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Effects of Season and Phenology-based Changes on Soil Erodibility and Other Dynamic RUSLE Factors for Semi-arid Winter Wheat Fields

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ABSTRACT

Time-dependent and phenology-based erodibility assessments in agricultural areas are extremely important for a more accurate evaluation of erosion. This paper aims to investigate soil erodibility factor (RUSLE-K) of the "Revised Universal Soil Loss Equation (RUSLE)" model in terms of phenological and seasonal variations in the 50 different winter wheat growing parcels with the interactions other dynamic RUSLE factors (RUSLE-R, RUSLE-C). For that, parcel-based erosion assessments were performed with the help of Dynamic Erosion Model and Monitoring System, digital elevation model, and satellite images in Polatlı, Ankara. Findings showed that RUSLE-K factor varied from 0.0150 to 0.0357 t ha h ha^{-1} MJ^{-1} mm^{-1} during the period the seeding germination to the end of the tillering from autumn to spring, and the lowest RUSLE-K was obtained when the plant was in the three-leaf stage. After the frost-free period, corresponding to the flowering and fertilization stages of the wheat plant, the RUSLE-K values changed between 0.0786 and 0.0976 t ha h ha^{-1} MJ^{-1} mm^{-1}. This reveals that erodibility can vary up to nine times due to seasonality. However, the other dynamic model factors are not taken into consideration. Considering all dynamic factors on soil losses, the change coefficients from the highest to the lowest were obtained for RUSLE-R, RUSLE-K and RUSLE-C, respectively. These changes caused soil losses to change by 82% during the year. So, this study is expected to shed new light on studies of wheat or other commonly cultivated crops to accurately assess the water erosion risk as a significant land degradation problem.

Keywords: Erodibility, Modeling, Normalize different vegetation index (NDVI), Satellite images, Sustainability, Water erosion

1. Introduction

Soil erosion is known to be significant threat to sustainability in the context of ecosystem services. In particular, it is primarily responsible for land degradation in the cultivated areas located in fragile ecosystems (FAO & ITPS 2015). In Turkey, water erosion is a major problem and the predicted average soil loss rate is higher than 5 t ha^{-1} y^{-1} in the 26.4% of agricultural lands (Erpul et al. 2020). Especially in the wheat production areas, which constitute 67% of the agricultural areas in which field crops are cultivated, it leads to a significant reduction in production potentials at the national scale. However, wheat demand tends to increase due to rising population density (Anonymous 2019). Hence, accurate estimation of land productivity under the accelerated soil erosion dynamics has great importance in terms of conservation natural resources. In this context, water erosion rates have been predicted by the empirically based 'Universal Soil Loss Equation (USLE)' or its renewed version 'Revised Universal Soil Loss Equation (RUSLE)' by integrating Geographic Information Systems (GIS) as of the beginning of the 21st century (Saygin et al. 2014; Panagos et al. 2015).

But, one of the most common criticisms of the RUSLE model is the over-estimation for actual soil loss rates. Although this situation is mostly associated with the topography factor of the model due to the increase in estimated soil losses at slopes steeper than 9% (McCool et al. 1987), there are some studies that emphasize that the rate of change in erodibility is quite high (Renard et al. 1994; Panagos et al. 2014; Benavidez et al. 2018).

Soil erodibility factor (USLE-K) stands for the resistance against to erosive agents of soil, and mostly correlates with intrinsic soil properties as a significant variable of the USLE model. Thus, it can be calculated by several equations based on these examined relationships instead of through laborious field studies (Römkens et al. 1997).

On the other hand, one of the most important problems encountered in simulating the USLE-K is the lack of seasonal assessment in terms of the simulation of the antecedent water contents and soil surface variations. Originally, it was thought of as a constant parameter and dominantly controlled by some soil properties such as soil texture. But studies over the past few decades have clearly shown that soil erodibility was not a constant variable due to heterogeneity in the physicochemical structure of soil that is influenced by many factors such as the time-dependent effects of canopy cover and climatic conditions. Indeed, seasonal variations in some soil conditions such as soil aggregation, crust formation, sealing, soil moisture contents, and freezing-thawing conditions significantly affects the shear stress of the soils (Huang & Laften 1996; Huang 1998; Auerswald et al. 2014). To increase the accuracy of the soil erodibility estimations, unlike in the USLE model, the equations were developed for calculating the semi-monthly soil erodibility factor (RUSLE-K) for a year in the RUSLE model. In this manner, the seasonal variation's effect on soil erodibility during the phenological development stages of crops can be easily simulated for agricultural areas in the RUSLE model instead of using a constant USLE-K value for a year (Renard et al. 1997).

