Research Article/Araştırma Makalesi

www.dergipark.gov.tr/mediterranean

MEDITERRANEAN AGRICULTURAL SCIENCES
(2019) 32(1): 95-99
DOI: 10.29136/mediterranean.468282

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

Kök ve yumru bitkilerin hasadıyla oluşan toprak erozyonunda kaybolan besin maddelerinin sera gazı ayak izi değerleri

Mehmet PARLAK

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

Corresponding author (*Sorumlu yazar*): M. Parlak, e-mail (*e-posta*): mehmetparlak06@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 Izmir-Odemis 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_2O_5, and 7.69 Mg of K_2O 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.

MAKALE BİLGİSİ

Alınış tarihi 08 Ekim 2018
Düzeltilme tarihi 14 Ocak 2019
Kabul tarihi 06 Mart 2019

***Anahtar Kelimeler*:**

Toprak erozyonu
Besin maddesi kayıpları
Sera gazı emisyonları
Patates
Havuç

ÖZ

Bitki hasadı nedeniyle toprak kaybı sürdürülebilir tarımı tehdit eden toprak erozyonunun önemli bir bileşenidir. Bitki hasadıyla oluşan toprak kaybı 1.81 ile 4.55 Mg ha^{-1} hasat^{-1} değerleri arasında değişmektedir. İzmir'in Ödemiş ilçesi, Konya ili, Sakarya'nın Geyve ilçesinde patates, havuç ve kereviz hasadındaki toprakla kaybolan besin maddelerine eşdeğer gübre üretimindeki sera gazları tahmin edilmiştir. Mineral gübrelerin üretimi küresel sera gazı emisyonuna katkıda bulunmaktadır. Çalışma alanında patates, havuç ve kereviz hasadıyla kaybolan toprak miktarı yılda yaklaşık 40x10^3 Mg'dir. Bu toprak kaybı yılda 32.93 Mg N, 3.21 Mg P_2O_5, ve 7.69 Mg K_2O kaybına neden olmaktadır. Gübrelerin üretimi esas alındığında sera gazı olarak atmosfere yılda 270 Mg CO_2 salınmaktadır. Bitki hasadı nedeniyle toprak kaybını azaltmak için toprak yönetimi uygulamalarında besin maddesi kayıpları ve sera gazı emisyonlarına daha fazla önem verilmelidir.

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; Oshunsanya 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 lost 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.

Isabirye 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 esculentus*) and red cocoyam (*Xanthosoma sagittifolium*) harvests in Nigeria than the plant nutrient losses of Isabirye 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_2O 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-Odemis, Konya, and Sakarya-Geyve in Turkey. Research sites are respectively located in Aegean Region, Central Anatolia and North East of Turkey. The Odemis 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 0-2% 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-Odemis, 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-Odemis 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 $M_{crop/p}$) 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 Odemis (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):

Total soil loss due to crop harvesting $SLCH_{spec}$ is dimensionless.

$$\text{Total } SLCH_{spec}(\text{kg kg}^{-1}) = \frac{Mds}{Mcrop} \quad (1)$$

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

$$SLCH_{crop}\ (\text{kg ha}^{-1}\ \text{harvest}^{-1}) = SLCH_{spec} \times M_{cy} \quad (2)$$

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.

$$\text{Nutrient loss (kg ha}^{-1}\ \text{harvest}^{-1}) = \text{Nutrient content (g kg}^{-1}\ \text{soil)} \times SLCH_{crop}\ (\text{kg ha}^{-1}\ \text{harvest}^{-1}) \quad (3)$$

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_2O_5 and K_2O respectively, their equivalents were calculated as follows:

Ammonium nitrate (Mg)= [100 x lost N (Mg ha^{-1} harvest^{-1}) / 33] x harvest area (ha) (4)

Triple superphosphate (Mg)= [100 x lost P_2O_5 (Mg ha^{-1} harvest^{-1}) / 48] x harvest area (ha) (5)

Potassium sulfate (Mg)= [100 x lost K_2O (Mg ha^{-1} harvest^{-1}) / 50] x harvest area (ha) (6)

where 33, 48 and 50 denote the percentages of N, P_2O_5 and K_2O in ammonium nitrate, triple superphosphate and potassium sulfate fertilizers, respectively.

