Received: 16 December 2021 | Revised: 9 March 2022 | Accepted: 13 March 2022

DOI: 10.1002/ldr.4262

RESEARCH ARTICLE

WILEY

Soil losses due to leek and groundnut root crop harvesting: An unstudied regional problem in Turkey

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Funding information
Canakkale Onsekiz Mart University the Scientific Research Coordination Unit, Grant/Award Number: FHD-2019-3068

Abstract

Soil loss from root crops is an increasingly significant problem studied for some species, such as potatoes, sugar beets, carrots, celery, and onions. It reduces soil fertility and, subsequently, soil productivity. For leek (*Allium porrum*) and groundnut (*Arachis hypogaea*), however, there is little information to date. More research on this topic could help farmers reduce the process of soil degradation. In some countries, such as Turkey, the production of these crops is perennial to supporting rural communities and ensuring food security. Therefore, it is important to quantify soil losses from leek and groundnut crops in Turkey. This study investigated the factors affecting soil losses and the cost of nutrients lost with the transported soil by analyzing randomly selected plants from 45 harvested leek and groundnut plots. Our results showed that soil losses reached 3.99 Mg ha^{-1} per harvest for leek and 1.04 Mg ha^{-1} for groundnut. Prevailing soil moisture explained 59% of the variability in the leek harvest and soil texture and bulk density for leek yield at harvest. In the groundnut harvest, 53% of the variability was explained by antecedent soil moisture and clay fraction for the groundnut yield at the time of harvest. The estimated annual cost of nutrients losses was $US 3.75 ha^{-1} for leek and $US 0.76 ha^{-1} for groundnut. It can be concluded that leek and groundnut harvesting causes soil and nutrient losses with considerable economic costs. Therefore, awareness should be raised among farmers and users. In addition, policymakers should consider the management of soil loss by crop harvesting (SLCH) processes.

KEYWORDS
harvest, land degradation, rural economy, soil erosion

1 | INTRODUCTION

It is well-known that soil erosion can affect agricultural lands through different processes, such as water, wind, or tillage, which are an ongoing environmental concern (Bogunovic et al., 2020; Borrelli et al., 2016; Frankl et al., 2012; Haregeweyn et al., 2015; Lemma et al., 2019; Nearing & Baffaut, 2017; Novara et al., 2019; Nyssen et al., 2000; Van Pelt et al., 2017). However, in recent decades, other researchers have been paying attention to another process that activates soil erosion in cultivated fields, the harvest (Auerswald et al., 2006; He et al., 2018; Oshunsanya et al., 2018; Panagos et al., 2019). During harvest, soil adhering to root and tuber crops (i.e., sugar beet, potato, and carrot), and loose soil or clods and stones, are harvested and transported from the field to another location. This process of soil erosion is referred to as harvest-related soil loss (SLCH) or harvest erosion (Parlak et al., 2016; Ruysschaert et al., 2004). Although most of the research focused on water, wind, or tillage erosion, SLCH is recently accepted as one of the most critical erosion processes with erosion rates comparable to the other mentioned processes. Borrelli et al. (2017) estimated that global soil loss by water erosion reached 35.9 Pg yr^{-1} in 2012. It means that the average soil loss could be approximately 2.8 Mg ha^{-1} yr^{-1}. During the harvest of some crops, some authors obtained similar results. For example, 3.44 Mg ha^{-1} yr^{-1} for cassava (Isabirye et al., 2007), 5.94 Mg ha^{-1} yr^{-1} for onions (Mwango et al., 2015), 5.60 Mg ha^{-1} yr^{-1} for carrots (Parlak et al., 2016), 4.00 Mg ha^{-1} yr^{-1} for celery (Parlak et al., 2018), and 6.27 Mg ha^{-1} yr^{-1} for garlic (Faraji et al., 2017). These reported values are higher than the barrier of 1.4 Mg ha^{-1} yr^{-1}, considered as the tolerable limit for soil formation (Verheijen et al., 2009). While SLCH has been studied for several crops, many still have updated information. This can lead to irreversible land degradation processes and food insecurity for rural areas. In our case study, leek and groundnut occupy a large planted area worldwide, but associated data is still scarce (Kuhwald et al., 2022).

Leek can be annual or biannual crops commonly grown to obtain their leaves, positively affecting human health (Tasar et al., 2015). In 2019, 2,192,476 t of leek with other alliaceous vegetables were produced in 136,103 ha globally. Indonesia (590,596 t), Turkey (234,052 t), the Republic of Korea (155,914 t), and Belgium (152,340 t) (FAO, 2019) is the top worldwide leek producers. Turkish leek production area reached 8163 ha in 2019. Torbalı District of Izmir represents approximately 17% (39,760 t) of the total national leek production (TUIK, 2019).

Groundnut, a valuable oil plant belonging to the legume family, is a valuable food source for humans and animals as it contains oil, proteins, carbohydrates, vitamins, and mineral substances. At the same time, groundnut is recognized as a plant with beneficial properties which improve soil quality (Prasad et al., 2009). In 2019, 48,756,790 t of groundnut were produced globally. China ranked first in the world with 17,519,600 t. India produced 6,727,180 t, Nigeria 4,450,050 t, Sudan 2,828,000 t, and United States 2,492,980 t of groundnut (FAO, 2019). In 2019, 169,328 t of groundnut were produced in 42,218 ha in Turkey. Groundnut production in the Bayramic District of Canakkale reaches up to 59 t in 2018 (TUIK, 2019).

Thus, the importance of these crops in their nutritional, economic value and distribution is visible throughout the world. Inadequate soil management effectiveness would result in soil losses comparable to those experienced by other crops during the harvest season. Therefore, the current study was conducted to determine: (1) the soil losses from harvesting leek and groundnut in some representative areas of Turkey; (2) the control factors that increase soil losses during the harvest of both crops; and, (3) the amount and cost of nutrients lost. We also compare the cost of nutrient losses in other root crops to determine whether SLCH should be considered for leek and groundnut, as we hypothesized.

