

## Article

# Soil Sensitivity to Wind and Water Erosion as Affected by Land Use in Southern Iran

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**Abstract:** Land degradation by soil erosion is one of the most severe environmental issues that is greatly dependent on land use management. In this study, the effects of long-term land use management (including annual cultivated field (ACF), fallow field (FF), rangeland (R), and orchard field (OF)), soil depth (0–10 and 10–20 cm), and soil organic matter content (SOM) on wind- and water-erosion indices were investigated in calcareous soils of southern Iran. Soil samples were collected from four above-mentioned land-use types, and some soil properties and erosion indices were measured. Results showed that the most of soil aggregates stability indices in the surface layer (0–10 cm) of OF were higher than those in ACF, FF, and R, respectively, by nearly 39%, 32%, and 47% for dry mean weight diameter of aggregates ( $MWD_{dry}$ ); 10%, 10%, and 48% for dry geometric mean weight diameter of aggregates ( $GMD_{dry}$ ); 21%, 17%, and 15% for water-stable aggregates (WSA); and 11%, 16%, and 31% for aggregate stability index (ASI). Moreover, the mean of the soil wind erosion indicators in OF (0–10 cm) were lower than those in ACF, FF, and R, respectively, by nearly 18%, 24%, and 26%, for wind-erodible fraction (EF); 43, 38, and 49% for soil erodibility to wind erosion (K); and 36%, 32%, and 41% for wind erosion rate (ER). In ACF, despite the high clay content, some aggregate stability indices such as  $MW\emptyset D_{dry}$  and WSA were the lowest among studied land-use types which showed the negative effects of conventional tillage practices. Depth factor had only a significant effect on dust emission potential (DEP) in ACF, FF, and OF. In addition, there were significant and strong correlations between SOM and  $MWD_{dry}$  ( $r = 0.79$ ), WSA ( $r = 0.77$ ), EF ( $r = -0.85$ ), K ( $r = 0.74$ ), and ER ( $r = 0.74$ ) in all datasets.



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**Keywords:** aggregate stability indices; conventional tillage practice; land degradation; soil erodibility factor; soil organic matter; soil structure

## 1. Introduction

Land degradation has been widely recognized as a global problem associated with desertification, low agricultural productivity, and rapid changes in ecosystems around the world, especially in arid and semi-arid regions like Iran [1,2]. Land degradation by soil erosion is one of the most severe environmental issues that affects many aspects of human life. Wind and water erosion, due to their detachment forces can transport soil components and are considered as the most important types of land degradation. In Iran, which is located in semi-arid areas with a mean annual precipitation between 200 and 400 mm, wind erosion is more important than water erosion. In these regions, soils are relatively dry for a long time during the year; consequently, the adhesion power between water and soil particles decreases and soil becomes more sensitive for transporting to off-site areas. One of the most important indices of soil erosion is soil sensitivity to erosion, the so-called soil erodibility factor, which is commonly known as the K-factor. The K-factor is related to the integrated effects of rainfall, runoff, infiltration, and wind power on soil loss [3,4]. There are several techniques to measure the K-factor including using soil

physiochemical properties, rainfall simulations, wind tunnel experiments, and erosion plot experiments [5]. Since the direct measurement of the K-factor is costly, time-consuming, invasive, and method-dependent, soil erosion evaluation indices such as soil aggregate stability indices (SASIs) have been commonly used to show soil resistance against wind and water forces. SASIs are very important in soil quality assessment [6] and are used to classify soil structure [7]. These indices commonly classified in two groups: (1) wind-erosion evaluation indices such as the dry mean weight diameter of aggregates ( $MWD_{dry}$ ), dry geometric mean weight diameter of aggregates ( $GMD_{dry}$ ), dry-stable aggregates (DSA), and wind-erodible fraction (EF), and (2) water-erosion evaluation indices such as the wet mean weight diameter of aggregates ( $MWD_{wet}$ ), geometric mean weight diameter of aggregates ( $GMD_{wet}$ ), water-stable aggregates (WSA), and aggregate stability index (ASI).

Land degradation is greatly dependent on land use management [8]. Land use management for agricultural activities such as crop rotation, fertilization, drainage, and irrigation are the most important and influential support activities that affect soil structure and, consequently, aggregate stability [9,10]. There is a relationship between the stability of soil aggregates and soil erosion; the higher the stability of soil aggregates, the greater resistance to soil compaction and erosion [11]. According to previous studies, soil compaction occurs and soil porosity decreases when forest land is changed to rangeland [12], but when rangeland is converted to forest land, infiltration increases and soil erosion decreases [13]. In addition, conservation and no-tillage systems compared to conventional tillage can conserve soil organic matter, decrease soil erosion, increase soil infiltration, aggregate stability, and microbial biomass [14,15]. Some studies showed that soil aggregate stability decreased under annual crop cultivation [16], continuous tillage, and arable crop production [6,17,18]. Therefore, soil aggregates can be considered to be dynamic soil properties that tend to rapidly respond to environmental changes [19]. Recently, more attention has been paid to investigating the effects of land use changes on soil properties. Anderson et al. [20] reported that the  $MWD_{wet}$  and WSA in coniferous forests and grasslands were significantly higher than those in croplands, including conventional-tillage and no-tillage agricultures. Furthermore, in Calcisol Leptosols, China, Tang et al. [21] reported the values of  $MWD_{dry}$ ,  $GMD_{dry}$ , and WSA in the different land types in the following order: wood land > grassland > shrub land > bare land. Furthermore, according to Nath and Lal [22], values of WSA and  $MWD_{wet}$  in no-tillage agricultural land were greater than those of the conventional-tillage of corn cultivation land use in the North Appalachian Region, USA.

According to abovementioned descriptions, the novel and necessary reasons for doing the present study are summarized through three important questions: (1) How can the wind- and water-erosion evaluation indices be affected by long-term management practices and land-use types (including annual cultivated field (ACF), fallow field (FF), rangeland ®, and orchard field (OF)) in calcareous soils? (2) How does soil depth treatment (0–10 and 10–20 cm) affect wind- and water-erosion evaluation indices? and (3) How can SOM content effect the wind- and water-erosion evaluation indices in calcareous soils?