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 (Wood and Cowie 2004).

Figure 1. A. Mechanical potato harvesting; B. Soils remained over potatoes after mechanical harvest; C. Manual carrot harvesting; D. Soils remained over carrots after mechanical harvesting; E. Manual celery harvesting; F. Soils left and accumulated in washing facility after manual celery harvesting.

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_2O_5 and K_2O losses were for manual carrot harvest, whereas the lowest N and K_2O 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_2O_5 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 $170.7x10^3$ 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 as 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.

Crop	Methods of harvesting	Element	Amount(g kg^{-1}) (mean±standard deviation)	Losses (kg $^{-1}$ ha^{-1} $harvest^{-1}$)
Potato	Mechanical harvesting (n= 39)	N	0.95±0.36	1.71
		P_2O_5	0.12±0.05	0.23
		K_2O	0.11±0.04	0.20
Carrot	Manual harvesting (n= 14)	N	0.68±0.30	3.81
		P_2O_5	0.06±0.03	0.35
		K_2O	0.28±0.11	1.56
Carrot	Mechanical harvesting (n= 18)	N	0.76±0.34	2.68
		P_2O_5	0.39±0.02	0.14
		K_2O	0.22±0.06	0.78
Carrot	Manual+ mechanical harvesting (n= 32)	N	0.73±0.32	3.31
		P_2O_5	0.05±0.03	0.22
		K_2O	0.25±0.09	1.12
Celery	Manual harvesting (n= 27)	N	1.25±0.45	5.02
		P_2O_5	0.05±0.02	0.22
		K_2O	0.37±0.08	1.48

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

Crop	Methods of harvesting	SLCH Mg ha^{-1} $harvest^{-1}$)	Harvest area[1] (ha)	SLCH (10^3Mg)	N (Mg)	A.N (Mg)[a]	CO_2-e (Mg)[d]	P_2O_5 (Mg)	TSP (Mg)[b]	CO_2-e (Mg)[e]	K_2O (Mg)	P.S (Mg)[c]	CO_2-e (Mg)[f]
Potato	Mechanical harvesting	1.81	9000	16.29	15.39	46.63	114.63	2.07	4.31	4.65	1.80	3.60	4.03
Carrot	Manual+mechanical harvesting[g]	4.55	5030	22.88	16.64	50.42	124.03	1.10	2.29	2.47	5.63	11.26	12.61
Celery	Manual harvesting	4.00	180	0.72	0.90	2.72	6.69	0.04	0.08	0.09	0.26	0.52	0.58
Total			14210	39.89	32.93	99.77	245.35	3.21	6.68	7.21	7.69	15.38	17.22

* Carbon footprint total for ammonium nitrate, triple superphosphate and potassium sulfate fertilizers was annually 269.78 Mg CO_2.

[1] Harvested area data were taken from Turkish Statistical Institute (2016).

[a] A.N: Ammonium nitrate(33% N); [b] TSP: Triple superphosphate(48% P_2O_5); [c] P.S: Potassium sulfate(50% K_2O); [d] Carbon footprint quantity for ammonium nitrate production; [e] Carbon footprint quantity for TSP production; [f] Carbon footprint quantity for potassium sulfate fertilizer production; [g] 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 $39.89x10^3$ 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

Bremner JM, Mulvaney CS (1982) Nitrogen-total. In: Page AL, Miller RH, Keeney DR (Eds.), Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties, 2nd ed. Agronomy No: 9, ASA,SSSA, Madison, Wisconsin, pp. 539–579.

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

Faraji M, Chakan AA, Jafarizadeh M, Behbahani AM (2017) Soil and nutrient losses due to root crops harvesting: a case study from southwestern Iran. Archives of Agronomy and Soil Science 63(11): 1523-1534.

Isabirye M, Ruysschaert G, Van Linden L, Poesen J, Magunda, MK, Deckers J (2007) Soil losses due to cassava and sweet potato harvesting: a case study from low input traditional agriculture. Soil and Tillage Research 92: 96-103.