Even though the effects of seasonal changes on soil erodibility, soil structure, crust formation and shear strength have been widely known from previous studies, RUSLE-K factor has been mostly used as a constant variable similar to USLE-K (Alewell et al. 2019). But, considering cultivated areas and phenological development stages of the different crop types, the assessment of monthly and seasonal variations in susceptibility of soils to erosive conditions is an important requirement due to strong climatic changes, especially in the fragile ecosystems characterized by irregular and intensive rainfalls, low vegetation cover, and fragile soil structure. At this point, the assessment of the time-dependent/seasonal changes' effects on the RUSLE-K values was defined as an important requirement, especially for sustainability of the cultivated areas in the arid and semi-arid climate zones (Ostovari et al. 2019). In this way, more accurate soil loss estimations can be achieved to determine the critical erosion periods if the time-dependent changes in soil erodibility are considered (Wu et al. 2018). At this point, interactions of RUSLE-K and RUSLE-C factors on erosion rates based on the rainfall erosivity changes in time periods should be taken into consideration on the axis of lumped structure of the RUSLE model. The cropping effect on soil losses is originally expressed by the RUSLE-C factor in RUSLE (Renard et al. 1997). And, it reveals the difference the soil loss rates between cropland and clean-tilled, continuous fallow field condition (Wischmeier & Smith 1978). Recently, it is determined by the help of remote sensing technology, which allows for easier and more reliable predictions of temporal and spatial differences of plant cover efficiency on soil erosion losses (Panagos et al. 2015). For example, Alexandridis et al. (2015) investigated the seasonality effect for estimating the RUSLE-C factor by using normalize different vegetation index (NDVI). They found a significant difference among their time-dependent evaluations. Similarly, Möller et al. (2017) studied on the parcel-specific NDVI profiles for phenological phases of the wheat plant, and they proposed the phenological evaluation scheme for the NDVI time series. Surely, if these and other similar studies, which are mainly related to the temporal changes in RUSLE-C and RUSLE-R factors during the year, can be developed to cover the changes in RUSLE-K factor with the time-dependent or phenology-based approaches, the accuracy rate of estimations for RUSLE model studies will be increased.

Thus, it was aimed to investigate the changes in soil erodibilities in terms of phenological development stages of winter wheat depending on the seasons in semi-arid Anatolian conditions. Regardingly, the variations among dynamic RUSLE factors (e.g. RUSLE-R, RUSLE-K and RUSLE-C factors) and their effects on soil loss rates were analysed in the semi-arid parcel-scale corresponding to the studied time periods. It was also attempted to present a more accurate and effective methodological framework to sustainably manage the soil resources by using limited databases and RUSLE methodology to evaluate water erosion risk on arid and semi-arid agricultural areas.

2. Material and Methods

2.1. Characteristics of the study area

The studied region is 78 km far from the capital of Turkey, and located in the Ilıca-Polatlı district at an average elevation of 886 m above mean sea level in the sub-agriculture basins of the Sakarya River. The geomorphological structure of the region consists of plateaus around hills and is generally comprised of conventional crop parcels under semi-arid Anatolian conditions. Winter wheat is the most common crop grown in the conventional bare fallow conditions for more than fifty years in the region. Due to climatic constraints, mostly preferred bread wheat varieties in the region were Bezostaia-1 (Spineless, white glume, hard grain, medium height), Tosunbey (Spined, white glume, white, hard grain, medium height), Esperiya (Spined, spike color white, grain color red, hard grain), Gerek-79 (Spined, glume and spike color brown, soft white grain, medium height) and Sonmez-2001 (Spineless, spike color white, grain color red, hard grain) according to the interviewed expert and farmers in the region. These types of bread are generally of very high quality and are known to be resistant to cold, drougth and bedding (Aktaş & Ünver İkincikarakaya 2010; Karabak et al. 2010; Gebremariam et al. 2020; Korkut et al. 2019; Baser 2020; Cevher et al. 2020; TGB 2020).

The climatic structure of the region was classified as cold semi-arid (type 'BSk') (Peel et al. 2007). Based on the region's 50-year average meteorological data, annual precipitation rate is 368 mm. The minimum, maximum, and average annual temperatures are -17.7 °C, 32°C, and 11.7 °C, respectively. Severe weather conditions in the region have led to freezing in the topsoil layer. The top 5 cm of soil are under frost conditions at least 41 days in a year. And, the depth of this frost layer is known to reach up to 20 cm deep from December to March (TSMS 2018). Within the scope of the study, 50 different rain-fed wheat farming parcels located around the Ilıcaozu, Hamamozu, and Korcesme streams - which pass through the region and feed the Sakarya River — were selected and sampled from 0 to 20 cm soil depth from each parcel, and, they dried and passed through a 2-mm sieve to use for chemical and physical analyses in the laboratory in order to predict the seasonal RUSLE-K values at the parcel scale in the fields. Wheat cultivation is carried out in all of these selected parcels under fallow conditions, and the coordinates of the sampling points are provided referenced with geographical projection GCS-WGS-1984 (Table 1).