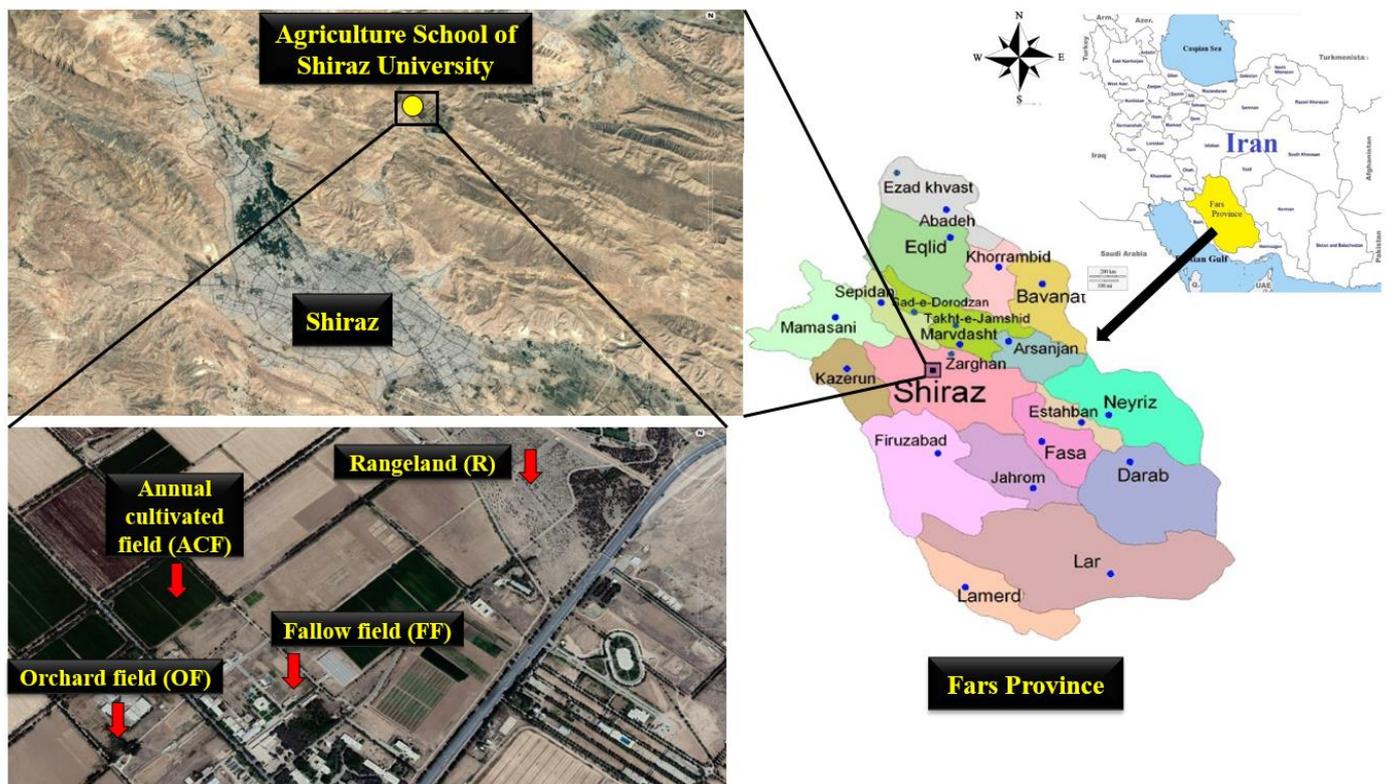
Although the direct measurement of the erodibility factor (K-factor) is very useful for the prevention of soil erosion, due to the difficulties and costs of direct measurements, many researchers have employed soil erosion indices for estimating the soil resistance against water and wind forces. Hence, the present study aimed to investigate the effects of land use and soil depth on some wind- and water-erosion evaluation indices in the calcareous soils of a semiarid region in southern Iran.

## 2. Materials and Methods

### 2.1. Study Area

The study site is located in the Bajgah region (the north of the Shiraz city), Fars province, Iran. The location has a mean altitude of 1810 m above sea level and is situated at the geographic coordinates  $29^{\circ}44'7''$  to  $29^{\circ}45'18''$  N, and  $52^{\circ}32'53''$  to  $52^{\circ}35'55''$  E (Figure 1). The mean annual precipitation and evaporation potential of the study area are about 400 and 2000 mm, respectively. Soils of the study area were placed in two separate series—

gravelly soil of the Kooye Asatied series (loamy-skeletal, carbonatic, mesic, and Fluventic Xerorthents) and non-gravelly soil of the Daneshkadeh series (Fine, carbonatic, mesic, and Typic Calcixerepts) [23]—and had been developed on a relatively similar calcareous (with a 38% mean value of calcium carbonate equivalent) alluvium parent materials and geological formations of Asmari, Jahrom, and Sachoon [24].



**Figure 1.** Geographical map of study area and sampling sites.

## 2.2. Soil Sampling and Analysis

In this study, four different long-term land-use types were selected: (1) ACF with about 20 years rotation of wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), corn (*Zea mays* L.), and canola (*Brassica napus* L.); (2) FF with >10 years of no cultivation; (3) R with permanent range shrubs; and (4) OF with about 25 years planted by pear (*Pirus communis* L.). The mentioned land-use types are research farms and have been monitored and controlled by the Agriculture School of Shiraz University. For each land-use type, three experimental plots (with dimensions of 2 × 2 m) were randomly considered. At each plot, three points were selected and composite samples of about 2 kg were taken from two depths of 0–10 and 10–20 cm. The samples were air dried, ground, passed through 2 and 4 mm sieves, and transferred to the laboratory for further analysis. The soil particle size distribution (sand, silt, and clay contents based on USDA classification) were measured by a sedimentation method using a hydrometer [25], soluble sodium ( $\text{Na}^+$ ) was measured in a saturated extract using the flame photometry method [26], soluble calcium ( $\text{Ca}^{2+}$ ) and magnesium ( $\text{Mg}^{2+}$ ) were measured in a saturated extract using titration with EDTA [27], the sodium adsorption ratio (SAR) was determined by using Equation (1), and the soil organic matter (SOM) content was obtained with the loss on ignition method [28], all of which are summarized in Tables 1 and 2.

$$\text{SAR} = \frac{\text{Na}^+}{\sqrt{\frac{(\text{Ca}^{2+} + \text{Mg}^{2+})}{2}}} \quad (1)$$

where SAR, Na<sup>+</sup>, Ca<sup>+</sup>, and Mg<sup>+</sup> are the sodium adsorption ratio ((meq L<sup>-1</sup>)<sup>0.5</sup>) and the soluble sodium, calcium, and magnesium (meq L<sup>-1</sup>), respectively.

### 2.3. Determination of Soil Erosion Indices

The soil aggregate stability and erodibility factor are two physical indicators of soil erosion [29]. Therefore, in order to understand the soil erosion condition of each land-use type, some soil erodibility and aggregate stability indicators were calculated for each. These indicators were divided into two groups: (1) soil erodibility indicators related to water erosion and (2) soil erodibility indicators related to wind erosion.

First, aggregate size distribution was determined with the dry-sieving method [30]. Using dry sieving data, the MWD<sub>dry</sub> and the GMD<sub>dry</sub> of aggregates were determined according to the following equations:

$$\text{GMD}_{\text{dry}} = \sum_{i=1}^n \bar{X}_i W_i \quad (2)$$

$$\text{MWD}_{\text{dry}} = \text{EXP} \left[ \frac{\sum_{i=1}^n W_i \text{Ln}(\bar{X}_i)}{\sum_{i=1}^n W_i} \right] \quad (3)$$

where  $\bar{X}_i$  is the mean diameter of any particular size range of particles (mm) and  $W_i$  is the weight of particles in that size range as a percentage of the total sample.

The K and wind erosion rate (ER) were calculated using MWD<sub>dry</sub> data [31] and the dominant wind velocity of the study area, which is about 9 m s<sup>-1</sup>.

$$K = 3.382(\text{MWD}_{\text{dry}})^{-1.732} \quad (4)$$

$$\text{ER} = 44.974(\text{MWD}_{\text{dry}})^{-1.39} \quad (5)$$

where K is soil erodibility to wind erosion, ER is the wind erosion rate (g m<sup>-2</sup> min<sup>-1</sup>), and MWD<sub>dry</sub> is the dry mean weight diameter of aggregates (mm).

