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Long-Term Analysis for Harvest Erosion Caused by Sugar Beet Production in Turkey

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Abstract: The sustainability of soil resources is under significant threat due to the accelerated anthropogenic pressures at the historical expansion of human population. In this context, soil erosion is defined as a limiting factor for human interests in terms of ecosystem services. As an erosion type, harvest erosion occurs by harvesting of the taproot and tuberous root plants such as sugar beet (*Beta vulgaris* L.), potato (*Solanum tuberosum* L.), carrot (*Daucus carota* L.) and chicory (*Cichorium intybus* L.), has begun to take attention in recent years. The objective of this study was to estimate soil loss due to harvest erosion and to economically analyze the transport of plant nutrients between 1999 and 2016 from sugar beet growing areas in Turkey. For this aim, the compiled data of 25 different sugar factories throughout Turkey were obtained from Türkşeker and soil loss estimations were performed and economically analyzed. According to the results, average soil loss rate was calculated as 3.41 Mg $ha^{-1}y^{-1}$ for the studied period (1999-2016). That means annually an average of 716983 Mg soil removed from the Türkşeker sugar beet production areas. This result indicated that harvest erosion represents only 0.9% of soil lost by water erosion in Turkey. But, if tolerable soil loss value considered as "1 Mg ha^{-1} y^{-1}", calculated soil loss values are above this critical value for all the factories. In addition, economic assessments of soil losses showed that costs are to be more than US $10 000 annually on the 60% of the factories due to removal of plant nutrients with harvest process. And, annually US $419 433 investment must be made to recover all these losses. Conclusively, harvest erosion as an ignored erosion type must be emphasized to the economic sustainability of natural resources in fragile ecosystems such as our country.

Keywords: Harvest erosion, sugar beet, soil and plant nutrient losses

1. Introduction

The soil is one of the basic components of the Sustainable Development Goals (SDG), designed as a framework to guide global development for a stronger global commitment and sustainable development over the next fifteen years. Today, it is clearly known that sustainability of soil resources under the accelerated anthropogenic pressures is seriously at risk.

According to reports on the subject, 33% of the world's soil degraded due to deforestation, population growth, urban expansion, climate change and unsuitable soil management practices. And soil erosion is the main type of these mentioned degradation causes threat on soil functions as a limiting factor for human interests (Anonymous, 2015a, 2015b and 2017a).

Soil loss due to crop harvest (SLCH) can be defined as the mass of soil carried away from the arable land by crop harvests such as sugar beet (*Beta vulgaris* L.), potato (*Solanum tuberosum* L.) and carrot (*Daucus carota* L.) (Li et al., 2006). Among these crops, sugar beet production has a very significant role in Turkey's agriculture as an indispensable rotational crop in Anatolian conditions for sugar industry (Oruç and Güngör, 2000). Turkey is the fifth largest sugar beet producer after France, Germany, the United States and Russia. According to 2016/2017 market year assessments, 19.592.000 MT sugar beet harvested from 321 953 hectare area in Turkey (Anonymous, 2017b). Despite such exhaustive production facilities exploiting land resources, many studies considered harvest erosion as a type of soil erosion (Poesen et al., 2001; Ruysschaert et al., 2004). The reason for not getting enough attention on this subject can be explained by the results obtained from several studies, which reported harvest erosion mostly close and/or lower than the tolerable soil loss values, which varies between 1 and 5 Mg ha^{-1} y^{-1}. But, it has been emphasized by many researchers who highlighted that there is a significant risk to land resources on intensively cultivated, rugged topographies that is not suitable for tillage operations (Govers et al., 1994; Poesen et al., 1997; Turkelboom et al., 1997).

