Greenhouse gas footprint of replacing nutrients lost through soil erosion due to root and tuber crops harvesting

Kök ve yumru bitkilerin hasadı de olusan toprak erozyonunda kaybolan besin maddelerinin sera ayak izi değerleri

Mehmet PARLAK

Canakkale Onsekiz Mart University, Lapseki Vocational School, Canakkale- TURKEY

Corresponding author (Sorumlu yazar): M. Parlak, e-mail (e-posta): mehmetparlako6@hotmail.com

ARTICLE INFO

Received 08 October 2018
Received in revised form 14 January 2019
Accepted 06 March 2019

Keywords:
Soil erosion
Soil nutrient losses
Greenhouse gas emissions
Potato
Carrot

ABSTRACT

Soil loss due to root crop harvesting (SLCH) is an important component of total soil erosion that threatens sustainable agriculture. Globally, it ranges from 1.81 to 4.55 Mg ha\(^{-1}\) per harvest. I assessed greenhouse gas (GHG) footprint of producing fertilizer to replace nutrients lost with soil due to potato (Solanum tuberosum L.), carrot (Daucus carota L.), and celery (Apium graveolens L.) harvesting in the İzmir-Ödemiş town, Konya province and Sakarya-Geyve town in Turkey. Production of mineral fertilizers contributes to the global GHG emissions. About 40x10\(^3\) Mg of soil per year was lost annually through potato, carrot and celery harvest from the study region, which resulted in 32.93 Mg of N, 3.21 Mg of P\(_2\)O\(_5\), and 7.69 Mg of K\(_2\)O losses per year. The fertilizer production to reduce the nutrients lost releases about 270 Mg CO\(_2\) per year. The large nutrient losses and GHG emissions warrant consideration of soil management practices to reduce SLCH.

ÖZ

Bitki hasadı nedeniyle toprak kaybı sürdürülebilir tarımsal alanda tehdit eden toprak erozyonunun önemli bir bileşenidir. Bitki hasadı nedeniyle toprak kaybı 1.81 ile 4.55 Mg ha\(^{-1}\) hasat\(^{-1}\) değerleri arasında değişmektedir. İzmir’ın Ödemiş ilçesi, Konya ili, Sakarya’nin Geyve ilçesinde patates, havuç ve kereviz hasadı nedeniyle toprak kaybı için bir tehditidir. Uzuv production to produce the nutrients lost due to potato (Solanum tuberosum), carrot (Daucus carota), and celery (Apium graveolens) harvesting resulted in 32.93 Mg of N, 3.21 Mg of P\(_2\)O\(_5\), and 7.69 Mg of K\(_2\)O losses per year. The fertilizer production to replace the nutrients lost releases about 270 Mg CO\(_2\) per year. The large nutrient losses and GHG emissions warrant consideration of soil management practices to reduce SLCH.