Chepil [32] and Chepil and Woodruff [33] showed that aggregates larger than 0.84 mm in diameter are resistant to wind erosion. As a result, wind EF became a commonly accepted measure of soil erodibility by wind:

$$\text{EF} = \frac{W_{<0.84}}{W_{\text{total}}} \times 100 \quad (6)$$

where EF is the wind-erodible fraction (%),  $W_{<0.84}$  is the weight of aggregates that are smaller than 0.84 mm in diameter (g), and  $W_{\text{total}}$  is the total weight of the soil sample (g).

The dust emission potential (DEP) of soil is considered to be the abundance of aggregates that are smaller than 0.063 mm in diameter; see Equation (7). These very fine particles can remain in suspension due to the low settling velocity of the fine particles [34].

$$\text{DEP} = \frac{W_{<0.063}}{W_{\text{total}}} \times 100 \quad (7)$$

where  $W_{<0.063}$  is the weight of particles that are smaller than 0.063 mm in diameter (g) and  $W_{\text{total}}$  is the total weight of the soil sample (g).

The percentage of WSA and DSA retained on sieves greater than 0.25 mm diameter were expressed as WSA > 0.25 mm and DSA > 0.25 mm indicators, respectively, as follows [35,36]:

$$\text{DSAorWSA} = \frac{W_{>0.25\text{mm}}}{W_{\text{total}}} \times 100 \quad (8)$$

where  $W_{>0.25\text{mm}}$  is the weight of aggregates that are greater than 0.25 mm (g) and  $W_{\text{total}}$  is the total weight of the soil sample (g).

The ASI was determined with a wet sieving apparatus. The apparatus is designed to determine aggregate stability by comparing aggregate distribution before and after disruption. It is based on the principle that unstable aggregates will break down easier when immersed into water. Prepared and weighted air-dried samples (<2 mm sieve) were used to determine the weights of the unstable part (which collapsed in distilled water in the first run) and the stable part (which collapsed in the last run due to the dispersing of the solution). After the run, the parts were dried at 105 °C for 24 h. Then, the aggregate stability index was calculated by using the following equation:

$$ASI = \frac{W_{ds}}{W_{ds} + W_{dw}} \quad (9)$$

where ASI is the aggregate stability index,  $W_{ds}$  is the weight of aggregates dispersed in dispersing solution (g), and  $W_{dw}$  is the weight of aggregates dispersed in distilled water (g).

#### 2.4. Statistical Analysis

At first, all soil properties and erodibility indicators were subjected to ANOVA tests to assess the differences between the treatments. Then, the mean values of the differences of soil properties and erodibility indicators between different land-use types and depths were compared by using one-way ANOVA followed by the least significant difference (LSD) post-hoc test ( $p < 0.05$ ). In this study, the ACF was the comparison basis of different soil properties and indicators between different land-use types. Relationships and correlations between soil erodibility indicators and SOM were analyzed by a simple linear regression and correlation coefficient ( $r$ ), respectively. All statistical analyses were performed in the STATISTICA software package at a 95% probability level, and the curve plotting and establishment of regression equations were done with the EXCEL and SPSS (version 23) software packages.

### 3. Results and Discussion

#### 3.1. Physical and Chemical Properties of Soils under Different Land-Use Types

Table 1 gives the average of some soil physico-chemical properties for different land-use types. The mean content of particle size distribution in the ACF, FF, R, and OF land-use types were 3.9%, 8.5%, 23.3%, and 19.6% for sand; 54.6, 57.3%, 58.1%, and 54.6% for silt; and 41.5%, 34.2%, 18.6%, and 25.8% for clay, respectively. The highest and lowest contents of clay were found in the ACF (41.5%) and R (18.6%) land-use types, respectively. In contrast to clay, the highest and lowest contents of sand were found in R (23.3%) and ACF (3.9%), respectively. There was no significant difference in silt content between all studied land-use types. The soil texture classes (based on USDA classification) in ACF, FF, R, and OF were silty clay, silty clay loam, silt loam, and silt loam, respectively (Table 1).

The mean of the soluble elements in the ACF, FF, R, and OF land-use types were 13.4, 10.5, 23.7, and 27.8 mg L<sup>-1</sup> for sodium; 51.8, 55.5, 124, and 82.2 mg L<sup>-1</sup> for calcium; and 50.2, 40.5, 16.8, and 51.5 mg L<sup>-1</sup> for magnesium, respectively. Furthermore, the mean of the SAR was 0.32, 0.26, 0.53 and 0.59 (meq L<sup>-1</sup>)<sup>0.5</sup> in the ACF, FF, R, and OF land-use types, respectively. In OF, the amount of soluble sodium was higher than for the other land-use types, which may have been due to the excessive use of manure fertilizers (especially cow manure) in the mentioned land use.

The results also revealed that the highest and lowest contents of SOM were attributed to OF at 0–10 cm of depth (5.03%) and FF at 10–20 cm of depth (2.25%), respectively. In addition, the results revealed that there were no significant differences in the mean of SOM at two studied depths of all studied land-use types. In general, SOM was high in OF due to the falling down of leaves in fall and the addition of the manure fertilizers. Additionally, SOM was relatively high in R, which has old shrubs with highly dense of roots up to a depth of 50 cm. The measured SOM ranked in descending order of OF > R > ACF > FF, which indicated that vegetation restoration was an effective factor for increasing SOM and consequently improving soil structure [37]. For OF and R, the increases in SOM

were attributed to the increases of organic matter net production since the accumulation rate of sticks, leaves, and roots was significantly greater than the decomposition rate after vegetation restoration in this region [38]. Similarly, Tang et al. [21] reported that soil organic carbon content (SOC) increased after vegetation restoration, and the SOC average of the woodland was significantly greater than that in the bare land, grassland, and shrubland. As reported by Zhu et al. [39], after ~15 years of restoration from abandoned cropland, a natural restoration grassland had a higher SOC than a Chinese red pine forest. Nath and Lal [22] showed that the SOC among different sites followed the trend of native forest > pastureland > no-tillage corn > conventional tillage corn.