Several attempts to evaluate harvest erosion were mostly performed in the European soil conditions. Koch (1996) stated that annually 4-8 Mg ha^{-1} soil was removed from sugar beet production areas in Germany. Ruysschaert et al. (2005) evaluated the variability of SLCH values for sugar beet areas in four West European countries (France, Belgium, the Netherlands, and Germany) for 1978-2000 period. And, they reported that SLCH values were 5.9 Mg $ha^{-1}y^{-1}$ (Netherlands), 13.8 Mg $ha^{-1}y^{-1}$ (France), 9.3 Mg ha^{-1} (Belgium) and 5.2 Mg $ha^{-1}y^{-1}$ (Germany). In Turkey, several studies by different researchers were also performed to evaluate the SLCH values. Some of them are as follows; Oruç and Güngör (2000) estimated soil tare values for the gross weight of harvested sugar beet as 10.24% and 11.20% for the period 1989-1999 in Turkey and in Eskişehir, respectively. It means that approximately 4.16 Mg $ha^{-1}y^{-1}$ soil in Turkey and 4.8 Mg $ha^{-1}y^{-1}$ soil in Eskisehir were transported from sugar beet fields annually. Similarly, for the period of 1990-2000, Öztaş et al. (2002) estimated the soil loss rate as 2.6 Mg ha^{-1} y^{-1} and the economic value of which was calculated as US $60000 based on soil analyzes and agricultural reports in sugar beet production areas in Erzurum. And, they calculated the average soil tare value as 8.6% for entire Turkey and reported annual soil loss prediction as 3.4 Mg $ha^{-1}y^{-1}$. Additionally, Parlak et al. (2008) reported that approximately 4.28 Mg ha^{-1} y^{-1} soil was transported from fields due to the sugar beet production according to 2005 production reports. And, the economic value of the removed N, P and K from topsoil by harvest erosion was calculated as approximately US $4 million for Turkey. More recently, Tuğrul et al. (2012) calculated an economic evaluation of the SLCH rates for all sugar beet growing areas in Turkey and reported that 3.86 Mg $ha^{-1}y^{-1}$ soil was transported from approximately 300.000 hectare sugar beet growing fields in Turkey and its cost was estimated as US $10 million. The difference between these studies is mostly related to evaluated time periods, locations and calculation of the soil tare values. In any case, overall findings showed that estimated soil loss rates were mostly lower than tolerable soil loss rates, but plant nutrition losses were fairly high when considered for the sustainability of nutrient balance in fragile ecosystems such as Turkey.

Within the scope of this study, it was aimed to evaluate the current status of long-term soil loss rates due to sugar beet harvesting facilities and assess the economic outputs of this type of soil erosion in Turkey.

2. Materials and Methods

2.1. Description of the study area

There are 33 sugar plants and 6 (yellow) starch-based sugar production factories in Turkey. 25 (grey) of which are public sugar beet production factories which belong to the General Directorate of the Turkish Sugar Corporation (Türkşeker) and 8 (green) are the private commercial firms (Anonymous, 2017b) (Figure 1).

2.2. Calculation of the soil loss rates due to crop harvest (SLCH)

Within the scope of the study, beet production quantities, planting areas, and proceeded beet amounts were evaluated in terms of the SLCH erosion from these 25 public sugar beet production sites. A compiled data of 25 different sugar factories from 1999 to 2016 throughout Turkey were obtained from Türkşeker. In addition to soil loss calculations, sediment associated-chemical transporting conditions in terms of plant nutrient losses and their economic equivalents were investigated for the studied period. In this context, totally 2731 soil analyses data points derived from Soil and Plant Nutrition Department of Türkşeker related to fertility parameters (N, P_2O_5 and K_2O contents of sugar beet production areas) were used.

Soil tare amounts due to sugar beet (*Beta vulgaris* L.) harvest to evaluate SLCH values were calculated by Equation 1. In general, soil tare amount (ST, %) is determined by the difference between the gross weight of beet (GW) and clean beet weight (CBW). However, a 5% regular deduction in the measured ST value was made since calculated ST was included in the top tare as soil tare (Oruç and Güngör, 2000).

$$ST=\frac{GW\text{-}CBW}{GW} \quad (1)$$

Where ST is soil tare (%), GW is the total gross weight of beet (beet, soil adhering to the roots, clinging soil, loose soil, and stones) (Mg) and CBW is clean beet weight (Mg).