2 | MATERIALS AND METHODS

2.1 | Study sites

Torbalı is located at 38° 09' N and 27° 23′ E, 46 km from Izmir City (Figure 1). It is surrounded by Bayındır and Tire in the east, Menderes in the west, Buca and Kemalpasa in the north, and Selcuk in the south. Torbalı District is characterized by a Mediterranean climate, with hot and dry summers and mild and rainy winters (Türkeş, 1996). According to Koppen's climate classification, the study area can be classified as Csa (GDM, 2022). According to long-term annual average values (1976–2020), the precipitation reaches 676 mm, and the mean temperature reaches 16.9°C (GDM, 2021). Soils in the Torbalı District can be classified as Typic Xerofluvents and Typic Haploxererts, according to Soil Taxonomy (Soil Survey Staff, 2014). Tomato, leek, cauliflower, olives, grapes, figs, peaches, and maize are the primary crops cultivated in the Torbalı District of Izmir.

The Bayramic District of Canakkale is a region that forms the middle part of the Biga Peninsula and is located between 38–40° N and 26–28° E. It is a semi-mountainous area, with hot and dry summers and more rainy and cold winters than expected in the Mediterranean climate. In the long-term period (1976–2020), the annual averages of Bayramic town are 656 mm for precipitations and 14.5 °C for temperature (GDM, 2021). Soils are classified as Typic Ustifluvents, according to Soil Taxonomy (Soil Survey Staff, 2014). Apples, olives, pears, almonds, peaches, and groundnut are the main crops grown.

2.2 | Crop and soil management

During the research period, leek seeds were sown in viols for 1 month (June 2019) and transplanted to the field in July 2019. Leek seedlings (about 20 cm tall) were planted in the field with 35 cm row spacing and 7 cm in-row plant spacing. Before planting, 250 kg ha^{-1} of DAP (di ammonivum phosphate) fertilizer was applied as a subsoil fertilizer. After the seedlings were planted in the field, 150 kg ha^{-1} of ammonium sulfate fertilizer was applied. Then, 25 kg of urea fertilizer was applied twice during the growing period. Drip- irrigation was used. For controlling the weeds, group A herbicide with 150 g l^{-1} fluazifop-P-butyl active ingredients, commercial name Fusilade Forte© at 500 ml ha^{-1} and 480 g L^{-1} oxyfluorfen active ingredient, E,14 group herbicide with Goal 4F© (commercial name) 400 ml ha^{-1} was applied. Leek fields were irrigated with drip-irrigation 3 days before harvest to facilitate leek extraction as well as plant and soil separation. Harvest was manually conducted in November 2019.

Groundnut seeds are sowed in April 2019 with an air seeder at 60 kg seed ha^{-1}. The distance between rows is 70 cm, and the in-row plant spacing is 15 cm. Urea was applied at 100 kg ha^{-1} (50 kg + 50 kg). Considering the development of the plant, the urea fertilizer was divided into two and applied to the soil. With the sowing, 100 kg of NPK (15-15-15) fertilizer ha^{-1} was used. The first hoeing was carried out 15–20 days after the first plant emergence, and the second hoeing was done 15 days after the first hoe. Due to its mechanism of action against the weed Johnson grass (*Sorghum halepense*), the groundnut was sprayed at a dose of 600 ml ha^{-1} with a herbicide called super gallant© with 108 g L^{-1} haloxyfop (P) methyl ester active ingredient, which is a group A herbicide. The super gallant application was made when weeds were 15–20 cm tall and had 5–6 leaves. The newly germinated weeds in the field were controlled with the second

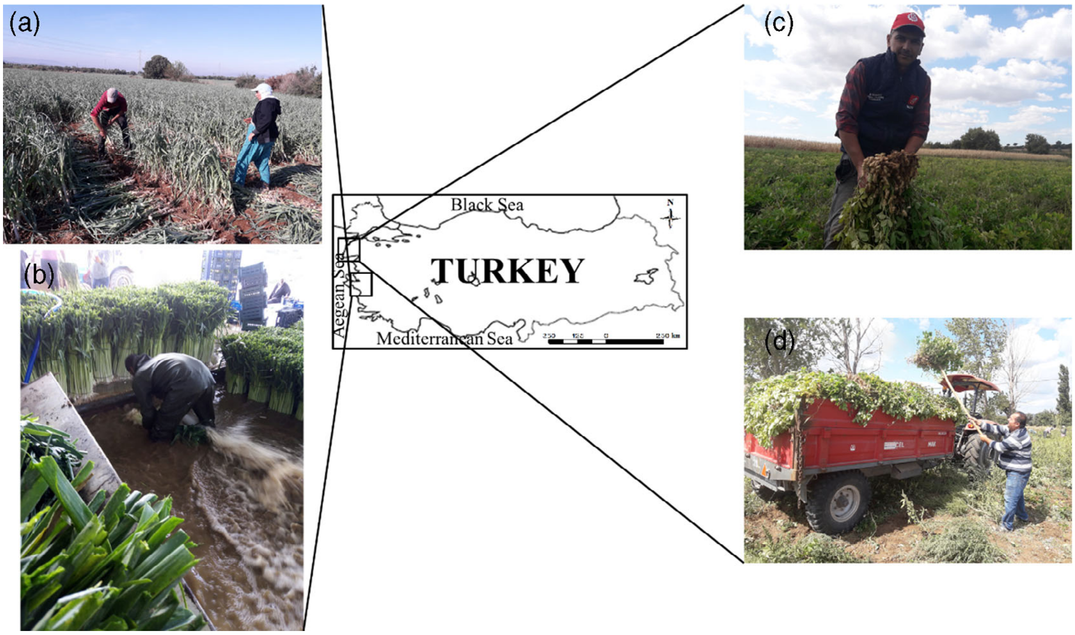

FIGURE 1 Study areas and examples of soil and crop sampling tasks. (a). Manual leek harvest; (b). Leek cleaning; (c). Manual groundnut harvest; (d). Groundnut loaded on a trailer [Colour figure can be viewed at wileyonlinelibrary.com]

application at the same dose 20–25 days after the first application. Manual harvesting was performed in September 2019. Immediately after harvest, they were moved indoors to protect the groundnut from crow damage. Groundnuts were dried on tables indoors.