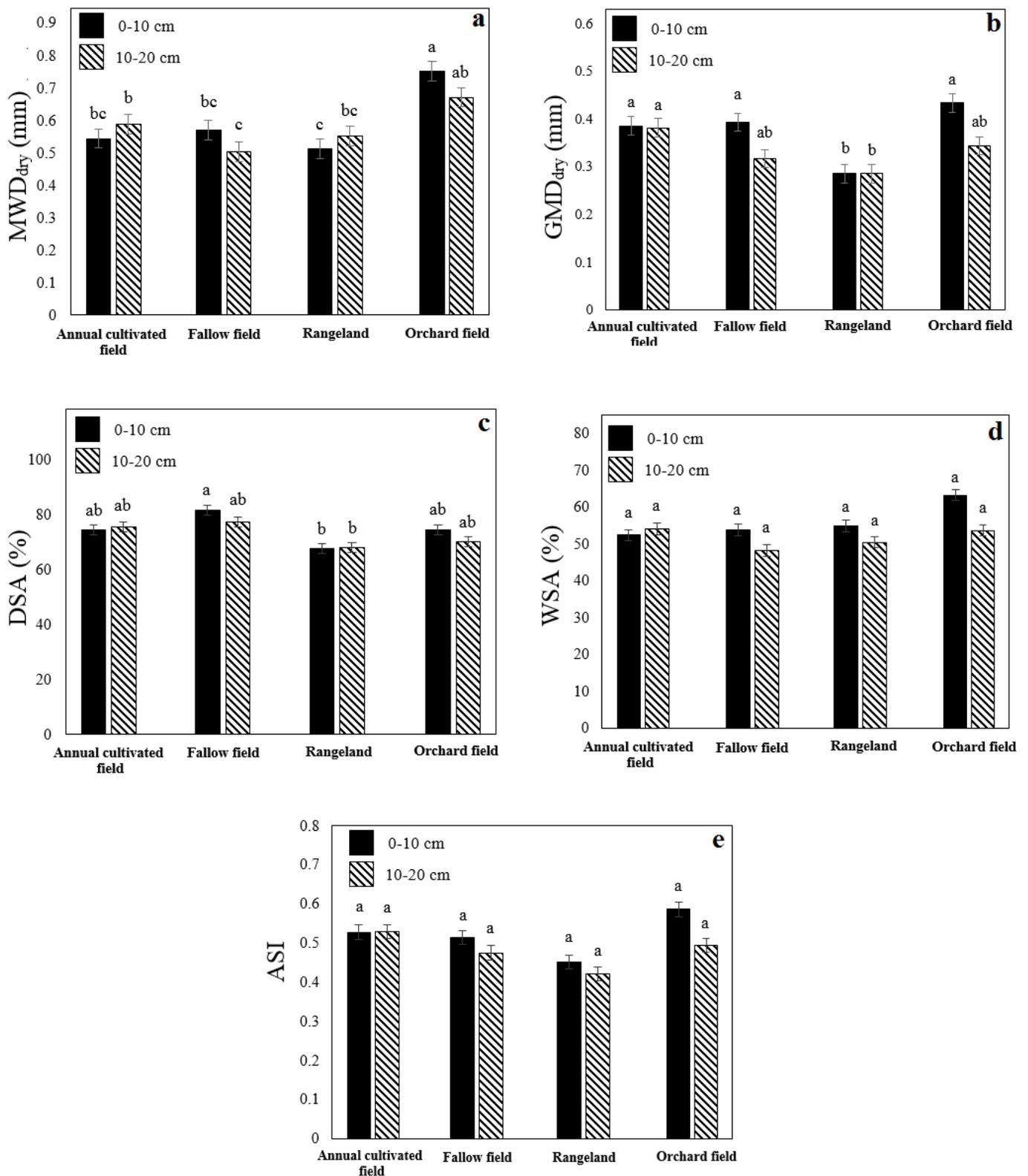
**Table 1.** Mean of some soil physico-chemical properties in different studied land-use types.

Property †	Annual Cultivated Field (ACF)	Fallow Field (FF)	Rangeland (R)	Orchard Field (OF)
Sand (%)	3.9	8.5	23.3	19.6
Silt (%)	54.6	57.3	58.1	54.6
Clay (%)	41.5	34.2	18.6	25.8
Texture class	Silty clay	Silty clay loam	Silt loam	Silt loam
Na <sup>+</sup> (mg L <sup>-1</sup> )	13.4	10.5	23.7	27.8
Ca <sup>2+</sup> (mg L <sup>-1</sup> )	51.8	55.5	124	82.2
Mg <sup>2+</sup> (mg L <sup>-1</sup> )	50.2	40.5	16.8	51.5
SAR ((meq L <sup>-1</sup> ) <sup>0.5</sup> )	0.32	0.26	0.53	0.59
CCE(%)	32.7	37.6	40.7	43.6

†: Sand: sand content; Silt: silt content; Clay: clay content; Texture class: soil texture class based on USDA classification; Na<sup>+</sup>: soluble sodium; Ca<sup>2+</sup>: soluble calcium; Mg<sup>2+</sup>: soluble magnesium; SAR: sodium adsorption ratio; CCE: calcium carbonate equivalent.

### 3.2. Soil Aggregate Stability Indices under Different Land-Use Types ( $MWD_{dry}$ , $GMD_{dry}$ , DSA, WSA, and ASI)

The results of the comparison of different soil aggregate stability indices between different studied land-use types and depths are shown in Figure 2. The highest mean of  $MWD_{dry}$  (0.75 mm) was observed in OF (0–10 cm), which was significantly different from the other land use types. There was no significant difference in the mean of  $MWD_{dry}$  in ACF, FF, and R at 0–10 cm of depth. The mean of the mentioned property was ranked in descending order as OF > FF > ACF > R at 0–10 cm. Furthermore, the results showed that the mean of  $MWD_{dry}$  in FF and R were 16.9% and 6.9% lower than ACF at 10–20 cm of depth, respectively (though this change between ACF and R was insignificant). The land use change from ACF to OF caused a 13.9% increase of the mentioned property's mean at 10–20 cm of depth (OF > ACF > R > FF). There was no significant difference in the  $MWD_{dry}$  between two studied soil depths in all studied land-use types (Figure 2a). According to Lal classification [40], there is severe limitation in aggregate stability in all studied land-use types. Lal [40] stated that soils with an  $MWD_{dry}$  between 0.5–1 and 1–2 mm have severe and moderate limitations, respectively. Despite high content of clay in ACF and FF, their low aggregate stability was probably due to the lower content of soil organic matter and high traffic of heavy agricultural implements, especially at inappropriate moisture. In R, we could declare that the low content of clay and the high livestock traffic may have been a possible reason for its low  $MWD_{dry}$  values. Additionally, the excessive use of manure fertilizers (especially cow manure) may be a possible reason for the low aggregate stability in OF due to increasing sodium values (the mean of the SAR was equal to 0.59 (meq L<sup>-1</sup>)<sup>0.5</sup> in OF) because sodium disperses soil particles and can destroy soil structure [41]. However, despite these reasons, a high content of SOM and a low traffic of heavy agricultural implements made OF have more stable aggregates compared to the other studied land-use types. Aggregate stability is a very important factor in soil structure and erosion intensity.



**Figure 2.** Mean comparison of MWD<sub>dry</sub> (a), GMD<sub>dry</sub> (b), DSA (c), WSA (d), and ASI (e) indices in studied land-use types and soil depths. Vertical bars represent standard deviations of the means. Values followed by different letters are significantly different ( $p < 0.05$ ).

Figure 2b shows that there was no significant difference in mean GMD<sub>dry</sub> between ACF, FF, and OF at 0–10 cm of depth, but the land-use change from ACF to R resulted in a significant decrease of 35% in mean GMD<sub>dry</sub>. The mean of the mentioned property at

0–10 cm of depth was ranked as  $OF > FF \approx ACF > R$ . Furthermore, at 10–20 cm of depth, there was no significant difference in mean  $GMD_{dry}$  between ACF, FF, and OF, while the mean of this property in R showed a significant decrease of 33.6% from ACF at 10–20 cm of depth ( $ACF > OF > FF > R$ ). The high values of the mean  $GMD_{dry}$  in ACF at 10–20 cm of depth could have been because of tillage practices that have compacted the underneath soils. Like  $MWD_{dry}$ , there was no significant difference in mean  $GMD_{dry}$  between 0–10 and 10–20 cm of depth in all studied land-use types. Each index had a different evaluation purpose. These results may have been due to the presence of a lower content of SOC as a result a limited microbial activity and lower root biomass in ACF, FF, and R, which may play a major role in the formation of soil aggregates [42]. The  $MWD_{dry}$  increases as the percentage of large aggregates retained in the sieve increases and, the  $GMD_{dry}$  is an estimate of the size of the most frequent aggregate size classes [30]. Those indices vary according to the management practices established in soil and show whether physical conditions have been improved. Animal grazing and the removal of plant residues from the soil surface layer are the main causes of the disturbance of soil aggregates [43,44]. The protection of the land from disturbance is not only essential for soil aggregates but also important for the management of the soil ecosystem, which ultimately influences the agricultural yield [45–47]. The results of this study are in line with the findings of other researchers in this regard.