Table 1- Soil sampling points (decimal degrees)

Parcel no	*POINT_X*	*POINT_Y*	*Parcel no*	*POINT_X*	*POINT_Y*	*Parcel no*	*POINT_X*	*POINT_Y*
1	39.310	32.206	18	39.312	32.223	35	39.280	32.223
2	39.312	32.208	19	39.310	32.223	36	39.279	32.210
3	39.315	32.206	20	39.305	32.216	37	39.281	32.210
4	39.315	32.208	21	39.304	32.220	38	39.285	32.213
5	39.320	32.207	22	39.306	32.221	39	39.285	32.211
6	39.317	32.207	23	39.314	32.230	40	39.285	32.210
7	39.322	32.209	24	39.313	32.227	41	39.284	32.210
8	39.324	32.210	25	39.303	32.222	42	39.285	32.208
9	39.326	32.212	26	39.302	32.224	43	39.300	32.187
10	39.328	32.214	27	39.304	32.229	44	39.302	32.192
11	39.327	32.216	28	39.305	32.230	45	39.304	32.201
12	39.324	32.212	29	39.306	32.231	46	39.303	32.190
13	39.320	32.214	30	39.305	32.232	47	39.303	32.186
14	39.319	32.212	31	39.309	32.233	48	39.305	32.188
15	39.320	32.209	32	39.325	32.249	49	39.308	32.201
16	39.318	32.209	33	39.300	32.245	50	39.308	32.205
17	39.313	32.209	34	39.301	32.243			

2.2. RUSLE model components

The RUSLE methodology predicts soil erosion rate by evaluating rainfall erosivity, soil erodibility, topographic structure, vegetation and support practices efficiency (Renard et al. 1997; Wischmeier and Smith 1978) (Eq. (1)).

$$A = R \times K \times L \times S \times C \times P \quad (1)$$

Where, A; mean annual soil loss (t ha^{-1} y^{-1}), R; rainfall erosivity (MJ mm ha^{-1} h^{-1} y^{-1}), K; soil erodibility (t ha h ha^{-1} MJ^{-1} mm^{-1}), L; slope length, S; slope steepness, C; cover management, and P; support practice factors.

RUSLE-R (Rainfall erosivity factor) was derived from the Dynamic Erosion Model and Monitoring System in the form of annual total, monthly and semi-monthly RUSLE-R distributions (Erpul et al. 2016).

Several equations were proposed for predicting the soil's resistance in terms of RUSLE-K factor for USLE/RUSLE model. However, nomograph equation is originally proposed to estimate seasonal soil erodibility values in RUSLE methodology (Renard et al. 1997). It is clearly known that nomograph is more suitable for less aggregated and medium-textured sandy and loamy soils than the clay soils such as Turkey (Römkens et al. 1997; Baskan & Dengiz 2008; Kapur et al. 2017; Alewell et al. 2019). For these reasons, the equation (2), proposed by Torri et al. (1997, 2002), was selected to estimate annual RUSLE-K factors for the studied parcels. Besides less data requirement, this equation reveal an appropriate relationship for soils having strong aggregate formation mechanism by considering the soil’s organic carbon and clay rates with other particle size classes in order to predict the RUSLE-K (Borselli et al. 2012). Also, it has been used in Turkey for generating a RUSLE-K map at the national scale (Erpul et al. 2020) and tested in different Anatolian conditions at the parcel and basin scales (Saygin et al. 2011; Yıldırım & Erkal 2013).

$$\mathrm{RUSLE-K} = 0.0293(0.65 - \mathrm{D_G} + 0.24\mathrm{D_G^2}) \times \exp\left\{-0.0021\left(\frac{\mathrm{OM}}{\mathrm{C}}\right) - 0.00037\left(\frac{\mathrm{OM}}{\mathrm{C}}\right)^2 - 4.02\mathrm{C} + 1.72\mathrm{C}^2\right\} \quad (2)$$

Where *OM;* organic matter content, *C;* clay content; *DG;* decimal logarithm for the geometric mean of particle sizes.

The following procedures and equations were used to obtain seasonal RUSLE-K factors from the constant annual RUSLE-K value as proposed by Römkens et al. (1997).

$t_{max} < t_{min}$ If, $t_{max} < t_i < t_{min}$

$$K_i = K_{max}(K_{min}/K_{max})^{(t_i - t_{max})/\Delta t} \tag{3}$$

Where K_i = RUSLE-K factor at any time (t_i in calendar days), K_{max} and K_{min}; RUSLE-K factor at times t_{max} and t_{min}, Δt; length of frost-free period or growing period (≤ 183 days), T_{av}; average daily air temperature.