2.3 | Sampling methodology

Leek and groundnut were harvested in November 2019 and September 2019, respectively (Figure 1a–d). Since leek and groundnut fields are small and machine harvest can be costly, manual harvest was practiced. Experiments were conducted in three different villages (Merkez, Ozbey, and Capak) of Torbalı metropolitan area, in Izmir Province, where leek mainly was cultivated; and in two villages (Pıtıreli and Cavusköy) next to Bayramic town, in Canakkale Province, where groundnut mainly was cultivated. A total of 27 leek samplings (3 villages × 3 leek fields × 3 plots = 27) and 18 groundnut samplings (2 villages × 3 groundnut fields × 3 plots = 18) were collected. Plot sizes were 2 × 2 m, both in leek and groundnut.

All plants were harvested from leek and groundnut plots. Eight plants and three plants were randomly selected from the harvested leek and groundnut plots. The plant density (plant ha^{-1}) was determined from the total number of leek and groundnut plants for each plot. The mass of wet soil adhering to plants was measured in the field immediately after harvest by weighing gross plant (plant mass + soil mass), washing the plants in a bucket, and weighing the individual clean plant (net crop mass or $M_{crop/p}$). The crop yield (M_{cy}) in Mg ha^{-1} was calculated from the average plant mass and plant density (Li et al., 2006).

2.4 | Determination of soil loss

The equations used to determine the quantity of soil loss due to the crop harvesting are given below (Ruysschaert et al., 2004), from Equations (1) to (3),

$$SLCH_{spec}\left(kg\,kg^{-1}\right) = (M_{ds} + M_{rf})/M_{crop} \tag{1}$$

$$SLCH_{spec/p}\,(g) = (M_{ds} + M_{rf})/N_{pl} \tag{2}$$

$$SLCH_{crop}\left(Mg\,ha^{-1}\,harvest^{-1}\right) = SLCH_{spec}\,x\,M_{cy,} \tag{3}$$

Where: $SLCH_{spec}$ (kg kg^{-1}) is the amount of soil loss related to the number of crops, M_{ds} represents the mass of oven-dry soil (kg), M_{rf} is the mass of rock fragments (kg), and M_{crop} means the net crop mass of the sample (kg). $SLCH_{spec/p}$ (g) is the amount of soil loss related to the individual crop or root, and N_{pl} represents the number of roots in the sample. Finally, $SLCH_{crop}$ (Mg ha^{-1} harvest^{-1}) is the total soil loss per unit area and harvest where and M_{cy} is the net crop yield (Mg ha^{-1} harvest^{-1}). Since rock fragments are left in the field during the harvesting, M_{rf} was not considered in Equation (1) and Equation (2).

2.5 | Soil analysis

Disturbed and undisturbed soil samples were taken from 0 to 20 cm depth with a stainless steel shovel and steel core during the harvest.

Soil samples were air-dried and passed through a 2 mm sieve. Analyses were carried out in the laboratory to determine some soil physical and chemical properties such as antecedent soil moisture content, bulk density, particle size analysis, carbonates ($CaCO_3$), organic matter, total N, available P, and K. Antecedent soil moisture content taken during harvest were determined by the gravimetric method (Topp & Ferre, 2002). The particle size distribution of soil samples was analyzed using the hydrometer method described by Gee and Or (2002). Bulk density was calculated through the known volume of steel core and weight of soil sampled by core at a time (Grossman & Reinsch, 2002). The calcium carbonate content of the soils was determined with the Scheibler calcimeter, as described in Loeppert and Suarez (1996). The concentration of soil organic matter was determined by the Walkley-Black method (Nelson & Sommers, 1996). Total N is determined by the Kjeldahl method (Bremner, 1996). The available P was extracted with $NaHCO_3$ and measured colorimetrically (Kuo, 1996). The plant-available K in the soil was extracted with 1 M NH_4OAc and was determined by flame emission photometry (Helmke & Sparks, 1996).

2.6 | Nutrient loss estimation and determination of fertilizer replacement

We calculated the nutrient losses and cost to replace nutrients lost with leek and groundnut harvest following Equations (4–8). The fertilizer equivalent was urea for N (46%), triple superphosphate for P (43%), and potassium sulfate for K (50%). The cost for each fertilizer component was: \$US307 Mg^{-1} for urea, \$200 Mg^{-1} for triple superphosphate, and \$US 694 Mg^{-1} for potassium sulfate.

$$\text{Nutrient loss}\left(\text{kg ha}^{-1}\,\text{harvest}^{-1}\right) = \text{Nutrient content}\left(\text{g kg}^{-1}\,\text{soil}\right) \times \text{SLCH}_{crop}\left(\text{Mg ha}^{-1}\,\text{harvest}^{-1}\right) \quad (4)$$

$$\text{Urea (kg)} = 100 \times \text{N removed}\left(\text{kg ha}^{-1}\,\text{harvest}^{-1}\right)/46 \quad (5)$$

$$\text{Triple superphosphate (kg)} = 100 \times \text{P}_2\text{O}_5\,\text{removed}\left(\text{kg ha}^{-1}\,\text{harvest}^{-1}\right)/43 \quad (6)$$

$$\text{Potassium sulfate (kg)} = 100 \times \text{K}_2\text{O removed}\left(\text{kg ha}^{-1}\,\text{harvest}^{-1}\right)/50 \quad (7)$$

$$\text{Nutrient cost}\left(\$\text{US ha}^{-1}\,\text{year}^{-1}\right) = \text{Fertilizer equivalent}\left(\text{kg ha}^{-1}\right) \times \text{Unit price}\left(\$\text{US Mg}^{-1}\right). \quad (8)$$

2.7 | Statistical analysis

To evaluate the correlation among SLCH values and other measured variables, we used PROC CORR, REG, and STEPWISE in SAS v. 9.4 (SAS Institute Inc., 2018). We evaluated the Spearman correlation coefficients using a significance level p ≤0.05. Multiple linear regression analysis ($SLCH_{spec/p}$) was used as the dependent variable. Soil water content, clay, silt, fine sand, coarse sand, bulk density, lime ($CaCO_3$), organic matter, plant density, and crop yield were used as the independent variable.