Soil aggregation can be increased with cropland conversion to no-tillage due to the rapid turnover of soil organic carbon in the soil layers [8]. Soil aggregate stability was supported here by constantly increasing soil organic matter up to the 10 cm of the soil layer (Table 2).

Regarding the mean DSA ( $>0.25$  mm), there was no significant difference between ACF and the other studied land-use types at both depths (Figure 2c). Moreover, there was no significant difference in the mean DSA between two depths of any land-use types, which was in line with the results of Mahmoodabadi and Ahmadbeigi [48], who reported that the influence of soil depth on  $DSA > 0.25$  mm was insignificant for all cultivation systems including wheat, barley, corn, alfalfa, fallow, and plowed. Extensive root systems, root exudates, and microbial activity (particularly of fungi) improve soil aggregation [8].

The results also revealed that OF (0–10 cm) exhibited the highest mean WSA ( $>0.25$  mm), while in most cases, the differences were insignificant. In addition, similar to DSA ( $>0.25$  mm), soil depth had no significant effect on WSA ( $>0.25$  mm) in all studied land-use types (Figure 2d). On average, the  $DSA > 0.25$  mm was much higher than the  $WSA > 0.25$  mm in each land-use type and depths, which was due to the differences in disruptive forces in the dry or wet sieving procedures. In the dry sieving procedure, the mechanical force of shaking is the only dominant agent of aggregate breakdown, while, in the presence of water (wet sieving), slaking occurs due to water stress aggregates [49,50].

The results of a mean comparison between different land-use types for ASI showed a similar trend to that of  $WSA > 0.25$  mm (Figure 2e). This was because the basis processes and disruptive forces for both indicators, including wet sieving, were similar.

Recent studies have shown that some soil quality and aggregate stability indices are changing with management and land-use types. Anderson et al. [20] reported that means of  $MWD_{wet}$  and WSA in coniferous forests and grasslands were significantly greater than the means of those properties in croplands, including conventional-tillage and no-tillage agriculture in the lower Mississippi river valley area. Tang et al. [21] showed the importance of  $MWD_{dry}$ ,  $MWD_{wet}$ ,  $GMD_{dry}$ ,  $GMD_{wet}$ , and WSA in the different types of land in the following order: woodland  $>$  grassland  $>$  shrub land  $>$  bare land. Delelegn et al. [51] revealed that changing the area of enclosure and eucalyptus plantation significantly improved soil organic matter and soil aggregate stability (SAS) compared with cropland in the highlands of northern Ethiopia. Similarly, Nath and Lal [22] showed that WSA and  $MWD_{wet}$  in the no-tillage corn land-use type were greater than those in the conventional tillage corn land-use type in the North Appalachian Region, USA. According to the results

of the present and other studies, land-use change has a major and important effect on soil aggregate stability, structure, and consequently on wind and water erosion.

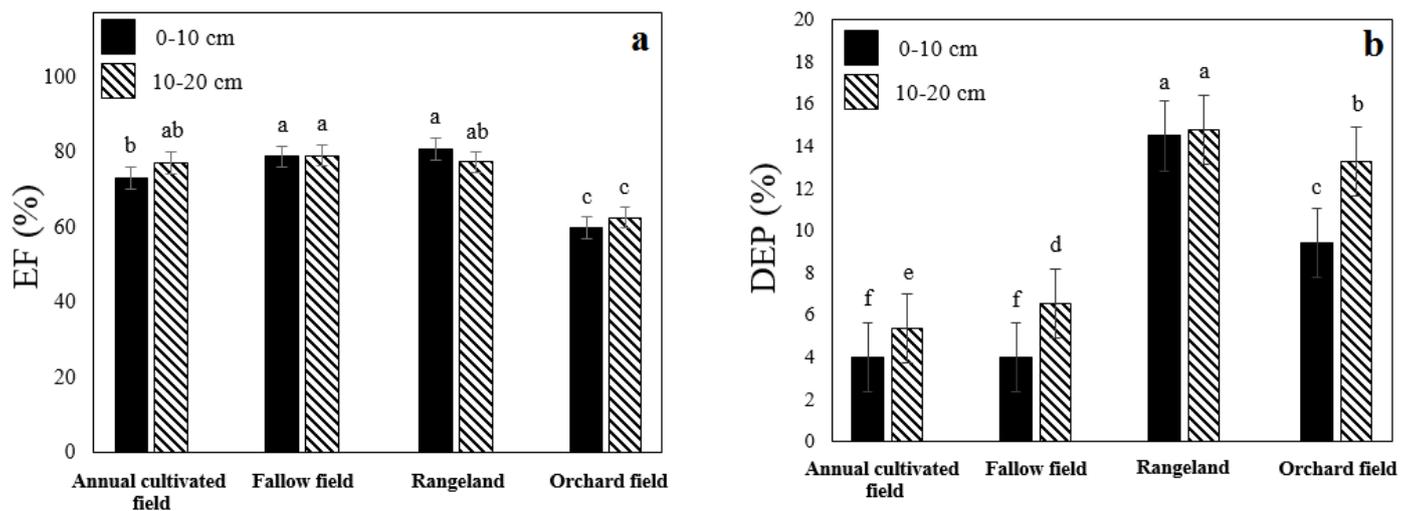
**Table 2.** Soil organic matter, aggregate stability, and erosion indices of different land-use types at two depths.

Property <sup>†</sup> /Index	Land Use							
	Annual Cultivated Field (ACF)		Fallow Field (FF)		Rangeland (R)		Orchard Field (OF)	
	0–10 cm	10–20 cm	0–10 cm	10–20 cm	0–10 cm	10–20 cm	0–10 cm	10–20 cm
SOM (%)	3.11 bc <sup>††</sup>	3.05 bc	2.51 c	2.25 c	3.72 ab	3.02 bc	5.03 a	4.07 ab
MWD <sub>dry</sub> (mm)	0.54 bc	0.59 b	0.57 bc	0.50 c	0.51 c	0.55 bc	0.75 a	0.67 ab
GMD <sub>dry</sub> (mm)	0.39 a	0.38 a	0.39 a	0.32 ab	0.29 b	0.29 b	0.43 a	0.34 ab
DSA (%)	74.3 ab	75.4 ab	81.4 a	77.2 ab	67.5 b	67.8 b	74.2 ab	70.0 ab
WSA (%)	52.4 a	54.2 a	53.9 a	48.2 a	55.0 a	50.5 a	63.3 a	53.7 a
ASI	0.53 a	0.53 a	0.51 a	0.48 a	0.45 a	0.42 a	0.59 a	0.49 a
EF (%)	73.0 b	77.1 ab	78.8 a	79.0 a	80.8 a	77.3 ab	59.8 c	62.5 c
DEP (%)	4.00 f	5.40 e	4.00 f	6.57 d	14.5 a	14.8 a	9.43 c	13.3 b
K	9.75 ab	8.55 b	9.06 ab	11.2 a	10.9 a	9.64 ab	5.60 c	6.77 bc
ER (g m <sup>-2</sup> min <sup>-1</sup> )	105 ab	94.6 b	99.1 ab	117 a	115 a	104 ab	67.4 c	78.5 bc