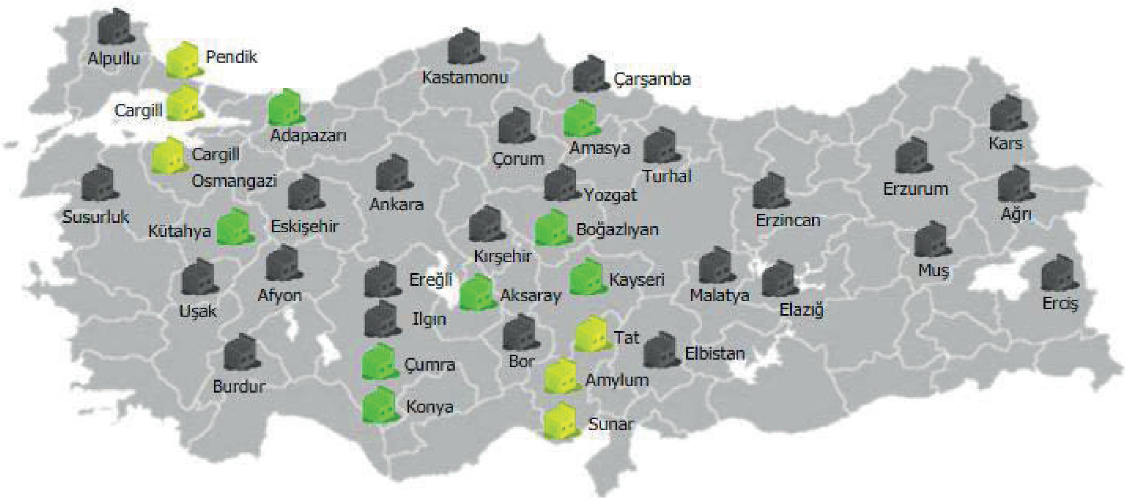

Figure 1. Sugar beet production locations in Turkey (Anonymous, 2017b)

After calculating the soil tare values, soil tare values before cleaning (STBC, %) was calculated according to Kromer (1989) and Tuğrul et al. (2012) (Equation 2).

$$STBC=\frac{100\times STAC}{100\text{-}CE} \quad (2)$$

Where STAC is the soil tare after cleaning process (%) and CE is the cleaning efficiency of the machine (%) accepted as 55.53% which was calculated with an experimental study for the cleaning machinery in Türkşeker factories (Tuğrul et al., 2012).

The SLCH values and its distribution over the factories were calculated with the Equation 3 and expressed as Mg ha^{-1} unit by dividing to the total planted area.

$$SLCH=\frac{STBC\times GW}{100} \quad (3)$$

To more accurately represent the SLCH values (Mg ha^{-1}y^{-1}), area-weighted average values were taken into consideration for the studied period 1999-2016 (Equation 4).

$$SLCH_{average}=\frac{\sum_{i=1}^{n} SLCH_i\times A_i}{\sum_{i=1}^{n} A_i} \quad (4)$$

3. Results and Discussion

For the 1999 – 2016 period, the total gross weight of harvested sugar beet obtained from Türkşeker factories was 188.13x10^6 Mg from 3784.66x10^3 hectare production area (Table 1). It is clear that there is a significant reduction in the sugar beet cultivation due to sugar law passed on April 2001.