Knudsen D, Peterson GA, Pratt PF (1982) Lithium, sodium, and potassium. In: Page AL, Miller RH, Keeney DR (Eds.), Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties, 2nd ed. Agronomy No: 9, ASA,SSSA, Madison, Wisconsin, pp. 225–245.

Li Y, Ruysschaert G, Poesen J, Zhang QW, Bai LY, Li L, Sun LF (2006) Soil losses due to potato and sugar beet harvesting in NE China. Earth Surface Processes and Landforms 31: 1003-1016.

Mwango SB, Msanya BM, Mtakwa PW, Kimaro DN, Deckers J, Poesen J, Lilanga S, Sanga R (2015) Soil loss due to crop harvesting in Usambara Mountains, Tanzania: the case of carrot, onion and potato. International Journal of Plant and Soil Science 4(1): 18-28.

Olsen SR, Sommers LE (1982) Phosphorus, In: Page, A.L., Miller, R.H., Keeney, D.R. (Eds.), Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties, 2nd ed. Agronomy No: 9, ASA,SSSA, Madison, Wisconsin, pp. 403-427.

Oruç N (2013) Estimation of soil lost and carbon footprint equivalent of soil nitrogen lost due to the sugar beet harvest in Turkey. In: 1. Central Asia Congress on Modern Agricultural Tecniques and Plant Nutrition. 01-03 October 2013, Bishkek, Kyrgyzstan.

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

Oshunsanya SO, Yu H, Li Y (2018) Soil loss due to root crop harvesting increases with tillage operations. Soil Tillage and Research 181: 93–101.

Parlak M, Karaca S, Turkmen N (2008) The cost of soil lost caused by sugar beet harvest: a case study for Turkey. Journal of Agricultural Sciences 14(3): 284–287.

Parlak M, Blanco-Canqui H (2015) Soil losses due to potato harvesting: a case study in western Turkey. Soil Use and Management 31: 525–527.

Parlak M, Palta Ç, Yokuş S, Blanco-Canqui H, Çarkacı DA (2016) Soil losses due to carrot harvesting in south central Turkey. Catena 140: 24–30.

Parlak M, Çiçek G, Blanco-Canqui H (2018) Celery harvesting causes losses of soil: a case study in Turkey. Soil Tillage and Research 180: 204–209.

Poesen J, Verstraeten G, Soenens R, Seynaeve L (2001) Soil losses due to harvesting of chicory roots and sugar beet: an underrated geomorphic process? Catena 43: 35–47.

Ruysschaert G, Poesen J, Verstraeten G, Govers G (2004) Soil loss due to crop harvesting: significance and determining factors. Progress in Physical Geography 28: 467–501.

Ruysschaert G, Poesen J, Notebaert B, Verstraeten G, Govers G (2008) Spaital and long term variability of soil loss due to crop harvesting and the importance relative to water erosion: a case study from Belgium. Agriculture, Ecosystems and Environment 126: 217-228.

Tirado R, Gopikrishna SR, Krishnan R, Smith P (2010) Greenhouse gas emissions and mitigation potential from fertilizer manufacture and application in India. International Journal of Agricultural Sustainability 8(3): 176-185.

Turkish Statistical Institute (2016) Agricultural data. http://www.tuik.gov.tr. Accessed 30 December 2016 (in Turkish).

Turkish Statistical Institute (2017) National Greenhouse Gas Inventory Report 1990-2015. Annual Report for Submission under the "United Nations Framework Convention on Climate Change". 517 pages.

Wang Z, Chen J, Mao S, Han Y, Chen F, Zhang L, Li Y, Li C (2017) Comparison of greenhouse gas emissions of chemical fertilizer types in China's crop production. Journal of Cleaner Production 141:1267-1274.

Wood S, Cowie A (2004) A review of greenhouse gas emission factors for fertilizer production. Research and Development Division, State Forests of New South Wales. Cooperative Research Centre for Greenhouse Accounting For IEA Bioenergy Task 38.

Yu H, Li Y, Zhou N, Chappell A, Li X, Poesen J (2016) Soil nutrient loss due to tuber crop harvesting and its environmental impact in the North China Plain. Journal of Integrative Agriculture 5(7): 1612-1624.