3 | RESULTS

3.1 | Soil physical and biological properties for leek and groundnut

Basic statistics of each variable and soil characteristics and plant production for leek and groundnut harvesting are provided in Figure 2. The texture classes of the leek-cultivated soils were determined as loam, sandy clay loam, and clay loam. The moisture content, bulk density, lime, and organic matter were 19.68 g g^{-1}, 1.42 g cm^{-3}, 5.17%, and 1.54%, respectively. Plant density and crop yields were 96,630 roots ha^{-1} and 24.63 Mg ha^{-1} harvest^{-1}, respectively for leek and 88,890 roots ha^{-1} and 6.84 Mg ha^{-1} harvest^{-1} for groundnut (Figure 3). Groundnut soils were sandy loam, loamy sand, and clay texture. The soil's moisture content, bulk density, $CaCO_3$, and organic matter contents were 7.37 g g^{-1}, 1.44 g cm^{-3}, 1.89%, and 1.15%, respectively.

3.2 | Soil loss after harvesting and correlation between soil and biological properties

In Figure 4, the parameters of SLCH are shown. In the case of $SLCH_{spec}$, there are no substantial differences between leek and groundnut harvests as the majority of values have a similar distribution. At the same time, the average for leek harvest, the average is 0.18 kg kg^{-1}, and for groundnut harvest, the average is 0.17 kg kg^{-1}. The minimum values are similar in cases, that is, 0.05 kg kg^{-1} for leek and 0.057 kg kg^{-1} for groundnut. There is a broader difference when we analyze the maximum values since, for leek, they amount to 0.382 kg kg^{-1} and for groundnut to 0.265 kg kg^{-1}, although, in this case, there is one value of 0.419 kg kg^{-1}, which is outside the standard deviation.

For $SLCH_{spec/p}$, the averages are 0.018, and 0.020 (g root^{-1}) for leek and groundnut harvest, respectively. The minimum values are similar in these cases, 0.005 for leek, and 0.0047 for groundnut. The maximum values are 0.0424 and 0.0331, respectively, although there is one value, 0.0524 (g root^{-1}), outside the standard deviation in the case of groundnut.

Finally, in the case of $SLCH_{crop}$, for leek and groundnut harvest, the averages are 3.99 and 1.04 (Mg ha^{-1} harvest^{-1}), respectively. This is a result of differences between both distributions. For this reason, the ranges were varied in both cases. While for leek, the difference between the maximum value, 7.52, and the minimal one, 1.51 (Mg ha^{-1} harvest^{-1}), is high, in the case of groundnut, the range is low, with the maximum of 1.93 and the minimum of 0.46 (Mg ha^{-1} harvest^{-1}).

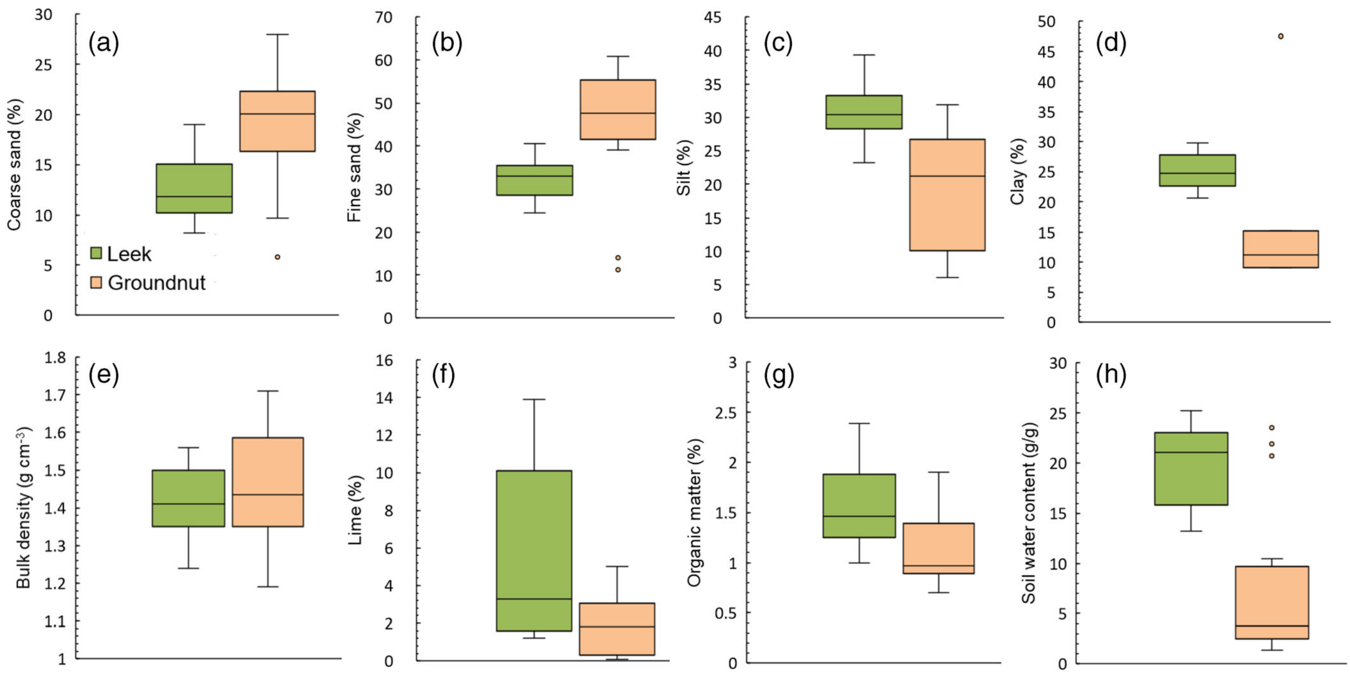

FIGURE 2 Boxplots representing soil properties for leek and groundnut. (a) coarse sand (%), (b) fine sand (%), (c) silt (%), (d) clay (%), (e) bulk density (g cm^{-3}), (f) lime (%), (g) organic matter (%), (h) soil water content (g g^{-1}) [Colour figure can be viewed at wileyonlinelibrary.com]