Table 1. Annual area weighted soil loss rates (Mg ha^{-1}) transported from field to all Türkşeker factories

Year	Planted area (ha) x 10^3	GW (Mg) x 10^6	STBC $_{average}$ (%)^a	SLCH$_{average}$ (Mg ha^{-1})^b
1999	326.75	13.6	6.63	2.81
2000	315.6	15.25	7.04	3.42
2001	263.03	8.14	6.51	2.53
2002	214.09	12.5	5.89	2.71
2003	228.1	9.73	6.82	2.92
2004	223.1	10.16	7.22	3.33
2005	221.95	10.5	7.89	3.81
2006	199.01	9.48	9.77	4.74
2007	175.28	7.51	7.55	3.29
2008	187.37	9.06	6.16	2.99
2009	187.45	10.37	7.06	3.92
2010	197.33	11.04	7.21	4.06
2011	178.27	9.74	7.01	3.76
2012	170.07	9.13	6.08	3.3
2013	177.11	10.01	5.11	2.89
2014	171.61	10.17	6.84	4.02
2015	158.15	9.49	5.4	3.27
2016	190.39	12.25	5.16	3.3

^{a}: Area weighted STBC$_{average}$ (%), ^{b}: Area weighted SLCH$_{average}$ values (Mg ha^{-1}y^{-1})

Despite the serious decrease in the production area, there is no significant decrease in the production amounts due to increased productivity. On the other hand, the sugar law needs a comprehensive evaluation of the risks of starch-based sugars and chemical sweeteners (i.e. isoglucose) on public health and socio-economic situations (Tosun and Arslan, 2016).

Variations in area weighted soil loss rates in Türkşeker sugar beet factories and their total planted area over time can be clearly seen in Figure 2. When an average assessment was made according to years, highest soil loss rate was observed as 4.66 Mg $ha^{-1}y^{-1}$ in 2006. While the lowest soil loss rate (2.02 Mg $ha^{-1}y^{-1}$) was measured in 2001 (Figure 2). Harvested crop data can be used to estimate soil loss rates. Thus, the lowest soil loss was seen in 2001, which was also the second lowest year for sugar beet production.

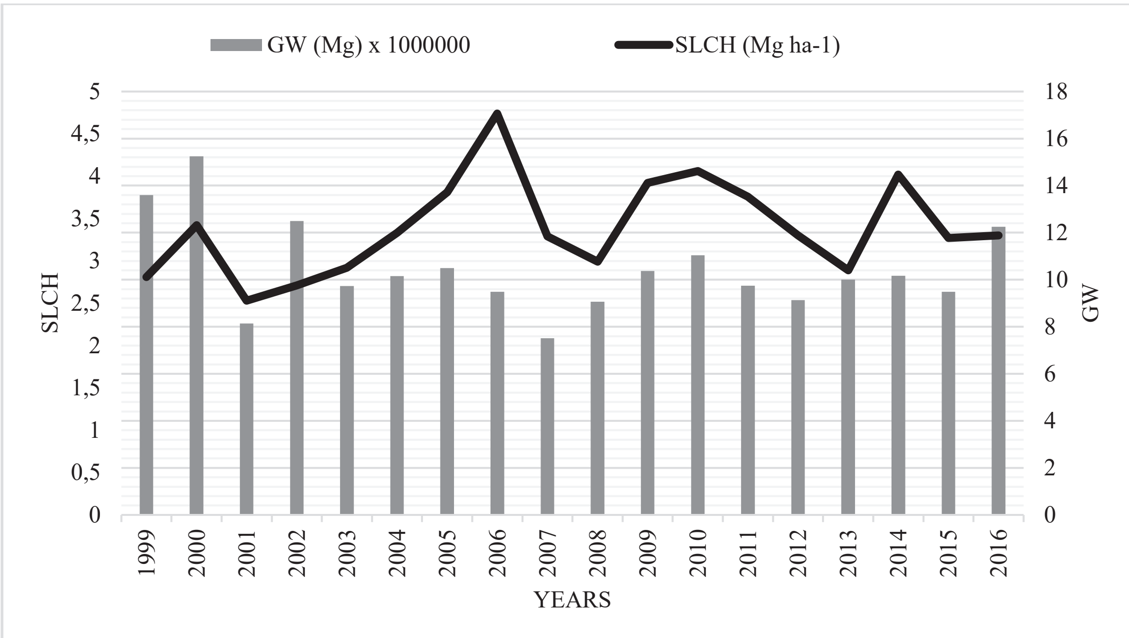

Figure 2. Variation of the soil loss trends according to the total gross weight of harvested sugar beet from factories