If, $t_i < t_{max}$ or $t_i > t_{min}$, then for T_{av} >-2.8 °C.

$$K_i = K_{min} exp[0.009(t_i - t_{min} + 365\delta] \tag{4}$$

With δ=1 if (t_i-t_{min}) ≤ 0 and δ=0 if (t_i-t_{min}) > 0 and for T_{av} ≤ -2.8 °C,

$$K_i = K_{min} \tag{5}$$

$$\text{If } K_i > K_{max} \quad K_i = K_{max} \tag{6}$$

$$\text{Or, If } K_i < K_{min} \quad K_i = K_{min} \tag{7}$$

Based on the proposed relationships, the following equations were used to calculate K_{max}, K_{min} and t_{max} variables.

$$K_{max}/K_{min} = 8.6 - 0.01R \tag{8}$$

$$K_{max}/K_T = 3.0 - 0.005R \tag{9}$$

$$t_{max} = 154 - 0.44R \tag{10}$$

$$\text{If,} t_{max} < 0, then \quad t_{max} = t_{max} + 365 \tag{11}$$

Where R = rainfall erosivity factor (RUSLE-R), K_T = annual RUSLE-K factor.

The time span for the phenological development stages of winter wheat was defined by taking into consideration national expert interviews and Landsat ETM + satellite images in the studied region.

The slope length (RUSLE-L) and slope steepness (RUSLE-S) factors, which are together defined as the topographic factor in the RUSLE (RUSLE-LS). This factor was obtained by an interaction between topography and flow accumulation (Eq. (12)) (Moore & Bruch 1986a, 1986b). Slope steepness was calculated by from Digital Elevation Model (DEM), and slope length for each pixel was evaluated as 15 m (Ogawa et al. 1997; Lee 2004).

$$LS = \left(\frac{\chi\eta}{22.13}\right)^{0.4} \cdot \left(\frac{\sin\theta}{0.0896}\right)^{1.3} \tag{12}$$

Where, χ; flow accumulation, η; cell size, and θ; slope steepness in degrees.

RUSLE-C factors (Crop management factor) were estimated by normalized difference vegetation index (NDVI) from Landsat ETM + satellite images. For that, 7 images which reflect to the periods of phenological development of the winter wheat were analysed for the studied fields in the 2015-2016 growing season. In there, it has been taken into consideration that conventional winter wheat cultivation in the selected parcels has been continuously carried out for at least five years. The imagery dates which includes the growing period of winter wheat plant were 10/10/2015, 26/10/2015, 20/11/2015, 03/04/2016, 28/04/2016, 30/05/2016 and 17/07/2016, respectively. In the next stage, NDVI values of the images were calculated by Eq. (13) to get RUSLE-C factors as proposed by van der Knijff et al. (2000).

$$C = \exp\left[-\alpha \times \frac{NDVI}{\beta - NDVI}\right] \tag{13}$$

Where; α and β: NDVI–C curve shape parameters (van der Knijff et al. 2000).

Since there were no agricultural and mechanical conservation practices applied for decreasing soil loss rates, the support practice factor (RUSLE-P) was assumed as 1.

Soil loss rates are estimated to correspond to satellite imaging dates and to take into account changes in other dynamic factors. In addition, these values were verified by the average area-weighted suspended sediment amounts measured from 11 different river observation stations since 1961 located in the basin. Besides that, the values were compared with the annual soil loss rate obtained from national soil erosion map statistics in Turkey (Erpul et al. 2020).

3. Results and Discussion

3.1. Soil properties

The studied soils have averagely 1.47% organic matter, 21.29% $CaCO_3$, 37.41% clay, 33.76% silt, and 28.82% sand and 0.034% salt contents with a pH of 7.79 (Table 2).

Table 2- Descriptive statistics of the primary soil properties

*Variable**	*Mean ± SE***	*StDev****	*Min*	*Max*
pH	7.79 ± 0.21	7.36	7.36	8.31
SC (%)	0.03 ± 0.003	0.02	0.01	0.09
C (%)	37.41 ± 0.93	6.54	25.35	49.93
Si (%)	33.76 ± 0.30	2.15	29.80	37.88
S (%)	28.82 ± 1.23	8.69	12.19	44.85
OM (%)	1.47 ± 0.10	0.69	0.23	3.21
$CaCO_3$ (%)	21.29 ± 1.47	10.42	4.19	58.85

*pH, Soil reaction; SC, Salt content; C, Clay; Si, Silt; S, Sand; OM, Organic matter; $CaCO_3$, Calcium carbonate; **Mean ± SE, Mean values ± standard errors; ***StDev, Standard deviation.