<sup>†</sup>: SOM: soil organic matter; MWD<sub>dry</sub>: dry mean weight diameter of aggregates; GMD<sub>dry</sub>: dry geometric mean weight diameter of aggregates; K: soil erodibility to wind erosion; ER: wind erosion rate; EF: wind-erodible fraction; DEP: dust emission potential; DSA: dry-stable aggregates; WSA: water-stable aggregates; ASI: aggregate stability index. <sup>††</sup>: Values followed by different letters are significantly different ( $p < 0.05$ ).

### 3.3. Wind Erosion Indicators under Different Land-Use Types (EF, DEP, K, and ER)

Figure 3 shows the mean comparison between different land-use types and soil depths for different wind erosion indicators. There were no significant differences for EF values between the two soil depths of any land-use types. However, there was a significant difference in the mean EF for different land-use types at 0–10 cm of depth. EF was the highest (80.8%) in R at 0–10 cm of depth and the lowest (59.8%) in OF at 0–10 cm of depth. The mean EF in FF and R at 0–10 cm of depth were 7.9 and 10.7% higher than ACF, respectively. The EF in OF was 22.1% lower than ACF. The means of EF at 0–10 cm of depth were ranked in descending order as R > FF > ACF > OF. There was no significant difference in EF between ACF, FF, and R at 10–20 cm of depth, while EF showed a significant decrease of 23.4% in OF compared to ACF at 10–20 cm of depth. Wind EF is the percentage of aggregates that are smaller than 0.84 mm in diameter [32]. All soil samples had an EF content greater than 40%, a threshold EF value above which wind erosion reaches values above the tolerable level [52,53]. This shows that all study areas are susceptible to wind erosion and cannot generate enough wind erosion-resistant structures [54]. EF was higher than 70% in ACF, FF, and R, while it was between 50–60% in OF. This means that OF is more resistant to wind erosion, which could be due to its high content of organic matter that had improved soil structure and aggregation. In comparison with plowing, no-till management systems have more stable aggregates and soil organic carbon [55]. Angers et al. [16] showed that soil aggregate stability decreased in agricultural fields under annual crops. In this study, the mean EF in ACF was significantly lower than that of FF and R at 0–10 cm of depth. This could be attributed to three reasons: (1) more clay content in ACF than other land-use types, which ensured better structure formation; (2) the detachment and transport of fine soil particles by seasonal winds in ACF due to more numerous and continuous tillage practices and crop operations at the surface layer; and (3) in fine textured soils, large and resistant clods and aggregates are formed through the tillage of cultivated soils [53]. As tillage practices and other crop operations in OF are low, soil structure and aggregate production can be enhanced there.

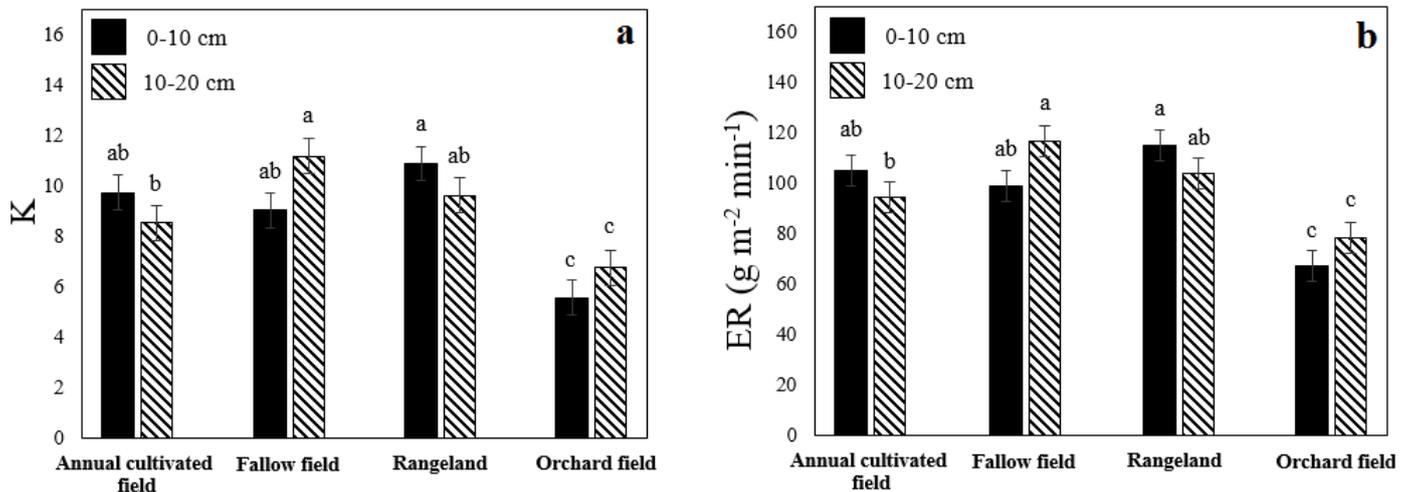


**Figure 3.** Mean comparison of (EF) (a) and (DEP) (b) indices in each land-use type and soil depth. Vertical bars represent standard deviations of the means. Values followed by different letters are significantly different ( $p < 0.05$ ).

The highest and lowest values of DEP were found in R at 10–20 cm of depth (14.8%) and FF and ACF at 0–10 cm of depth (4%), respectively. There was a significant difference in DEP between different land-use types at 0–10 cm of depth. The DEP in R and OF (0–10 cm) was 3.6 and 2.4 times higher than ACF, respectively. The mean values of DEP in the different types of land use were ranked as  $R > OF > FF \approx ACF$  at 0–10 cm of depth and  $R > OF > FF > ACF$  at 10–20 cm of depth. Generally, DEP was found to be higher in the soil depth of 10–20 cm than in the surface soil. Soil depth increased the DEP in ACF, FF, R, and OF by 35%, 64.3%, 2.1%, and 41%, respectively. However, this increment was not significant in R. This could be explained by the transport of fine particles through wind erosion. Wind erosion is a very material-sorting and -removing process [56,57]. These results can explain the occurrence of wind erosion in the study area that transported the finer airborne particles of  $<0.063$  mm to off-site area. In present study, R is located close to a hill; consequently, the height of the hill caused seasonal winds to not have contact with fine particles of surface soils to transport them to off-site areas. The results of this research also showed that rangelands in the studied area are very much prone to wind erosion due to the high amount of erodible fine particles. In a semiarid region of Argentina, Colazo and Buschiazzo [53] showed that cultivation increased EF in medium textured soils (silt and clay between  $215$  and  $500$   $\text{g kg}^{-1}$ ) but not in sandy (silt and clay  $< 215$   $\text{g kg}^{-1}$ ) of fine textured soils (silt and clay  $> 500$   $\text{g kg}^{-1}$ ), which was in line with our findings. The studied soil samples had a fine texture, and our results are completely in line with the results of Colazo and Buschiazzo [53].

