.
34. Moebius-Clune, B. N., van Es, H. M., Idowu, O. J., Schindelbeck, R. R., Kimetu, J. M., Ngozea, S., Lehmann, J. and Kinyangi, J. M. 2011. Long-term Soil Quality Degradation along a Cultivation Chronosequence in Western Kenya. *Agr. Ecosyst. Environ.*, **141:** 86–99.
35. Nelson, D. W. and Sommer, L. E. 1982. Total Carbon, Organic Carbon, and Organic Matter. In: "*Methods of Soil Analysis*", (Ed.): Page, A. L.. 2nd Edition, ASA

Monogr., 9(2), American Society of Agronomy Madison, WI, PP. 539–579.

36. Norouzi, M., Ayoubi, S., Jalalian, A., Khademi, H. and Dehghani, A. A. 2010. Predicting Rainfed Wheat Quality and Quantity by Artificial Neural Network Using Terrain and Soil Characteristics. *Acta. Agri. Scan. Soil Plant Sci.,* **6(4):** 341–352.
37. Olson, K. R., Lal, R. and Norton, L. D. 1994. Evaluation of Methods to Study Soil Erosion-Productivity Relationships. *J. Soil Water Conserv.,* **49:** 588–590.
38. Olsen, S. R., Cole, C. V., Watanabe, F. S. and Dean, L. A. 1954. *Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate*. US Dep. of Agric. Circ., 939 PP.
39. Pérez-Rodríguez, R., Maria Jose Marques, M. J. and Bienes, R. 2007. Spatial Variability of the Soil Erodibility Parameters and Their Relation with the Soil Map at Subgroup Level. *Sci. Total Environ.,* **378:** 166–173.
40. Pieri, C., Dumanski, J., Hamblin, A. and Young, A. 1995. Land Quality Indicators. WB Discussion Paper No. 315, Washington DC.
41. Renard, K., Foster, G. R., Weesies, G. A. and Porter, J. P. 1991. RUSLE (Revised Universal Soil Loss Equation). *J. Soil Water Conserv.,* **46:** 30–33.
42. Rhoton F. E. and Duiker S.W. 2008. Erodibility of a Soil Drainage Sequence in the Loess Uplands of Mississippi. *Catena*, **75:** 164–171.
43. Ries, J. B. and Hirt, U. 2008. Permanence of Soil Surface Crusts on Abandoned Farmland in the Central Ebro Basin/Spain. *Catena,* **72:** 282–296.
44. Samani, A. N., Ahmadi, H., Jafari, M., Boggs, G., Ghoddousi, J. and Malekian, A. 2009. Geomorphic Threshold Conditions for Gully Erosion in Southwestern Iran (Boushehr-Samal Watershed). *J. Asian Earth Sci.,* **35:** 180–189.
45. Sarah, P. 2006. Soil Organic Matter and Land Degradation in Semi-arid Area, Israel. *Catena*, **67:** 50 – 55.
46. Shahriari , A., Khormali , F., Kehl , M., Ayoubi , Sh. and Welp, G. 2011. Effect of a Long-term Cultivation and Crop Rotations on Organic Carbon in Loess Derived Soils of Golestan Province, Northern Iran. *Int. J. Plant Produc.* **5:** 147–152.
47. Shresthaa, D. P., Zinck, J. A. and Van Ranst, E. 2004. Modelling Land Degradation in the Nepalese Himalaya. *Catena*, **57:** 135–156.
48. Soil Science Society of America. 1997. *Glossary of Soil Science Terms*. Madison, WI, 138p.
49. Soil Survey Staff. 2010. *Keys to Soil Taxonomy*. 11th Edition, USDA-Natural Resources Conservation Service, Washington, DC, 365p.
50. SSEW. 1982. *Soil Survey Laboratory Methods*. Technical Monographs No. 6**,** Harpenden, UK.
51. Wang, Z., Liu B., Wang, X. Y., Gao X. F. and Liu, G. 2009. Erosion Effect on the Productivity of Black Soil in Northeast China. *Sci. China Series D. Earth Sci.,* **52(7):** 1005–1021.
52. Wischmeier, W. H. and Smith, D. D. 1978. *Predicting Rainfall Erosion Losses: A Guide to Conservation Planning*. Agriculture Handbook No. 537, US Department of Agriculture, Washington, DC, PP. 13–27.
53. Ye, L. and Van Ranst, E. 2009. Production Scenarios and the Effect of Soil Degradation on Long-term Food Security in China. *Global Environ. Chang.*, **19(4):** 464–481.
54. Yong, Z., Minzan, L. and Junning, Z. 2009. Correlation between Soil Electrical Conductivity and Winter Wheat Yield. *Transactions of the Chinese Society of Agricultural Engineering, 2*, Available at the: http://en.cnki.com.cn/Article_en/CJFDTOTAL-NYGU2009S2007.htm.
55. Zhang, K., Li, S., Peng, W. and Yu, B. 2004. Erodibility of Agricultural Soils and Loess Plateau of China. *Soil Till. Res.,* **76:** 157–165.
56. Zehetner, F. and Miller, W. P. 2006. Erodibility and Runoff-infiltration Characteristics of Volcanic Ash Soils along an Altitudinal Climosequence in the Ecuadorian Andes. *Catena,* **65:** 201–213.

رابطه بین باروری خاک و فرسایش پذیری در دیمزارهای گندم در شمال غربی ایران

ع. ر. واعظی و ح. ع. بهرامی

چکیده

فرسایش خاک به وسیله آب، عامل عمده تخریب زمین به ویژه در مناطق نیمه‌خشک است. در این مناطق توان باروری خاک معمولاً پایین بوده و افت کیفی خاک منجر به کاهش شدید عملکرد می‌شود. این مطالعه در منطقه‌ای کشاورزی با وسعت ۹۰۰ کیلومتر مربع در ناحیه‌ای نیمه‌خشک در شمال غربی ایران به منظور تعیین رابطه بین باروری خاک و فرسایش پذیری انجام گرفت. برای این منظور عملکرد دانه گندم و فرسایش‌پذیری خاک به طور جداگانه در ۱۰۸ کرت واقع در ۳۶ کشتزار دیم تحت باران طبیعی طی دوره ۲ ساله از فروردین ۱۳۸۴ تا فروردین ۱۳۸۶ اندازه‌گیری شدند. بر اساس نتایج، تفاوت-های معنی‌داری بین کشتزارهای مورد بررسی از نظر عملکرد گندم ($p< ۰/۰۰۱$) و نیز فرسایش‌پذیری خاک ($p< ۰/۰۰۱$) مشاهده شد. این تفاوت‌ها با تغییرات ویژگی‌های خاک در زمین‌های مورد بررسی همراه بود. رابطه‌ای منفی بین عملکرد گندم و فرسایش‌پذیری خاک وجود داشت ($R^۲ = ۰/۷۷$). تجزیه رگرسیونی چندگانه خطی نشان داد که عملکرد گندم و فرسایش‌پذیری خاک هر دو با پایداری خاکدانه و نفوذپذیری خاک به ترتیب با ضریب تعیین ($R^۲$) برابر ۰/۷۴ و ۰/۹۰ ارتباط دارند. ماده آلی و کربنات کلسیم معادل به عنوان مؤثرترین ویژگی‌های خاک از نظر بهبود پایداری خاکدانه و نفوذپذیری خاک بودند. این مطالعه نشان داد که خاک‌های با درصد پایینی از خاکدانه‌های پایدار در آب و نیز خاک‌های با نفوذپذیری پایین، حساسیت بالایی به فرسایش آبی داشته و توان پایینی در تولید محصول دارند.