3.2. Time and phenology-based changes in the RUSLE model components

In these clay rich soils, the semi-monthly RUSLE-K factors demonstrated that significant changes occurred in terms of soil erodibility during the year (Table 3). The seasonal variation maps of the parcel-based RUSLE-K values are also figured out of the situation (Figure 1). Before the winter months when the soil temperature is extremely low, and wheat plant is in the three-leaf stage, RUSLE-K value was reached the lowest value (0.0108 t ha h ha^{-1} MJ^{-1} mm^{-1}) in the year. However, the highest RUSLE-K value was estimated as 0.0976 for spring season when rainfall is concentrated, corresponding to the flowering and fertilization stage of wheat.

Table 3- Seasonal and phenological RUSLE-K factors

Seasons	*Phenological periods*	*Intervals*	*Mean ± SE*[a]	*StDev*[b]	*Min*	*Max*
Winter	Vernalization & Tillering	1 - 15 Jan	0.0182 ± 0.0002	0.0011	0.0164	0.0203
		16-31 Jan	0.0210 ± 0.0002	0.0013	0.0189	0.0235
		1 - 15 Feb	0.0240 ± 0.0002	0.0015	0.0216	0.0269
		16-29 Feb	0.0270 ± 0.0002	0.0017	0.0243	0.0302
Spring	Tillering	1 -15 March	0.0309 ± 0.0003	0.0019	0.0278	0.0346
		16-31 March	0.0357 ± 0.0003	0.0022	0.0321	0.0399
	Stem elongation	1 -15 Apr	0.0408 ± 0.0004	0.0025	0.0368	0.0457
		16-31 Apr	0.0467 ± 0.0004	0.0029	0.0421	0.0523
	Booting	1-15 May	0.0535 ± 0.0005	0.0033	0.0482	0.0598
	Flowering & Fertilization	16-31 May	0.0872 ± 0.0008	0.0053	0.0786	0.0976
Summer	Milk stage	1-15 June	0.0734 ± 0.0006	0.0045	0.0661	0.0821
	Dough stage	16-31 June	0.0617 ± 0.0005	0.0038	0.0556	0.0691
	Physiological maturating	1 - 15 July	0.0520 ± 0.0005	0.0032	0.0468	0.0582
	Harvest	16-31 July	0.0432 ± 0.0004	0.0027	0.0389	0.0484
	Bare soil	1 - 15 Aug	0.0364 ± 0.0003	0.0022	0.0328	0.0407
		16-31 Aug	0.0302 ± 0.0003	0.0019	0.0273	0.0339
Autumn		1 -15 Sept	0.0254 ± 0.0002	0.0016	0.0229	0.0285
		16-31 Sept	0.0214 ± 0.0002	0.0013	0.0193	0.024
		1 -15 Oct	0.0180 ± 0.0002	0.0011	0.0162	0.0202
	Seeding & Germination	16-31 Oct	0.0150 ± 0.0001	0.0009	0.0135	0.0168
	Emergence	1-15 Nov	0.0126 ± 0.0001	0.0008	0.0114	0.0141
	Three leaf stage & Tillering	16-31 Nov	0.0120 ± 0.0001	0.0007	0.0108	0.0134
Winter	Tillering	1-15 Dec	0.0137 ± 0.0001	0.0008	0.0124	0.0154
		16-31 Dec	0.0159 ± 0.0001	0.001	0.0143	0.0178
Annual		RUSLE-K[c]	0.0528 ± 0.0005	0.0032	0.0476	0.0591

[a] Mean values ± standard errors; [b] Standard deviation; [c] Annual average RUSLE-K value.

There, the estimated average erodibility values in the autumn season from seeding to tillering stage changed from 0.0156 to 0.0194. Taking into consideration the winter season from tillering to the vernalization stage of wheat, the average RUSLE-K values varied between 0.0179 and 0.0223. However, the values in the spring season were two times higher than the winter season, ranging between 0.0442 and 0.0549 from tillering to milk stage. Similarly, in the summer season from milk stage to harvest, the RUSLE-K values in the region changed between 0.0445 and 0.0553. Annually, average RUSLE-K value of all studied parcels was found to be 0.0528 t ha h ha^{-1} MJ^{-1} mm^{-1}.