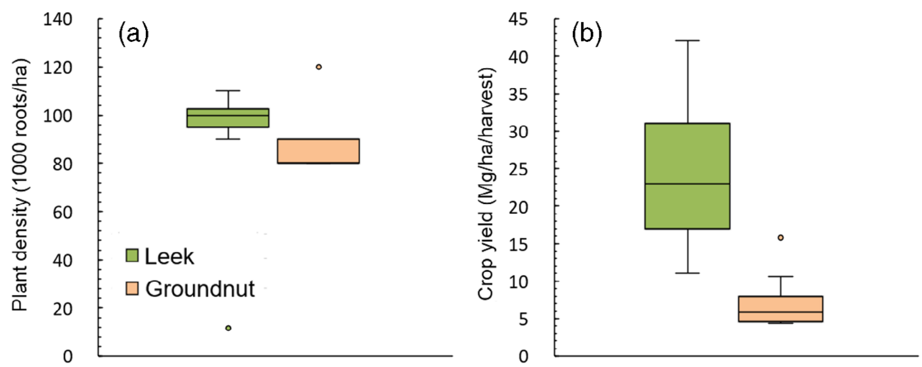

FIGURE 3 Box plot of (a) plant density (1000 roots ha^{-1}) and (b) crop yield (mg ha^{-1} $harvest^{-1}$) [Colour figure can be viewed at wileyonlinelibrary.com]

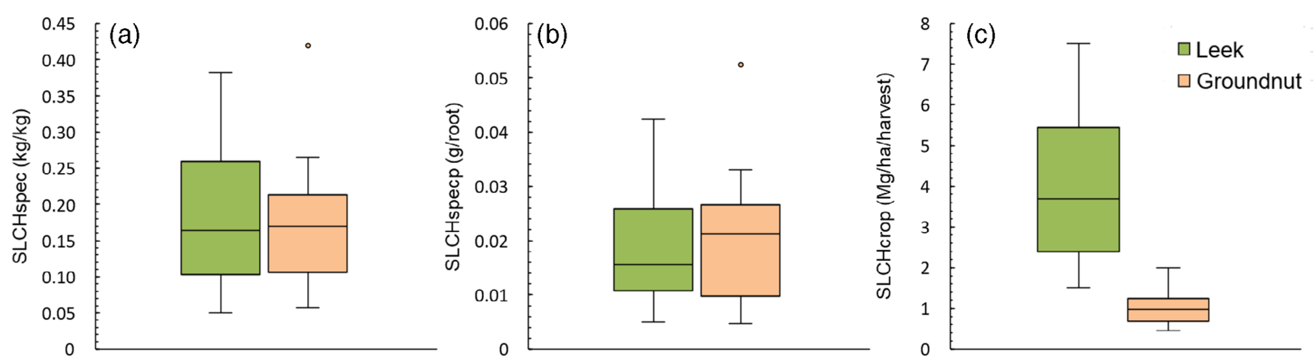

FIGURE 4 Boxplot of soil loss due to harvesting (SLCH) parameters for leek and groundnut. (a) $SLCH_{spec}$ (kg kg^{-1}), (b) $SLCH_{spec/p}$ (g $root^{-1}$), (c) $SLCH_{crop}$ (mg ha^{-1} $harvest^{-1}$) [Colour figure can be viewed at wileyonlinelibrary.com]

3.3 | Correlations and statistical significance among soil loss results and soil and crop parameters

Correlation coefficients between all variables in leek harvest were calculated (Table 1). Significant relationships were determined between antecedent soil moisture content and $SLCH_{spec}$ ($r^2 = 0.75$), $SLCH_{spec/p}$ ($r^2 = 0.68$), and $SLCH_{crop}$ ($r^2 = 0.62$).

Table 2 reveals the correlation coefficients between all variables in the groundnut harvest. A positive relationship was determined between $SLCH_{spec}$ and soil moisture content ($r^2 = 0.61$), silt content ($r^2 = 0.54$), $CaCO_3$ ($r^2 = 0.49$), and organic matter ($r^2 = 0.59$). A negative relationship was determined between $SLCH_{spec}$ and fine sand ($r^2 = 0.70$), coarse sand ($r^2 = 0.53$), plant density ($r^2 = 0.47$), and groundnut yield ($r^2 = 0.47$). A positive relationship was determined between $SLCH_{spec/p}$ and soil moisture content ($r^2 = 0.61$), clay ($r^2 = 0.66$), silt ($r^2 = 0.35$), $CaCO_3$ ($r^2 = 0.49$), and organic matter ($r^2 = 0.59$). A negative relationship was also determined between $SLCH_{spec/p}$ and fine sand ($r^2 = 0.70$), coarse sand ($r^2 = 0.53$), plant density ($r^2 = 0.58$), and groundnut yield ($r^2 = 0.48$). A positive relationship was determined between $SLCH_{crop}$ and soil moisture content ($r^2 = 0.66$), clay ($r^2 = 0.71$), and organic matter ($r^2 = 0.63$). Finally, negative relationships were observed between $SLCH_{crop}$ and fine sand ($r^2 = 0.65$) (Table 3).

Multiple regression equations between $SLCH_{spec/p}$ and some soil properties and other parameters in leek harvest are given in Table 3. 59% of the variability in soil loss is explained by soil moisture, clay, lime, coarse sand, fine sand, bulk density, and leek yield at harvest (Equation 1). In the equation, soil moisture at harvest and leek yield explains 2.54% of the variability in soil loss.

3.4 | Comparison of soil losses among crops and cost of nutrient losses

In our study, soil loss with leek harvest (3.99 Mg ha^{-1} yr^{-1}) was lower than onion, carrot, radish, and celery harvest (Table 4). It was determined that the soil loss in sugar beet, cassava, red cocoyam, sweet potato, yam, and potato harvest was higher.