1. Introduction

Soil loss due to crop harvesting (SLCH) is defined as the loss of top soil from arable land during harvesting of crops such as potato, yam (Dioscorea spp), sugar beet (Beta vulgaris L.), carrot, leek (Allium porrum L.), and groundnut (Arachis hypogaea L.). SLCH not only contributes to the total soil erosion but also causes nutrient losses, affecting agricultural sustainability (Poesen et al. 2001; Ruysschaert et al. 2004; Parlak et al. 2008; Parlak et al. 2016; Oshunanya et al. 2018). Nutrient-enriched soil attached to the roots is removed with the harvest of tuber and root crops including potato, carrot, celery, sugar beet, cassava (Manihot esculenta), radish (Raphanus sativus), yam, and many others. The importance of SLCH in comparison with water erosion has been shown in several studies. The SLCH can constitute about 20% of the total soil loss from root crop fields (Poesen et al. 2001). For example, the average of SLCH for all five crops (radish, beetroot, garlic, potato and sugar beet) was estimated as 4.42 Mg ha\(^{-1}\) which was similar to soil losses caused by water erosion in the catchments in Iran (Faraji et al. 2017). Also, in Flanders area of Belgium, Ruysschaert et al. (2008) found that 46% of soil loss was due to crop harvesting and the rest due to water erosion when the total sediment loss was 3.7 Mg ha\(^{-1}\). While SLCH is recognized as a contributor to soil degradation (Li et al. 2006; Parlak et al. 2016), the amount of nutrient lost with SLCH is not much discussed.
Isabiyre et al. (2007) reported soil losses due to manual cassava and sweet potato harvests in eastern Uganda respectively as 3.4 Mg ha$^{-1}$ and 0.2 Mg ha$^{-1}$. Researchers reported plant nutrient loss values as 1.71 kg N ha$^{-1}$ harvest$^{-1}$, 0.16 kg P ha$^{-1}$ harvest$^{-1}$ and 1.08 kg K ha$^{-1}$ harvest$^{-1}$ for cassava; as 0.14 kg N ha$^{-1}$ harvest$^{-1}$, 0.01 kg P ha$^{-1}$ harvest$^{-1}$ and 0.15 kg K ha$^{-1}$ harvest$^{-1}$ for sweet potato. Oshunsanya (2016) reported higher plant nutrient losses due to white cocoyam (Colocasia esculenta) and red cocoyam (Xanthosoma sagittifolium) harvests in Nigeria than the plant nutrient losses of Isabiyre et al. (2007) for cassava and sweet potato. Yu et al. (2016) in a research carried out in Northern China Plain, indicated total N loss due to potato harvest as 2.2 kg ha$^{-1}$ harvest$^{-1}$ and indicated that the loss in available P contents was 13-16 times more than the values reported by Mwango et al. (2015) in Tanzania.

Production of chemical fertilizers to replace the nutrients lost with SLCH could increase net GHG emissions. For example, in India, which is the second largest synthetic N fertilizer producer of the world, it is estimated that GHG emissions from synthetic N fertilizer reached 100 million Mg of CO$_2$ equivalent (CO$_2$-e) in 2007 (Tirado et al. 2010). In China, not considering direct N$_2$O emissions from the field, the average fertilizer production-induced GHG emissions from 1993 to 2012 were 259.21 Mg CO$_2$-e, or 47.1% of the total GHG emissions (Wang et al. 2017). In Turkey, chemical fertilizer production was 3.576,598 Mg in 2013 (Turkish Statistical Institute 2016), but the extent of GHG emissions has not been investigated. I evaluated the GHG footprint of producing fertilizer to replace N, P, and K lost with SLCH of potato, carrot and celery in Turkey and extrapolated results to the study region.

2. Materials and Methods

2.1. Description of the study areas

This study was conducted at three sites in Izmir-Odems, Konya, and Sakarya-Geyve in Turkey. Research sites are respectively located in Aegean Region, Central Anatolia and North East of Turkey. The Odems site is located in Izmir province (38° 16' N latitude and 27° 59' E longitude). Soil is loam with 0-2% slope. The Konya site is located in the Central Anatolian Plateau (37°38'N latitude and 33°35' E longitude). Soil is clayey with 2-5% slopes. Geyve site is located in Sakarya province (40° 30' - 40° 45' N latitude and 30° 13' - 30° 29' E longitude). Soils are silt loam, silt clay loam, and clayey with 0-2% slopes. According to the meteorological station (1950-2005) in Izmir-Odems, Konya and Sakarya-Geyve, annual precipitation is 689, 316, and 640 mm, respectively (DMI 2014).

2.2. Sampling protocol

The SLCH data reported for the study region were used for this study (Parlak and Blanco-Canqui 2015; Parlak et al. 2016; Parlak et al. 2018). Data on the harvest area under potato, carrot and celery production, which are common crops, were collected from Izmir-Odems town, Konya province, and Sakarya-Geyve town in Turkey (Turkish Statistical Institute 2016).

The amount of soil attached to potato, carrot, and celery at harvest was determined to estimate SLCH. Plant and soil sampling was performed in January 2013 for potato, in November 2013 for carrot and in November 2016 for celery. Two-row potato harvester was used in potato harvest and plot size was 1.65x2.3 m. Manual harvest was performed for carrot from 2x2 m plots. Combine carrot harvester was used for machine carrot harvest from 2x4 m plots. All plants were harvested from potato, carrot, and celery plots. 50 to 70 samples were randomly taken from carrot plots, 30-40 from potato plots and 7-11 from celery plots. Since plant densities are different, number of samplings were also different. Before harvesting, the average plant density, which is equal to the number of roots or tubers per area, was determined.