Average soil loss rate for Türkşeker was calculated as 3.41 Mg $ha^{-1}y^{-1}$ for the period between 1999 and 2016 (Figure 3). That means an annual of $717x10^3$ Mg soil removed from the Türkşeker sugar beet production areas between 1999 and 2016. When we evaluated all sugar beet production sites in Turkey (Anonymous, 2017b), an estimated 1097.86 x 10^3 Mg soil was removed from $322x10^3$ hectares area due to the sugar beet harvest in 2016. According to the annual suspended-sediment yields in Turkey, 121.45x106 Mg soil, rich in organic matter and nutrients, removed due to water erosion. Given this figure, harvest erosion in water erosion types corresponds to only 0.9% of the amount of soil loss (Erpul and Saygın, 2012). This rate is about three times higher than the loss rate found by Oruç and Güngör (2000). It was due to the consideration of suspended-sediment yield as the value of soil loss induced by water erosion in this study (Erpul and Saygın, 2012).

When assessments were made in terms of soil loss measured in factories (Figure 3), the lowest soil loss rate was obtained from Erciş, while the highest soil loss was observed on Elbistan in terms of area weighted average value. Soil loss rates in Ankara, Bor, Çarşamba, Ilgın and Turhan factories were slightly higher than overall average while Alpullu, Elazıg, Kırşehir, Malatya, and Susurluk had much higher rates. Elbistan factory showed the highest soil loss rate as 6.69 Mg $ha^{-1}y^{-1}$ and it was higher than 5 Mg ha^{-1} y^{-1} value which is accepted as the upper limit for tolerable soil loss in arid-semi-arid agricultural conditions. Since the rate of soil loss is 48 times higher than the rate of soil formation in Turkey, it is necessary to reduce the soil loss rates below the tolerable limits (Erpul and Saygın, 2012).

According to Oruç and Güngör (2000), the average soil loss rate due to sugar beet harvest for the 1989-1999 period was 4.16 Mg $ha^{-1}y^{-1}$ for