Table 5 presents annual soil and plant nutrient losses due to leek and groundnut removal from the field. The annual costs of the lost N, P_2O_5, and K_2O during harvesting of leek and groundnut were estimated as 3.75 and 0.76 US$ ha^{-1}, respectively. While the loss of N, P_2O_5, and K_2O (kg ha^{-1} $harvest^{-1}$) in the leek harvest is 3.22, 0.45, and 1.0, respectively, these values are 0.69, 0.046, and 0.20, in the groundnut harvest.

4 | DISCUSSION

In leek and groundnut harvest, soil losses were determined as 3.99 Mg ha^{-1} $harvest^{-1}$ and 1.04 Mg ha^{-1} $harvest^{-1}$, respectively. Also, the data, including the relationships between soil loss with SLCH and other parameters, are given in Tables 1 and 2. Different studies also supported our results. Li et al. (2006) reported a positive relationship between soil loss and sand and a positive relationship between soil loss and moisture in manual sugar beet harvesting. Sumithra et al. (2013) determined that the most important factor affecting soil loss in cassava harvest is soil moisture content. Parlak et al. (2016) stated a negative ($r^2 = 0.61$) relationship between $SLCH_{spec}$ and $CaCO_3$ in manual harvesting of carrots. Yu et al. (2016) reported a positive relationship between soil loss and soil moisture in potato and sweet potato harvest.

Li et al. (2006) reported a positive ($r^2 = 0.70$) relationship between soil loss and clay in the potato harvest. Yu et al. (2016) found a positive relationship between soil loss and clay content in potato and sweet potato crops. Faraji et al. (2017) reported a significant positive relationship between soil loss and soil moisture in manual harvesting of radish in Iran. Oshunsanya et al. (2019) found a positive relationship between soil loss and organic matter ($r^2 = 0.47$) and clay ($r^2 = 0.86$) in manual harvesting of yam. They discovered a negative relationship between soil loss and sand. Parlak et al. (2020) found

TABLE 1 Spearman correlation coefficients among SLCH variables for manually harvested leek, soil water content (SWC), soil texture, bulk density, $CaCO_3$, organic matter, plant density, and leek yield

	$SLCH_{spec}$	$SLCH_{spec/p}$	$SLCH_{crop}$	SWC	Fine sand	Coarse sand	Clay	Silt	Bulk density	$CaCO_3$	Organic matter	Plant density
$SLCH_{spec/p}$	0.97*											
$SLCH_{crop}$	0.75*	0.69*										
SWC	0.75*	0.68*	0.62*									
Fine sand	0.26	0.18	0.06	0.23								
Coarse sand	0.60*	0.63*	0.38*	0.38	0.25							
Clay	−0.37	−0.36	0.04	−0.19	−0.74*	−0.40*						
Silt	−0.42*	−0.37	−0.32	−0.36	−0.76*	−0.67*	0.39*					
Bulk density	−0.04	−0.17	−0.16	−0.07	0.37	−0.29	−0.21	−0.06				
$CaCO_3$	−0.46*	−0.43*	−0.09	−0.27	−0.76*	−0.49*	0.87*	0.56*	−0.23			
Organic matter	−0.34	−0.35	−0.05	−0.24	−0.75*	−0.40*	0.74*	0.59*	−0.19	0.84*		
Plant density	−0.04	0.01	−0.15	−0.04	−0.25	−0.19	0.14	0.30	−0.12	0.14	0.06	
Leek yield	−0.66*	−0.66*	−0.08	−0.56	−0.38*	−0.47*	0.55*	0.37	0.04	0.51	0.51*	−0.02

*Correlation is significant at the 0.05 level.

TABLE 2 Spearman correlation coefficients among SLCH variables for manually harvested groundnut, soil water content (SWC), soil texture, bulk density, $CaCO_3$, organic matter, plant density, and groundnut yield

	$SLCH_{spec}$	$SLCH_{spec/p}$	$SLCH_{crop}$	SWC	Fine sand	Coarse sand	Clay	Silt	Bulk density	$CaCO_3$	Organic matter	Plant density
$SLCH_{spec/p}$	0.99*											
$SLCH_{crop}$	0.77*	0.76*										
SWC	0.61*	0.61*	0.66*									
Fine sand	−0.70*	−0.70*	−0.65*	−0.95*								
Coarse sand	−0.53*	−0.53*	−0.61	−0.94*	0.88*							
Clay	0.67	0.66	0.71*	0.96	−0.96*	−0.87*						
Silt	0.54*	0.35*	0.45	0.81*	−0.86*	−0.87*	0.72*					
Bulk density	0.22	0.25	0.38	0.35	−0.22	−0.45	0.27	0.29				
$CaCO_3$	0.49*	0.49*	0.56	0.80	−0.82*	−0.88*	0.73*	0.92*	0.32			
Organic matter	0.59*	0.55	0.63*	0.86*	−0.90**	−0.85*	0.86*	0.81*	0.21	0.89*		
Plant density	−0.47*	−0.58*	−0.31	−0.29	0.36	0.26	−0.28	−0.37	−0.18	−0.30	−0.13	
Groundnut yield	−0.47*	−0.48*	0.08	−0.14	0.27	0.04	−0.13*	−0.31	0.30	−0.20	−0.17	0.51*

*Correlation is significant at the 0.05 level.

significant relationships between soil loss and soil moisture ($r^2 = 0.45$), clay ($r^2 = 0.49$), and silt ($r^2 = 0.57$) in sod production areas.

Li et al. (2006) discovered that 50% of the variability in soil loss in manual sugar beet harvesting could be explained by soil moisture at harvest, 60% by clay content, and 43% by crop yield. Parlak et al. (2018) stated that 25% of the variability in celery harvest varies with soil moisture and clay content at harvest. Dada et al. (2016) reported that the factors affecting soil loss in manual harvesting of yam are soil moisture and clay content at harvest.

Multiple regression equations between $SLCH_{spec/p}$ and some soil properties and other parameters in groundnut harvest are given in Table 2. 53% of the variability in soil loss is explained by soil moisture, clay, and groundnut yields at harvest. Poesen et al. (2001) stated that 47% of the variability in soil loss in sugar beet harvest in Belgium varies with precipitation during the harvest season. 14% and 39% of the variability in soil losses in cassava and onion harvests, respectively, were described by the soil moisture content at the time of harvest (Isabirye et al., 2007; Mwango et al., 2015). Parlak et al. (2016) found that 89% of the variability in soil loss in manual harvesting of carrots could be explained by crop yield, clay, silt, and organic matter.