According to Equations (3) and (4), both K and soil ER were calculated from  $MWD_{dry}$ , and their trends were found to be similar to those of  $MWD_{dry}$  (Figure 4). There were no significant differences in K and ER at the two studied depths in any of studied land-use types. The results showed that the highest and lowest values of both K and ER were found in FF (10–20 cm) and OF (0–10 cm), respectively. There were no significant differences in K and ER between ACF, FF, and R at 0–10 cm of depth. Furthermore, those properties at 10–20 cm of depth did not show significant differences between ACF and R, while the land-use change from ACF to FF and OF at 10–20 cm of depth caused significant increments and decrements, respectively, of 31% and 26.3% for K and 23.7% and 20.5% for ER at 10–20 cm of depth. The soil erodibility factor is a quantitative description of the inherent erodibility of a particular soil. K, which is related to many soil properties, is one of the most important indicators of soil sustainability. Macroaggregates at the soil surface are resistant to wind movement [58,59]. In fact, soils containing smaller aggregates were found to be more sensitive to wind speed. Because of that, the erodibility and wind erosion rate values in OF were lower than in the other land-use types (greater aggregates in OF). Different soils have

varying erodibility levels due to differences in their mechanical structure and physical and chemical properties. Wind erosion depends on soil erodibility, which is defined as the susceptibility of the soil to wind velocity and is reflected in deflation and abrasion [60]. Therefore, any agent reducing soil cohesion increases its erodibility [61]. Soil erodibility has been attributed to different parameters such as soil texture, surface roughness, and organic matter content [61–63].



**Figure 4.** Mean comparison of K (a) and ER (b) indices in each land use and soil depth. Vertical bars represent standard deviations of the means. Values followed by different letters are significantly different ( $p < 0.05$ ).

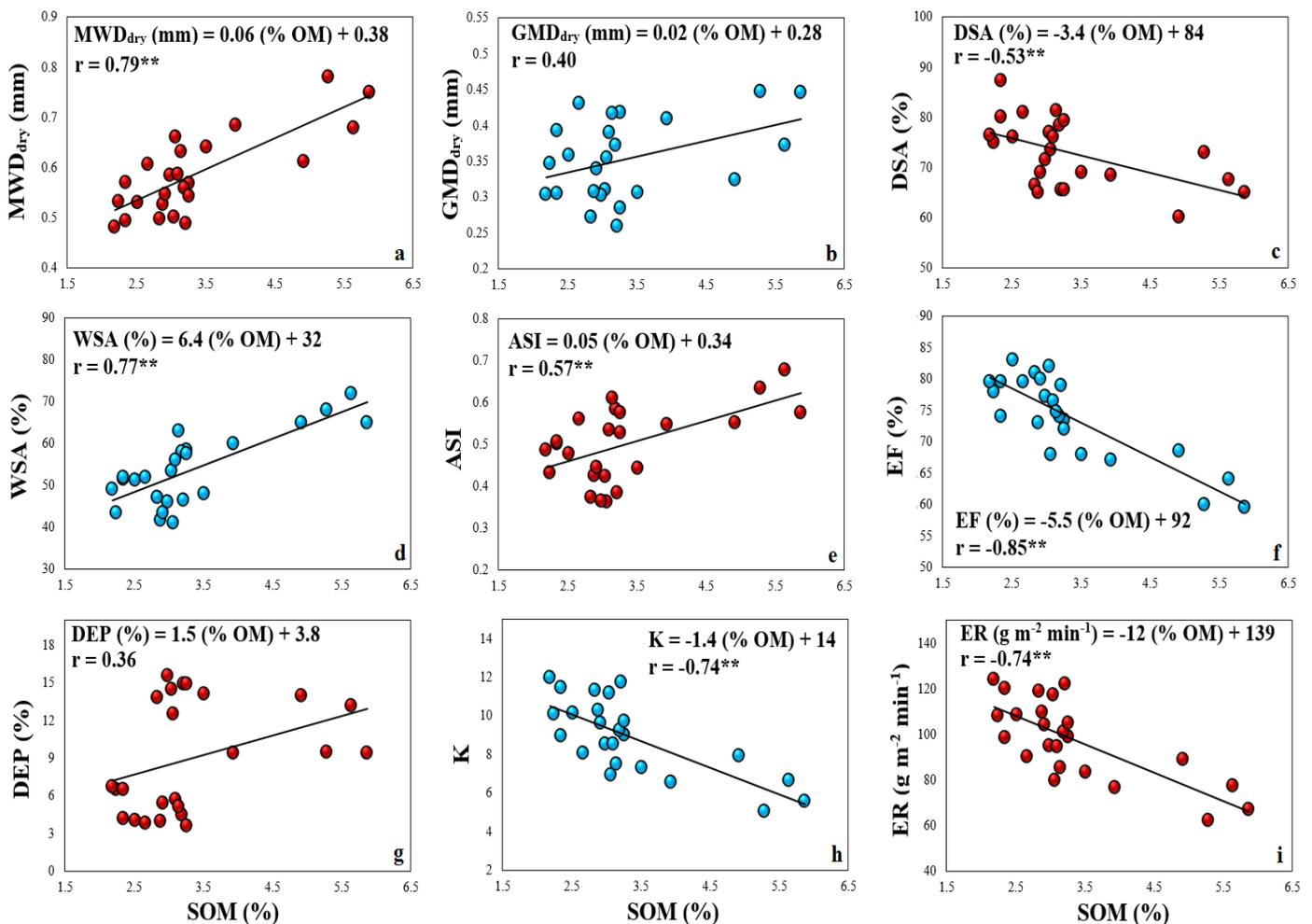
### 3.4. Relationship among Soil Organic Matter, Aggregate Stability, and Erosion Indices

Table 3 shows the correlation coefficient ( $r$ ) among the SOM, soil erosion, and aggregate stability indices. Furthermore, Figure 5 shows a linear regression between the SOM and soil erosion and aggregate stability indices in all soil samples. Correlations were determined to identify how the SOM and different indices related to each other. According to Table 3, the K and ER indices strongly correlated with SOM,  $MWD_{dry}$ ,  $GMD_{dry}$ , WSA, and ASI (negative correlation), as well as EF (positive correlation). The  $MWD_{dry}$ ,  $GMD_{dry}$ , WSA, and ASI represent the aggregate stability and size indices. Therefore, more coarse and stable aggregates were able to decrease wind erosion and lead to low values of K and ER. Based on the work of Chepil [32] and Chepil and Woodruff [33], high values of  $<0.84$  mm particles resulted in more values of soil erodibility to wind erosion and wind erosion rate. Xiao et al. [64] reported that an aggregate stability index calculated based on MWD, fast wetting, slow wetting, and mechanical breakdown could replace the erodibility factor of interrill and rill erosion in the Water Erosion Prediction Project (WEPP) model. Furthermore, Yan et al. [65] revealed the WEPP model overestimated the interrill erosion rate, as well as interrill soil loss and runoff rate are strongly related to the stability index (which was concluded from MWD values) of Ultisols. In wind erosion, the process is much simpler than water erosion due to the kind of erosivity force. In addition to the energy needed from water to transport soils, water molecules caused the disintegration of the soil structure. In wind erosion, aggregates with higher stability are able to better resist the erosivity force of wind. Therefore, with increases in aggregate stability indices, the erodibility of soil decreases.