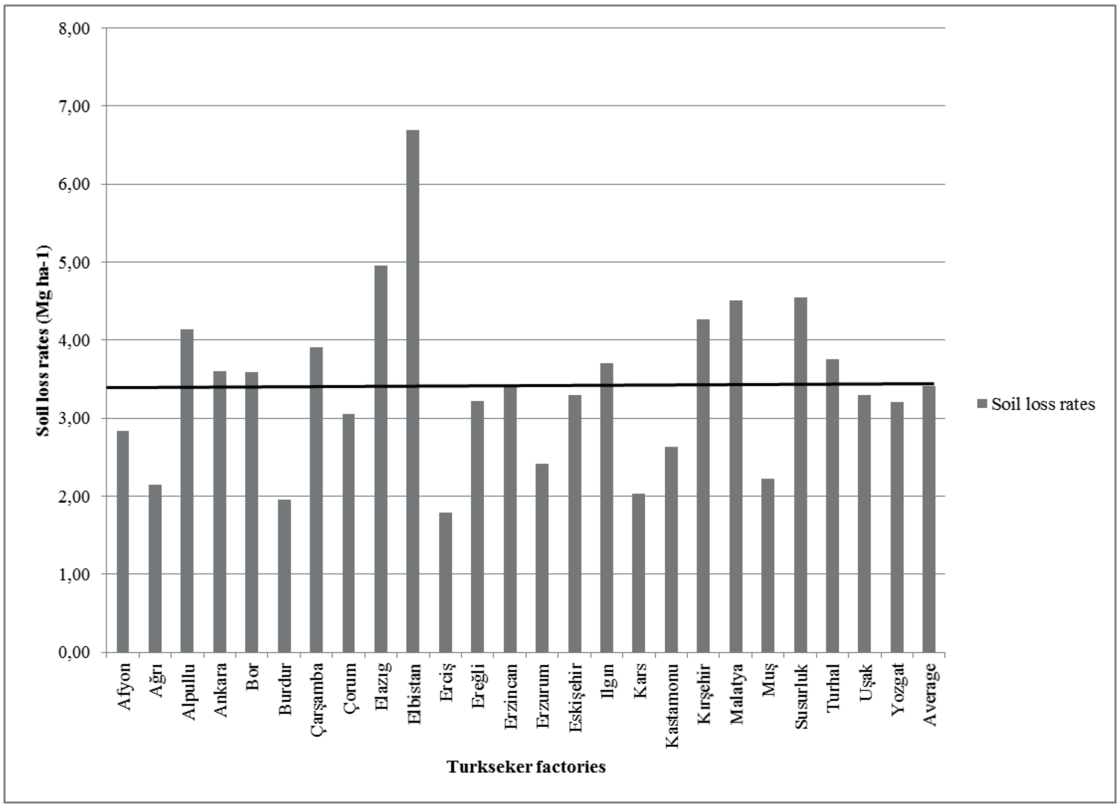

Figure 3. Average soil loss rates of Türkşeker factories between 1999 and 2016

Turkey. Reports of Öztaş et al. (2002) also confirmed this prediction for 1990 and 2000 period. They estimated average soil loss rate of 3.4 Mg $ha^{-1}y^{-1}$ for Turkey. In addition, Parlak et al. (2008) predicted the annual soil loss rate slightly higher as 4.28 Mg $ha^{-1}y^{-1}$ for the year of 2005. Differences between obtained results are mostly related to soil tare calculation approach. Tuğrul et al. (2012) carried out a significant study to evaluate the efficiency of cleaning machine in the Türkşeker sugar beet factories. They calculated the efficiency of cleaning machine as 53.33% and draw a more accurate procedure for soil tare prediction. This factor was not considered in previous studies. According to their results, soil loss rate due to crop harvest in Ankara sugar factory areas were calculated as 3.86 Mg $ha^{-1}y^{-1}$ based on the collected data from 2000 to 2008.

In order to make an evaluation of the economic aspects of soil loss in terms of fertility and analysis of the relationships between soil losses and productivity, a compressive database on the fertility parameters (N, P_2O_5 and K_2O contents of sugar beet production areas) was used which was derived from Soil and Plant Nutrition Department of Türkşeker (Table 2). Thus, plant nutrient losses were calculated by the aid of totally 2731 soil analyses results (Table 3).

The equivalent amounts of plant nutrients removed with harvested sediment-associated to roots were shown in Table 3. According to the estimations, annually US $419 433 investment must be made to recover the nutrient losses (Table 3). Nitrogen losses correspond to 92% of this investment. As widely known, nitrogen is the primary nutrient element for the vegetative growth of sugar beet. Phosphorus and potassium correspond to 5% and 3% of this investment, respectively. When compared with similar studies in terms of estimated costs (Öztaş et al., 2002; Parlak et al., 2008; Kaplan et al., 2012), differences among them can be explained by decreasing planting area, changes on SLCH values due to variations in production techniques, and increased fertilizer prices (Tuğrul et al., 2012).

When nutrient cost assessments were made for the factories due to harvest erosion (Figure 3), the lowest investment to recover the nutrient losses should be done for Kars, while the highest should be done for Ilgın factory. The differences are correlated to the size of planted area among the factories. Not surprisingly, increased planted area led to increased soil loss rates and nutrient losses. Results clearly showed that cost of losses is more than $10 000 per year in 60% of factories.