Soil loss in leek harvest was 1.49 times lower than in onion, while it was 266-times higher than soil loss in red cocoyam. The soil loss in the groundnut harvest (1.04 Mg ha^{-1} yr^{-1}) was higher than in other crops (sugar beet, red cocoyam, sweet potato, and yam) except for cassava and potato, onion, garlic, carrot, radish, and celery. Soil loss in groundnut harvest was 69-times higher than in red cocoyam; while 5-times lower than in carrot harvest. The reason for the difference between the SLCH values determined in our research and the SLCH values determined by other researchers is soil properties, agronomic practices, and climatic conditions (Dada et al., 2016; Faraji et al., 2017; Parlak et al., 2016, 2021; Yu et al., 2016).

The PESERA (Pan-European Soil Erosion Risk Assessment) model determined the average soil erosion as 1.72 and 1.85 Mg ha^{-1} yr^{-1} in the Kücük Menderes basin and the Marmara basin where Izmir-Torbalı and Canakkale Bayramic are located (Berberoglu et al., 2020). According to Erpul et al. (2020), using the RUSLE method, the soil erosion was 20.03 Mg ha^{-1} yr^{-1} in agricultural areas of Izmir and 23.23 Mg ha^{-1} yr^{-1} in Canakkale. Soil loss caused by leek harvest is 2.32-times higher than the value found by Berberoglu et al. (2020), and it was 5.02-times lower than the value determined by Erpul et al. (2020). Soil loss in groundnut harvest was determined as 1.78-times and 22.34-times lower than the values found by Berberoglu et al. (2020) and Erpul et al. (2020), respectively. Tolerable soil loss is between 2.2 and 11.2 Mg ha^{-1} yr^{-1}(Schertz & Nearing, 2002). Soil loss in leek harvest (3.99 Mg ha^{-1} yr^{-1}) was in this range, and soil loss in groundnut harvest was low even at the lower value of 2.2 Mg ha^{-1} yr^{-1}.

In the present study, soil denudation rates for leek and groundnut harvests were respectively calculated as 0.28 and 0.07 mm yr^{-1}. Soil denudation rate was reported as 0.33 mm yr^{-1} for chicory and sugar beet (Poesen et al., 2001); 0.30 mm yr^{-1} for five crops (sugar beet, radish, potato, garlic, and beetroot) (Faraji et al., 2017); 3.17 mm yr^{-1}

TABLE 3 Multiple regression equations between $SLCH_{spec/p}$ parameter and some soil properties and other parameters in leeks and groundnuts

Crop	Leek		
No	Equation	R^2	*p*
1	$SLCH_{spec/p}$ (g/root) = 0.0171 + 0.00104 SWC (gg^{-1}) − 0.000125 clay (%) − 0.000465 lime (%) + 0.00101 coarse sand (%) − 0.000610 fine sand(%) + 0.0002 bulk density (g cm^{-3}) − 0.000293 leek yield (Mg ha^{-1} $harvest^{-1}$)	0.59	0.001
2	$SLCH_{spec/p}$ (g/root) = 0.0069 + 0.00112 SWC(gg^{-1}) − 0.000452 leek yield (Mg ha^{-1} $harvest^{-1}$)	0.54	0.000
Crop	**Groundnut**		
No	**Equation**	R^2	*p*
3	$SLCH_{spec/p}$ (g/root) = 0.0218–0.000649 SWC (gg^{-1}) + 0.000828 clay (%) − 0.00164 groundnut yield (Mg ha^{-1} $harvest^{-1}$)	0.53	0.003
4	$SLCH_{spec/p}$ (g/root) = 0.0236 + 0.000834 SWC (gg^{-1}) + 0.0013 organic matter (%) − 0.00162 groundnut yield (Mg ha^{-1} $harvest^{-1}$)	0.43	0.012

TABLE 4 Soil losses in crops were manually harvested in different countries and different soil types (mean ± standard deviation)

Crop	Region/country	Soil	$SLCH_{crop}$ (Mg ha^{-1} yr^{-1})	Reference
Sugar beet	China	Loam, silt loam, silty clay loam	1.00 ± 0.60	Li et al., 2006
Cassava	Uganda	n.a.	3.44 ± 3.46	Isabirye et al., 2007
Onion	Tanzania	Sandy clay loam	5.94 ± n.a.	Mwango et al., 2015
Garlic	Turkey	Clay, sandy clay loam	3.23 ± 2.12	Parlak & Everest, 2021
Red cocoyam	Nigeria	Loamy sand	0.015 ± n.a.	Oshunsanya, 2016
Sweet potato	Nigeria	n.a.	0.09 ± 0.04	Oshunsanya, 2016
Carrot	Turkey	Clay, clay loam, sandy clay loam	5.60 ± n.a.	Parlak et al., 2016
Radish	Iran	n.a.	4.10 ± n.a.	Faraji et al., 2017
Celery	Turkey	Silty loam, clay loam, silty clay loam, silty clay, clay	4.00 ± 1.91	Parlak et al., 2018
Yam	Nigeria	Sandy loam	0.23 ± n.a.	Oshunsanya et al., 2018
Potato	China	Loam, silt loam, silty clay loam	1.20 ± 0.80	Li et al., 2006
Leek	Turkey	Loam, sandy clay loam, clay loam	3.99 ± 1.70	This study
Groundnut	Turkey	Sandy loam, loamy sand, clay	1.04 ± 0.44	This study

Abbreviation: n.a.: not available.