**Table 3.** Correlation coefficient (r) among studied soil organic matter, aggregate stability, and erosion indices (n = 24).

	SOM	MWD <sub>dry</sub>	GMD <sub>dry</sub>	DSA	WSA	ASI	EF	DEP	K	ER
SOM <sup>†</sup>	1.00									
MWD <sub>dry</sub>	0.79 **	1.00								
GMD <sub>dry</sub>	0.40	0.68 **	1.00							
DSA	-0.53 **	-0.19	0.38	1.00						
WSA	0.77 **	0.60 **	0.55 **	-0.08	1.00					
ASI	0.57 **	0.54 **	0.70 **	0.16	0.89 **	1.00				
EF	-0.85 **	-0.88 **	-0.51 *	0.35	-0.60 **	-0.52 **	1.00			
DEP	0.36	0.14	-0.52 **	-0.61 **	0.07	-0.32	-0.20	1.00		
K	-0.74 **	-0.98 **	-0.69 **	0.16	-0.58 **	-0.53 **	0.85 **	-0.11	1.00	
ER	-0.74 **	-0.98 **	-0.69 **	0.17	-0.58 **	-0.54 **	0.86 **	-0.11	1.00 **	1.00

<sup>†</sup>: SOM: soil organic matter (%); MWD<sub>dry</sub>: dry mean weight diameter of aggregates (mm); GMD<sub>dry</sub>: dry geometric mean weight diameter of aggregates (mm); K: soil erodibility to wind erosion; ER: wind erosion rate (g m<sup>-2</sup> min<sup>-1</sup>); EF: wind-erodible fraction (%); DEP: dust emission potential (%); DSA: dry-stable aggregates (%); WSA: water-stable aggregates (%); ASI: aggregate stability index. Superscripts \* and \*\* represent significantly in *p* < 0.05 and *p* < 0.01 levels, respectively.



**Figure 5.** Relationship and correlation between SOM and MWD<sub>dry</sub> (a), GMD<sub>dry</sub> (b), DSA (c), WSA (d), ASI (e), EF (f), DEP (g), K (h), and ER (i). *r* shows correlation coefficient. \* and \*\* are significant *p* < 0.05 and *p* < 0.01 correlations between variables, respectively.

According to Figure 5, there were positive linear relationships between SOM and some indices including MWD<sub>dry</sub>, GMD<sub>dry</sub>, DEP, WSA, and ASI, with correlation coefficients (*r*) of 0.79, 0.4, 0.36, 0.77, and 0.57, respectively (however, the relationships between SOM and GMD<sub>dry</sub> and DEP were not statistically significant). Highly significant positive linear rela-

tionships between SOM and  $MWD_{dry}$ , WSA, and ASI showed that organic matter content may have an important role in protecting soil against wind and water in the calcareous soils of southern Iran (Figure 5). Similarly, in a typical karst Gorge region, Tang et al. [21] reported that  $MWD_{dry-wet}$ ,  $GMD_{dry-wet}$ , and WSA had positive relationships with the contents of SOC. Wang et al. [66] revealed that  $MWD_{wet}$  was significantly correlated with SOC ( $r = 0.83$ ). Kalhoro et al. [67] reported that SOC had negative correlations with  $MWD_{dry}$ ,  $GMD_{dry}$ , and WSA, which was not in line with our results. In addition, our results revealed that the correlation coefficients ( $r$ ) between SOM and K, ER, EF, and DSA were  $-0.75$ ,  $-0.74$ ,  $-0.85$ , and  $-0.53$ , respectively (Figure 5). Strong correlations between SOM and K, ER, and EF proved that with increasing organic matter soil erodibility, the wind erosion rate and wind erodible fraction decreased due to SOM helping to make larger-sized aggregates (Figure 5). The presented results were consistent with those of Colazo and Buschiazzo [53] in soils of in a semiarid environment of Argentina and of Guo et al. [68] in north China, which showed a negative relationship between SOC and EF. Liu et al. [63] showed that with increasing SOM, the values of K decreased in soils of southwest China.

In general, both the formation of macroaggregates and the accumulation of SOC appears to increase soil aggregation faster than it increases soil carbon [69,70]. This indicates the significant impact of land management on soil aggregation, including impacts of organic matter turnover and the destruction of aggregates by tillage practices.

#### 4. Conclusions

Land degradation is greatly dependent on land use management. Since the direct measurement of the K-factor is costly, time-consuming, invasive, and method-dependent, erosion evaluation indices such as SASIs have been commonly used to show soil resistance against wind and water forces. Furthermore, there is a lack of information in the literature about the effects of long-term land use and land management (including ACF, FF, R, and OF), soil depth treatment (0–10 and 10–20 cm), and SOM on wind- and water-erosion indices, especially in calcareous soils. Therefore, the objective of present paper was to investigate the effects of land-use and depth changes on some wind- and water-erosion evaluation indices in the calcareous soils of a semiarid region in southern Iran. The results revealed that the most of the mean soil aggregate stability indicators in the surface layer treatment (0–10 cm) in OF were higher than those in ACF, FF, and R by nearly 39%, 32%, and 47% for  $MWD_{dry}$ ; 10, 10, and 48% for  $GMD_{dry}$ ; 21%, 17%, and 15% for WSA; and 11, 16, and 31% for ASI, respectively. Furthermore, the mean soil wind-erosion indicators in OF (0–10 cm) were lower than ACF, FF, and R by nearly 18%, 24%, and 26% for EF; 43%, 38%, and 49% for K; and 36%, 32%, and 41% for ER, respectively. In general, a high content of SOM and low machinery/livestock traffic in OF caused aggregates to be larger and more stable than in the other studied land-use types. In ACF, despite the high clay content, some aggregate stability indicators such as  $MWD_{dry}$  and WSA were the lowest among the studied land-use types that showed the negative effects of conventional tillage practices. Depth factor only had a significant effect on DEP in ACF, FF, and OF. This property was the highest in R at 10–20 cm of depth due to its location (R is close to an elevated hill). Furthermore, the results revealed that there were positive correlations between SOM and some indices including  $MWD_{dry}$ ,  $GMD_{dry}$ , DEP, WSA, and ASI, with correlation coefficients ( $r$ ) equal to 0.79, 0.4, 0.36, 0.77, and 0.57, respectively, and negative correlations with K, ER, EF, and DSA, with  $r$  equal to  $-0.75$ ,  $-0.74$ ,  $-0.85$ , and  $-0.53$ , respectively. Strong correlations between SOM and values of  $MWD_{dry}$ , K, ER, EF, WSA, and ASI proved that with the increasing content of soil organic matter, the size of the aggregates became greater. Some recommendations for farmers to prevent their field to be eroded by wind and water erosion include (1) to substitute conventional tillage systems with no-tillage and minimum tillage practices, (2) to preserve soil organic matter on the soil surface layer, and (3) to decrease the machinery/livestock traffic as much as possible.

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