The mass of adhering wet soil per root or tuber was measured in the field immediately after harvesting by weighing gross crop mass (mass of tuber plus mass of moist soil), washing the tubers in a bucket, and weighing the individual tuber (net crop mass or $M_{crop}$) again. The net crop masses were also used to calculate the average root or tuber mass, while the crop yield ($M_{cy}$, in Mg ha$^{-1}$) was calculated from the average root or tuber mass and the plant density (Li et al. 2006). The gravimetric soil moisture content was determined in the 0-20 cm depth before the harvesting.

2.3. Soil sampling and soil analysis

Soil samples taken for nutrient analysis were 39 from mechanically harvested potato fields in Odems (Figure 1.A and B), 32 from manually and mechanically harvested carrot fields in Konya (Figure 1.C and D), and 27 from manually harvested celery fields in Geyve (Figure 1.E and F) for the 0-20 cm soil depth. Soil samples were taken from the plots during the harvest. Soil was analyzed for total N, available P, extractable K concentrations. Total nitrogen, available P, and extractable K were assessed using the methods described by Kjeldahl (Bremner and Mulvaney 1982), Olsen and Sommers (1982), and Knudsen et al. (1982), respectively.

2.4. Soil loss estimation

I used the following equations to characterize SLCH (Ruysschaert et al. 2004):

\[
\text{Total soil loss due to crop harvesting } SLCH_{spec} \text{ is dimensionless.}
\]

\[
\text{Total } SLCH_{spec}(kg \, kg^{-1}) = \frac{M_{ds}}{M_{crop}} (1)
\]

where $M_{ds}$ is the mass of oven-dry soil (kg), and $M_{crop}$ is net crop mass of the sample (kg).

\[
SLCH_{crop} (kg \, ha^{-1} \, harvest^{-1}) = SLCH_{spec} \times M_{cy} (2)
\]

where $M_{cy}$ = net crop yield (kg ha$^{-1}$ harvest$^{-1}$).

Nutrient loss (expressed on elemental basis) through crop harvesting was estimated using Eq. 3.

\[
\text{Nutrient loss (kg ha}^{-1}\text{harvest}^{-1}) = \frac{\text{Nutrient content (g kg}^{-1}\text{soil}) \times SLCH_{crop} (kg \, ha^{-1} \, harvest^{-1}) (3)}{25}
\]

2.5. Determination of fertilizer equipment

Since ammonium nitrate, triple superphosphate and potassium sulfate are the most common fertilizers, which are used to provide N, P$_2$O$_5$ and K$_2$O respectively, their equivalents were calculated as follows:
2.6. Carbon footprint quantity for fertilizers

Carbon footprint quantity for ammonium nitrate production (Mg)= Ammonium nitrate (Mg) x 2.46 \( (7) \)

Carbon footprint quantity for triple superphosphate production (Mg)= Triple superphosphate (Mg) x 1.08 \( (8) \)

Carbon footprint quantity for potassium sulfate fertilizer production (Mg)= Potassium sulfate (Mg) x 1.12 \( (9) \)

Carbon footprint values for ammonium nitrate, triple superphosphate and potassium sulfate fertilizers (Mg CO\(_2\)-equivalent Mg\(^{-1}\) fertilizer) were respectively taken as 2.46, 1.08 and 1.12 \( \text{(Wood and Cowie 2004)} \).
3. Results and Discussion

Table 1 presents the N, P, and K losses due to SLCH for different crops across the three sites in Turkey. The greatest N, P, and K losses were for manual carrot harvest, whereas the lowest N and K losses were for mechanical potato harvest. The differences in nutrient losses among sites were due to differences in both SLCH and nutrient status. The lowest P loss was for mechanical carrot harvest (Table 1). In this study, the N lost with mechanical harvest of potato was lower than the value reported by Mwango et al. (2015), while the P and K losses were higher than those reported by Mwango et al. (2015).