TABLE 5 Cost of nutrient losses with soil loss due to leek and groundnut harvesting

Crop	Nutrient	Soil nutrient concentration (g kg^{-1}) mean ± SD	Nutrient losses (kg ha^{-1} $harvest^{-1}$)	Fertility equivalents	Total cost (US$ ha^{-1} $harvest^{-1}$)
Leek	N	807.40 ± 175.20	3.22	7.00 kg urea (46%)	2.15
	P_2O_5	49.38 ± 16.39	0.45	1.05 kg triple superphosphate (43%)	0.21
	K_2O	207.00 ± 83.90	1.00	2.00 kg potassium sulfate (50%)	1.39
Total					3.75
Groundnut	N	655.60 ± 179.00	0.69	1.50 kg urea (46%)	0.46
	P_2O_5	21.72 ± 5.31	0.046	0.11 kg triple superphosphate (43%)	0.02
	K_2O	165.40 ± 143.70	0.20	0.40 kg potassium sulfate (50%)	0.28
Total					0.76

for celery (Parlak et al., 2018); 0.31 mm yr^{-1} for garlic (Parlak & Everest, 2021); and 0.13 mm yr^{-1} for sugar beet (Parlak et al., 2021). Soil denudation rate determined in leek was lower than sugar beet and higher than other crops (chicory and sugar beet, potato, five crops, celery, and garlic). The value in groundnut was lower than in other crops. The global soil formation rate was estimated as 0.11 mm yr^{-1} (Stockmann et al., 2014). It refers to 110 mm of soil being removed from croplands in 1000 years. While the detected value in leek is 2.54-times higher than the soil formation rate, the value in groundnut is lower than the global soil formation rate. As long as the soil denudation rate in the leek harvest continues, soil fertility will decrease. As a result, crop yield will decrease. Soil loss due to crop harvesting is as essential as water and wind erosion. An average of 75,000 million tons of soil is transported by water and wind erosion every year worldwide (European Commission, European Soil Data Center, 2016). The mean soil loss in croplands in Turkey was determined as 8.42 Mg ha^{-1} yr^{-1} (Erpul et al., 2020). An area of 548 million hectares worldwide is under the threat of wind erosion. Regarding wind erosion, the Asian continent is the highest with 222 million hectares, and the African continent is the second with 186 million hectares (Lal, 2001). It was reported that wind erosion is approximately 500,000 hectares of land, ranging from moderately to significantly in Turkey, and 70% of this area is within the borders of Konya Province (Acar & Dursun, 2010).

Washing leek, potato, and sugar beet in the cleaning sites causes sedimentation and water pollution in water resources. Fertile and nutrient-rich soil water bodies, creeks, or rivers and drains, suffer eutrophication problems. Previous researchers also reported harvesting-induced siltation in water bodies (Isabiryе et al., 2007; Kuhwald et al., 2022; Li et al., 2006; Mwango et al., 2015; Oshunsanya, 2016; Oshunsanya et al., 2019; Parhizkar et al., 2021; Parlak & Everest, 2021; Yu et al., 2016). The loss of soils through harvest erosion reduces their productive capacity and increases transportation costs and phytosanitary risks.

In especially vulnerable climates, like those associated with the Mediterranean basin or arid and semiarid areas, soil losses by harvesting should be analyzed in addition to soil losses caused by rainfall or tillage (González-Hidalgo et al., 2007; Maetens et al., 2012) and wind-erosion (Fenta et al., 2020). This issue has not yet been adequately addressed in areas cultivated with other conventional crops such as olives (Taguas et al., 2015), vineyards (Rodrigo-Comino, 2018), or citrus (Niu et al., 2021). The values obtained with this study are higher than with the olive, vineyards, and citrus researches. The implementation of appropriate soil management practices (Bombino et al., 2021; Naseri, 2019) has become an essential issue in the formulation of land use planning. This is because, frequently, planning strategies do not give sufficient attention to preventing soil losses (Komatsuzaki & Ohta, 2007; Rodrigo-Comino et al., 2018).

Different researchers also calculated the annual costs for nutrient loss in different crops. In Iran, annual costs for nutrient loss in radish and beetroot harvesting were respectively reported as 10.19 and 15.40 $US ha^{-1} (Faraji et al., 2017). In Turkey, such a value was reported as 2.92 $US ha^{-1} for potato harvesting (Parlak & Blanco-Canqui, 2015), 6.18 $US ha^{-1} for celery harvesting (Parlak et al., 2018), 10.74 $US ha^{-1} for garlic harvesting (Parlak & Everest, 2021), and 1.57 $US ha^{-1} for sugar beet harvesting (Parlak et al., 2021). The cost of nutrients lost by leek harvest was higher than sugar beet and potato and lower than radish, beetroot, celery, and garlic. Groundnut harvesting costs are lower than the other crops (radish, beetroot, potato, celery, garlic, and sugar beet).

5 | CONCLUSIONS

In this study, soil loss from manual harvesting of leek in western Turkey was 3.99 Mg ha^{-1} harvest^{-1}. Soil loss from manual harvesting of groundnut in northwestern Turkey was 1.04 Mg ha^{-1} harvest^{-1}. Soil loss from leek and groundnut harvests was lower than other crops reported in other studies. Although the levels we observed (3.99 and 1.04 Mg ha^{-1} harvest^{-1}) are below the tolerable rate of soil loss, this poses a risk to the sustainability of soil resources in croplands where leek and groundnut are grown intensively. It is concluded that it is critical to expand the literature on this study conducted with leek and groundnut, to support future research in different areas and climates.

Soil resources should be managed efficiently for sustainable use. It is well known that SLCH causes significant soil losses, and therefore, training activities should be conducted to raise awareness among farmers. In addition, it is suggested that an expansion of studies on SLCH could attract the attention of authorities and policymakers as the current data available could provide farmers and policymakers with an excellent opportunity for sustainable land-use policies.

ACKNOWLEDGMENT

This work was supported by Canakkale Onsekiz Mart University the Scientific Research Coordination Unit, Project number: FHD-2019-3068.

CONFLICT OF INTEREST

The authors have declared no conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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How to cite this article: Parlak, M., Everest, T., Tunçay, T., Caballero-Calvo, A., & Rodrigo-Comino, J. (2022). Soil losses due to leek and groundnut root crop harvesting: An unstudied regional problem in Turkey. *Land Degradation & Development*, *33*(11), 1799–1809. https://doi.org/10.1002/ldr.4262