Table 2. Fertility properties of soils in Türkşeker sugar beet planting areas (total n=2731)*

Factories	n (sample size)	Total N (mg kg^{-1})	Available P (mg P_2O_5 kg^{-1})	Extractable K (mg K_2O kg^{-1})
Afyon	137	997.8 ± 35.2	71.30 ± 4.81	780.1 ± 70.4
Ağrı	20	861.8 ± 52.2	59.97 ± 9.28	406.6 ± 30.5
Alpullu	25	845.0 ± 49.4	113.5 ± 18.7	421.1 ± 31.8
Ankara	128	765.6 ± 26.3	37.9 ± 2.44	482.5 ± 17.8
Bor	103	898.7 ± 48.4	52.01 ± 3.37	782.5 ± 41.4
Burdur	122	1176.0 ± 53.1	82.76 ± 6.10	585.6 ± 70.5
Çarşamba	1	1040 ± 0.00	40.9 ± 0.00	311.8 ± 0.00
Çorum	87	818.0 ± 24.6	23.72 ± 1.97	480.0 ± 20.9
Elazıg	22	658.9 ± 24.5	64.0 ± 14.8	342.0 ± 36.1
Elbistan	94	1052.7 ± 23.6	55.08 ± 3.32	425.7 ± 20.3
Erciş	59	544.9 ± 38.5	43.78 ± 4.45	356.2 ± 27.4
Ereğli	275	864.0 ± 20.8	37.42 ± 1.80	462.1 ± 16.7
Erzincan	49	858.6 ± 37.6	22.48 ± 2.56	254.3 ± 17.7
Erzurum	101	1228.6 ± 34.5	80.81 ± 7.06	624.0 ± 40.5
Eskişehir	276	1042.8 ± 29.7	52.6 ± 5.17	596.8 ± 19.0
Ilgın	300	1019.0 ± 25.6	48.69 ± 2.94	403.2 ± 12.8
Kars	16	1261.6 ± 55.4	53.5 ± 17.7	416.7 ± 30.4
Kastamonu	55	846.6 ± 35.1	50.45 ± 4.82	299.1 ± 14.7
Kırşehir	244	781.1 ± 19.3	43.85 ± 1.97	626.1 ± 18.0
Malatya	111	866.4 ± 49.2	30.15 ± 2.51	299.9 ± 14.6
Muş	107	970.7 ± 31.4	53.31 ± 4.72	680.8 ± 37.3
Susurluk	22	661.4 ± 50.4	80.4 ± 12.5	328.1 ± 37.5
Turhal	208	878.9 ± 19.3	38.95 ± 1.96	412.5 ± 18.3
Uşak	62	958.1 ± 58.9	47.70 ± 5.52	412.5 ± 24.4
Yozgat	107	788.5 ± 36.8	26.95 ± 1.39	446.7 ± 21.5

*: Used database on the fertility parameters (in Table 2) for the analysis of the relationships between soil losses and productivity was taken from Dr. Ahmet Pişkin, *Plant Nutrition and Soil Department, General Directorate of the Turkish Sugar Corporation (Türkşeker)*

Table 3. Annual costs of N, P, and K losses due to harvest erosion in sugar beet production areas in Turkey