Total removed soil values were estimated respectively as 16.29x10^3 Mg for potato, 22.88x10^3 Mg for carrot, and 0.72x10^3 Mg for celery in this study (Table 2). Similar with current findings, previous researchers also reported significant soil removal from the fields due to crop harvesting. Faraji et al. (2017) reported that 431x10^3 Mg soils were removed from 170.7x10^6 ha potato farming lands in Iran; Li et al. (2006) indicated that 6x10^6 Mg soils were removed from the fields due to sugar beet and potato harvest in China. In Belgium, soil loss due to potato, fodder beet, sugar beet and chicory harvests was reported annually 1.4x10^6 Mg (Ruysschaert et al. 2008). The amount of CO_2 released to atmosphere through the production of chemical fertilizers was considered as C footprint. The release was higher for ammonium nitrate than triple superphosphate and potassium sulfate fertilizer production in this study. The C footprint values for the production of chemical fertilizers were the largest for carrot (139.11 Mg CO_2-eq) and the smallest for celery production (7.36 Mg CO_2-eq) (Table 2).

In Turkey, greenhouse gas emissions by agricultural sector in 2013 was 57.2 million ton (Turkish Statistical Institute 2017). Present value (269.78 Mg) was lower than the GHG of agricultural sector. Among the commercial fertilizers, N fertilizers have the greatest C footprint. The manufacture of N fertilizers is very fossil-fuel intensive and thus its contribution to emissions through CO_2 is very high (Tirado et al. 2010). Similarly, Oruç (2013) assessed the data of 25 public and 8 private sugar factories in Turkey between 2005-2012 (for 8 years) and reported soil loss due to sugar beet harvest as 4.54 Mg ha^{-1}, total soil N loss as 20 157 Mg, total C footprint value of ammonium nitrate (35% N) as 141 392 Mg. Oruç (2013) calculated the amount of CO_2 released to atmosphere from 2 644 003 ha land area in 8 years as 141 392 Mg. My estimated annual CO_2 value (0.019 Mg ha^{-1} year^{-1}) was lower than the value (0.05 Mg ha^{-1} year^{-1}) reported by Oruç (2013).

Many are unaware of the large amount of nutrients removed with SLCH. My study suggests that losses of nutrients with SLCH are high and deserve attention. Improvement in root and tuber crop harvesting techniques, soil management, and nutrient use efficiency is needed to reduce GHG emissions. My results could differ from other regions due to differences in soil, crop, harvesting technique and agronomic practices influencing SLCH (Ruysschaert et al. 2004), but it highlights the implications that nutrient losses due to crop harvesting can have on GHG emissions.

Table 1. Amounts of N, P_2O_5 and K_2O lost during harvesting of potato, carrot and celery.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Methods of harvesting</th>
<th>Element</th>
<th>Amount (g kg^{-1})(mean±standard deviation)</th>
<th>Losses (kg ha^{-1} harvest^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potato</td>
<td>Mechanical harvesting (n= 39)</td>
<td>N</td>
<td>0.95±0.36</td>
<td>1.71</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P_2O_5</td>
<td>0.12±0.05</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>K_2O</td>
<td>0.11±0.04</td>
<td>0.20</td>
</tr>
<tr>
<td>Carrot</td>
<td>Manual harvesting (n= 14)</td>
<td>N</td>
<td>0.68±0.30</td>
<td>3.81</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P_2O_5</td>
<td>0.06±0.03</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>K_2O</td>
<td>0.28±0.11</td>
<td>1.56</td>
</tr>
<tr>
<td>Carrot</td>
<td>Mechanical harvesting (n= 18)</td>
<td>N</td>
<td>0.76±0.34</td>
<td>2.68</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P_2O_5</td>
<td>0.39±0.02</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>K_2O</td>
<td>0.22±0.06</td>
<td>0.78</td>
</tr>
<tr>
<td>Carrot</td>
<td>Manual+ mechanical harvesting (n= 32)</td>
<td>N</td>
<td>0.73±0.32</td>
<td>3.31</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P_2O_5</td>
<td>0.05±0.03</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>K_2O</td>
<td>0.25±0.09</td>
<td>1.12</td>
</tr>
<tr>
<td>Celery</td>
<td>Manual harvesting (n= 27)</td>
<td>N</td>
<td>1.25±0.45</td>
<td>5.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P_2O_5</td>
<td>0.05±0.02</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>K_2O</td>
<td>0.37±0.08</td>
<td>0.48</td>
</tr>
</tbody>
</table>