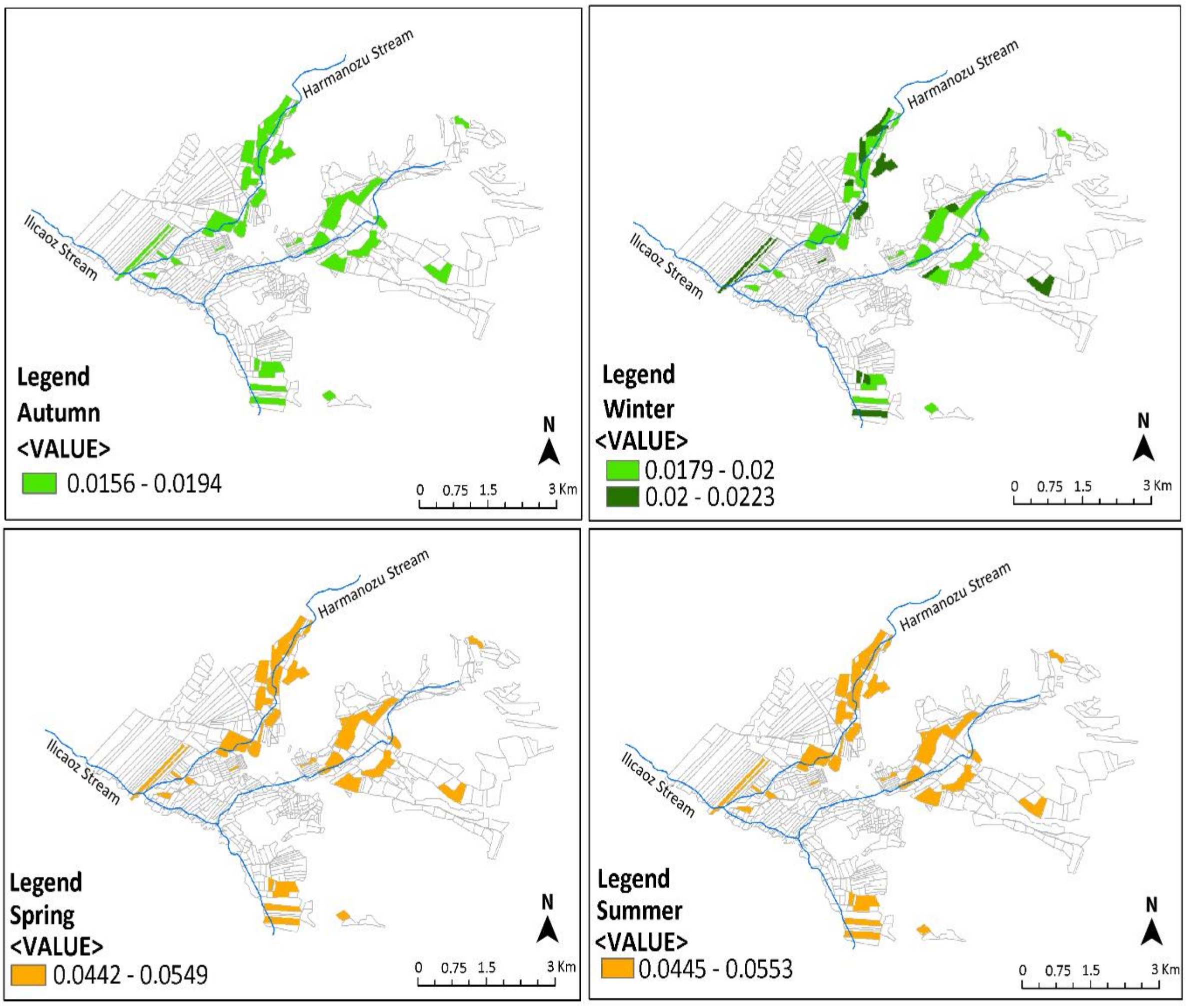

Figure 1- Prediction maps of the seasonal RUSLE-K factors

Time-dependent changes in soil erodibility are generally associated with three soil characteristics. These are freezing, soil texture and soil water (Römkens et al. 1997). In the study, it is clearly observed that freezing conditions at surface lead to lower erodibility values of the studied parcels from autumn to spring. As stated by Kværnø and Øygarden (2006), seasonal freezing lead to profound effects on soil erodibility. Phenologically, this period corresponds to a time-span covers from seeding germination to the vernalization stages in the winter wheat plant. And, RUSLE-K factors had the lowest values, ranging from 0.0108 to 0.0168. Because of decreasing soil temperatures during this period, the soils have more stable and impermeable structure (Oztas & Fayetorbay 2003).

With the end of frost conditions, higher soil moisture content increases the susceptibility of the soils against to erosive agents due to the weakening of soil strength in spring (Bajracharya & Lal 1992). This effect can be clearly seen from stem elongation to flowering and fertilization stages (1 April – 31 May). After this frost-free period, intensive rainfalls make the soils more vulnerable to detachment processes, especially in Mediterranean environments (Arnaez et al. 2007; Comino et al. 2016), and the predicted highest erodibility value in the flowering and fertilization stage (16 - 31 May) clearly reveals this situation. Thus, the soils reached the highest erodibility values, ranging between 0.0786 and 0.0976 in spring (Table 4). Certainly, the presence of canopy cover on the soil surface is an extremely important variable in this stage in which increased sensitivity has a serious effect on sediment yield (Loch, 2000). According to the typical canopy cover values of winter small grain plants (Yoder et al. 1997), 35% of the soil surface is generally covered with plant during this phenological stage. In a general mean, 65% of the field is exposed to the destructive effects of rainfall during this stage (Renard et al. 1997). Within the scope of the study, RUSLE-C values estimated from NDVI values obtained with the help of satellite images confirm the current literature (Figure 2).