Factories	Fertility equivalent of losses (kg da^{-1})			Required fertilizer amounts (Mg)			Total cost to cover the losses			Total cost of the harvest erosion
	N losses	P losses	K losses	Urea (46% N)	TSP (43%)	K_2SO_4 (50%)	Urea (46% N)	TSP (43%)	K_2SO_4 (50%)	
Afyon	0.28	0.2	0.06	76	5.8	3.89	$20.521	$1.580	$1.624	$23.724
Ağrı	0.18	0.11	0.02	24.04	1.54	0.54	$6.490	$420	$225	$7.136
Alpullu	0.35	0.4	0.04	20.29	2.46	0.89	$5.478	$671	$372	$6.521
Ankara	0.28	0.1	0.01	56.8	2.3	0.96	$15.335	$627	$399	$16.361
Bor	0.32	0.17	0.04	84.23	4.69	3.15	$22.741	$1.277	$1.317	$25.335
Burdur	0.23	0.19	0.06	59.14	5.24	2.64	$15.968	$1.427	$1.101	$18.495
Çarşamba	0.41	0.17	0.01	23.67	1.04	0.28	$6.390	$282	$116	$6.788
Çorum	0.25	0.06	0.01	45.9	1.16	0.48	$12.393	$317	$201	$12.911
Elazıg	0.33	0.21	0.01	23.47	1.61	0.47	$6.337	$438	$197	$6.972
Elbistan	0.7	0.39	0.02	112.52	6.63	2.43	$30.381	$1.807	$1.013	$33.201
Erciş	0.1	0.04	0.01	11	0.52	0.16	$2.969	$140	$66	$3.176
Ereğli	0.28	0.1	0.01	101	4.04	1.61	$27.271	$1.102	$671	$29.043
Erzincan	0.29	0.07	0.01	30.76	0.74	0.16	$8.304	$202	$68	$8.573
Erzurum	0.3	0.24	0.06	50.9	4.4	2.36	$13.742	$1.199	$986	$15.927
Eskişehir	0.34	0.18	0.03	125.68	7.07	3.63	$33.934	$1.927	$1.515	$37.377
Ilgın	0.38	0.18	0.02	153.99	8.02	2.78	$41.576	$2.186	$1.161	$44.923
Kars	0.26	0.14	0.03	9.18	0.53	0.19	$2.479	$143	$79	$2.701
Kastamonu	0.22	0.11	0.01	34.05	1.84	0.47	$9.193	$501	$197	$9.892
Kırşehir	0.33	0.15	0.02	76.25	3.58	1.93	$20.588	$975	$804	$22.367
Malatya	0.39	0.12	0.01	45.09	1.45	0.38	$12.175	$396	$157	$12.728
Muş	0.22	0.12	0.04	47.16	2.69	1.57	$12.734	$733	$657	$14.124
Susurluk	0.3	0.24	0.02	24.97	2.15	0.61	$6.742	$585	$253	$7.580
Turhal	0.33	0.13	0.01	112.27	4.68	1.66	$30.312	$1.275	$693	$32.280
Uşak	0.32	0.15	0.02	28.35	1.45	0.51	$7.653	$394	$214	$8.262
Yozgat	0.25	0.07	0.01	46.15	1.33	0.51	$12.460	$363	$213	$13.036
Total							$384.166	$20.967	$14.299	$419.433

N: Nitrogen, P: Phosphorus, K: Potassium, TSP: Triple superphosphate

4. Conclusions

Even though harvest erosion described as a significant erosion type, it was taken less into consideration, compared to other erosion types. Crops such as sugar beet (*Beta vulgaris* L.), potato (*Solanum tuberosum* L.) and carrot (*Daucus carota* L.) are harvested with a considerable amount of soil. And, it presents a constant threat to the sustainability of limited resource availability especially for the fragile ecosystems where the soil formation processes like our country require lots of time. Results clearly indicated that soil losses of sugar beet factories are below the tolerable rates (5 Mg ha^{-1} y^{-1}) except Elbistan factory. However, if 1 Mg ha^{-1} y^{-1} is taken as a threshold value for tolerable soil loss, all of the studied factory results were above this critical level. In addition, estimated costs are found to be more than US $10000 annually in the 60% of the factories in terms of the nutrient content losses. Conclusively, harvest erosion is an important issue and it must be emphasized like other erosion types, both for economic and sustainable resource management in Turkey.

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