Table 2. Data are calculated for the study areas based on data on SLCH and nutrient losses from the study sites*.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Methods of harvesting</th>
<th>SLCH (Mg ha^{-1} harvest^{-1})</th>
<th>Harvest area (ha)</th>
<th>SLCH (10^5 Mg)</th>
<th>Nutrient loss (Mg)</th>
<th>CO_2-eq (Mg)</th>
<th>CO_2 (Mg)</th>
<th>P.S (Mg)</th>
<th>TSP (Mg)</th>
<th>CO_3-eq (Mg)</th>
<th>CO_3 (Mg)</th>
<th>K_2O (Mg)</th>
<th>P.S (Mg)</th>
<th>CO_3-eq (Mg)</th>
<th>CO_3 (Mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potato</td>
<td>Mechanical harvesting</td>
<td>1.81</td>
<td>9000</td>
<td>16.29</td>
<td>15.39</td>
<td>46.63</td>
<td>114.63</td>
<td>2.07</td>
<td>4.31</td>
<td>4.65</td>
<td>1.80</td>
<td>3.60</td>
<td>4.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carrot</td>
<td>Manual+ mechanical harvesting</td>
<td>4.55</td>
<td>5030</td>
<td>22.88</td>
<td>16.64</td>
<td>50.42</td>
<td>124.03</td>
<td>1.10</td>
<td>2.29</td>
<td>2.47</td>
<td>5.63</td>
<td>11.26</td>
<td>12.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Celery</td>
<td>Manual harvesting</td>
<td>4.00</td>
<td>180</td>
<td>0.72</td>
<td>0.90</td>
<td>2.72</td>
<td>6.69</td>
<td>0.04</td>
<td>0.08</td>
<td>0.09</td>
<td>0.26</td>
<td>0.52</td>
<td>0.58</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Carbon footprint total for ammonium nitrate, triple superphosphate and potassium sulfate fertilizer was annually 269.78 Mg CO_2-
1 Harvested area data were taken from Turkish Statistical Institute (2016).
2 A.N: Ammonium nitrate(33% N); 3 TSP: Triple superphosphate(48% P_2O_5); 4 P.S: Potassium sulfate(50% K_2O); 5 Carbon footprint quantity for ammonium nitrate production; 6 Carbon footprint quantity for TSP production; 7 Carbon footprint quantity for potassium sulfate fertilizer production; Since the data were not available for manual and mechanical harvests, manual and mechanical harvested areas were provided together.
4. Conclusion

In Izmir-Odemis, Konya, Sakarya-Geyve, annually 39.89×10^3 Mg soil is lost due to potato, carrot and celery harvest. This estimated soil loss results in the removal of 32.93 Mg of N, 3.21 Mg of P_2O_5 and 7.69 Mg of K_2O. Considering C footprint values for fertilizer production, it is estimated that 269.78 Mg CO_2 are annually released to the atmosphere. The high CO_2 release of should be a concern to farmers, researchers, government agencies, and others on the potential negative impacts of SLCH on GHG. Additional research is needed on the effects of SLCH on C footprint under different crops, soils, harvest techniques, and climatic zones.

Acknowledgement

I wish to thank Dr. Humberto Blanco-Canqui for recommendations and English review and corrections.

References


DMI (2014) Meteorological Bulletin Turkish State Meteorological Service (in Turkish).


Oshunsanya SO (2016) Quantification of soil loss due to white cocoyam (Colocasia esculenta) and red cocoyam (Xanthosoma sagittifolium) harvesting in traditional farming system. Catena 137: 134-143.