Table 4- Descriptive statistics for the RUSLE variables

Variable	*Mean ± SE[a]*	*StDev[b]*	*Min[c]*	*Max[d]*	*Var[e]*	***CV[f]***
RUSLE-R	7.80 ± 2.13	5.65	0.85	14.58	31.88	**72.34**
RUSLE-K	0.0376 ± 0.0099	0.0263	0.0120	0.0872	0.00069	**69.90**
RUSLE-LS	2.95 ± 0.00	0.00	2.95	2.95	0.00	0.00
RUSLE-C	0.546 ± 0.108	0.286	0.118	0.854	0.082	**52.30**
A	0.332 ± 0.102	0.271	0.0257	0.805	0.0732	**81.49**

[a] Mean values ± standard errors; [b] Standard deviation; [c] Minimum values; [d] Maximum values; [e] Variance; [f], Coefficient of variation.

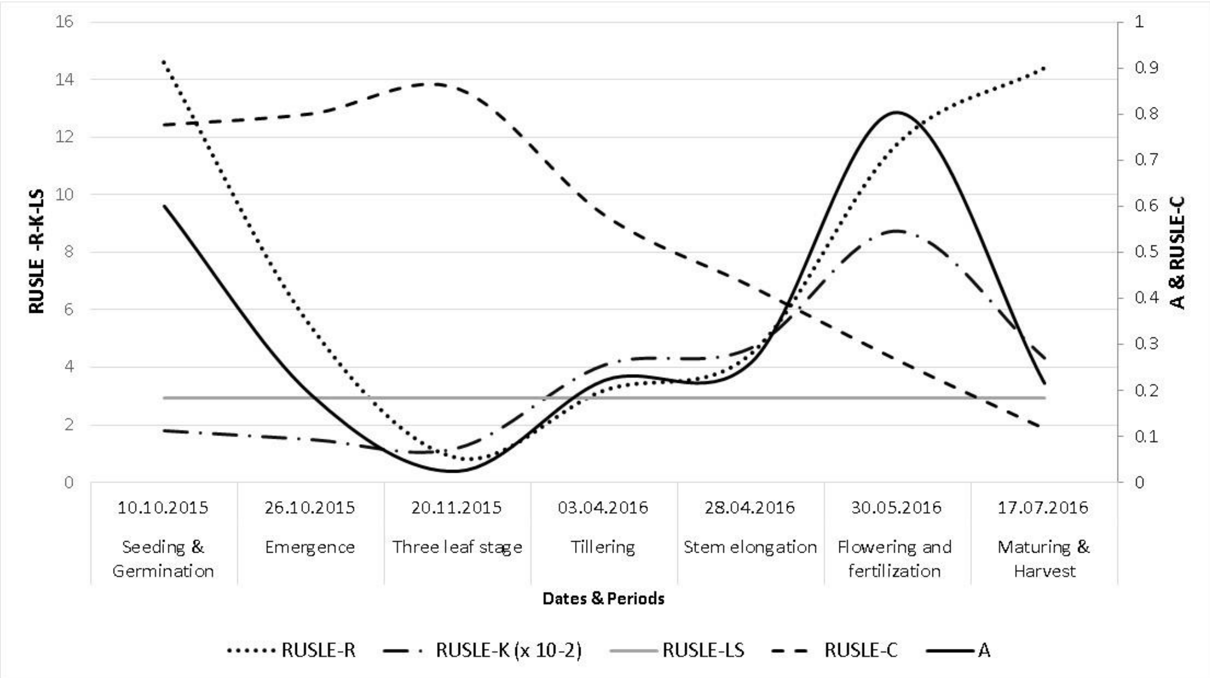

Figure 2- Predicted RUSLE sub-factors and the soil loss rates

In summer, increasing soil temperatures and decreasing soil-water contents under the fallowing typical Mediterranean semi-arid climate conditions lead to gradually decreasing erodibility potentials of the soils (López-Vicente et al. 2008). This time-span phenologically includes the period from the milk stage of the plants to the harvest. Evidently, the findings showed that the RUSLE-K values gradually decreased as a result of increasing temperatures and decreasing moisture contents of the soils. In this manner, it is obviously stated that erodibility potential of the soils changes up to nine times during a year and this situation can lead to significant changes on soil loss estimations when the other factors in the RUSLE model are not considered.

On the other hand, it is also known that changing climatic and vegetation coverage conditions lead to a temporary change in the dynamics within the RUSLE-R and the RUSLE-C factors, not only in the RUSLE-K (Ferreira & Panagopoulos 2014). For example, Baiamonte et al. (2019) investigated the RUSLE-R and RUSLE-C factor's time scale effects and their inter- and intra-annual interactions in terms of soil erosion variability. Similarly, Schmidt et al. (2018) also studied on temporal patterns of vegetation to evaluate spatial and temporal variations of RUSLE-C by measuring the temporal variation of vegetation fraction factor based on soil loss rates and RUSLE-R factor ratios. Apart from these, other model researchers have drawn attention to the same issue and pointed out that seasonal changes on soil losses are particularly closely related to the R and C factors (Panagos et al. 2015). Although the effects of climatic differentiation on model-based soil loss estimates are emphasized, it is thought that there are serious changes in soil erodibility and significant interactions with other factors (Sanchis et al. 2008). Therefore, the other RUSLE sub-factors were also estimated in the study. For this purpose, the changes in each model sub-factor were evaluated for phenological periods in which wheat plant was found in seven different dates where satellite images were taken. And, the lowest soil losses were phenologically estimated at three leaf stage of the plant, that was, at the time when rainfall erosivity and soil erodibility factors were the lowest, although RUSLE-C had the highest value in the plant growing period (Figure 2).

In a comparison to be made in terms of coefficient of variations (CV) values of the dynamic RUSLE sub-factors, the highest variance was observed in RUSLE-R and the second was RUSLE-K, and lastly RUSLE-C. The effect of these changes leads to approximately 82% change in soil losses according to the image dates and corresponding phenelogical periods (Table 4).

This situation reveals that the role of time-dependent changes in RUSLE-R and RUSLE-K factors and their interactions' effects on soil loss rates are notableand these factors should not be evaluated as a constant variable, especially in fragile ecosystems due to the seasonal changes in soil moisture conditions (Huang 1998). In general, the direct impact of seasonal variations on soil erodibility is often overlooked in modeling studies (Sanchis et al. 2008; Alewell et al. 2019). One of the most important issues to be pointed out in the study is to reveal the effect of changes in the rainfall erosivity and erodibility on the soil loss rates by assuming no cover efficiency (representing RUSLE-C factor in RUSLE) and conservation practices (representing RUSLE-P factor in RUSLE). Certainly, the presence of canopy cover on the soil surface which means the decrease in RUSLE-C remarkably limits soil losses especially under heavy rainfall conditions where soil has higher susceptibility to erosive forces (Gallo et al. 2005). In addition, it is known that during periods when the soil surface is bare, especially in the semi-arid and arid agricultural areas of the Mediterranean climate zone, accurate prediction of the changes in RUSLE-R and RUSLE-K variables have a significant impact on combating water erosion threat (Panagos et al. 2015).

3.3. Comparing suspended sediment rates with model-based soil loss estimations

In the Sakarya basin, annual area-weighted suspended sediment rate measured regularly since 1961 from 11 observation stations is 0.79 t ha^{-1} y^{-1} and annual particle detachment rates due to water erosion processes is estimated as 4.2 t ha^{-1} y^{-1} by RUSLE model (Erpul et al. 2020). Estimated average soil loss rates from this parcel-based model study were lower than actually observed sediment yields from the region (Table 4). This is closely related to topographic conditions. Lower slope degrees in the studied parcels have caused to predict lower soil erosion rates compared to the long and steep flow paths in the regional scales or stream basins in real (Alewell et al. 2019).

Consequently, this investigation can give significant support to product-based soil erodibility assessments by evaluating the time-dependent and phenology-based variations for rain-fed, wheat-growing parcels in Anatolian conditions. In addition, seasonality in terms of the erodibility factor in the USLE/RUSLE model was not sufficiently explored for arid and semi-arid environments. In this context, findings indicate the necessity of time-dependent and phenology-based evaluations to perform more accurate soil erosion assessments for sustaining the fragile agricultural areas.

4. Conclusions

In this study, it was investigated that the changes in the RUSLE-K factor as a dynamic factor of RUSLE model depending on seasonal and product-based axis for semi-arid winter wheat parcels in the central Anatolian condition where traditional wheat production systems are widely applied. In addition, the effects of other dynamic model variables such as RUSLE-R and RUSLE-C factors on predicted soil losses were also evaluated within the RUSLE model approach. Obtained results clearly reveal that seasonal changes in the RUSLE-K factor could have quite significant effects on soil loss rates even if the changes in other dynamic factors are not considered. When all dynamic factors were considered together, the factors leading to the highest variability on soil losses were determined as RUSLE-R, RUSLE-K and RUSLE-C, respectively. Consequently, it is thought that this study can contribute to increasing the accuracy of erosion estimates even in limited soil data sets by raising awareness of similar ecosystems and regions where traditional wheat production systems are widely applied. And so, it is expected to shed new light on studies of other cultivated crop types to more accurately assess the water erosion risk as one of the most significant land degradation problems in these fragile agricultural ecosystems.

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