Comparing Soil Erosion Rates on Terraced and Sloping Cultivated Land in Palestine Using FRN \(1^{37}\text{Cs}\) Trace

**Orwa Houshia**, 1 **Moncef Benmansour**, 2 **Lionel Mabit**, 3 **Emil Fulajtár**, 4 **Saber Abu-Jabal**, 5 **Ismail Hroub**, 6 and **Rafat Odeh** 6

1Department of Chemistry, Arab American University, Jenin, State of Palestine
2Centre National de L’Energie des Sciences et des Technique Nucleaires (CNESTEN), Division of Water, Soil and Climate, Rabat, Morocco
3Soil and Water Management and Crop Nutrition Laboratory, The International Atomic Energy Agency (IAEA), Seibersdorf, Vienna, Austria
4Soil and Water Management & Crop Nutrition Section, Joint FAO/IAEA Division of Nuclear Techniques, Food and Agriculture, International Atomic Energy Agency, Vienna, Austria
5Department of Chemistry, An-Najah National University, Nablus, State of Palestine
6Radiation Protection & Detection Unit, Ministry of Health Qadoora Street Ramallah, Ramallah, State of Palestine

Correspondence should be addressed to Orwa Houshia; orwa.houshia@aauj.edu

Received 25 July 2022; Revised 1 September 2022; Accepted 12 September 2022; Published 30 September 2022

**1. Introduction**

Agriculture is an important cultural tradition vital to the economy of the West Bank, Palestine. Also, agriculture plays a vital role in the region’s future. Palestinians are coping in creative ways [1] every day despite the challenges of establishing a livelihood or any sustainable economic activity based on agriculture. Whether the challenge lies in water scarcity, soil degradation [2], or blockade restrictions, Palestinian families implement innovative and collaborative approaches to living off the land [3]. However, the land suitable for agriculture in Palestine is shrinking due to soil erosion, land degradation, and water erosion, which in turn affect soil properties and functions [4–7] and cause the loss of soil, which is not renewable on the human timescale. Consequently, these factors represent a major threat to the soil and water resources the country needs to ensure sustainable agricultural production.

Within this context, and in order to provide a comprehensive assessment of the magnitude of these problems...
and to support the selection of effective soil conservation measures, quantitative data on the extent and rates of soil erosion under various agroecological conditions and land use systems were needed [8]. Integrated land and water management practices improve agricultural production and enhance soil productivity and its resilience against desertification and other impacts of climate change and variability. Radionuclide and stable isotopic techniques can be used to study soil erosion and land degradation problems [9]. Data on soil erosion acquired by conventional methods takes several years to obtain and is time consuming. Furthermore, it is labor-intensive, and these conventional methods do not provide for the spatial distribution of soil erosion. On the other hand, the 137Cs isotope tracer fills the deficits of the conventional methods and facilitates the investigation of soil erosion on a much better timescale, so there is no need for costly, labor-intensive long-term monitoring.

2. Methodology

2.1. Study Area. The study area is located in the Central Highland in the Jenin Province, which receives annual precipitation of about 300 mm (Figure 1). The sampling sites were selected to acquire soil samples within the Jenin Province. The reference site at an elevation of 293 m above sea level was covered with shrub vegetation and had a slope of about 2%. The other two sites were labeled Terrace Site, which at an elevation of 246 m above sea level, cultivated land on a terrace with a slope of 2%, and foot slope site, which at an elevation of 140 m above sea level, cultivated land on a foot slope that was not terraced and had a slope of 3%. The difference in slope inclination is very small, but the important difference is the slope length (field length), which is very short on the terrace (10–15 m) and several folds longer at the foot slope field (60 m).

2.2. Field Sampling. The sampling design is as follows:

2.2.1. Reference Site. Grid sampling of 1.5 m (24 samples) (3×8), bulk samples, 30 cm depth, and a distance between two points is 1.5 m.

2.2.2. Terrace Site. Sampling along 3 transects containing 8 points in each transect (24 soil samples), bulk samples, 30 cm depth, and a distance of 1.5 m between two points.

2.2.3. Foot slope Site. Sampling along 3 transects containing 8 points in each transect (24 soil samples), bulk samples, 30 cm depth, and a distance of 1.5 m between two points.

3. Sample Preparation and 137Cs Analysis

Physical preparation of the soil samples was performed at the Palestine National Agricultural Center (NARC) including drying and light grinding. Then, samples were oven dried at 105 degrees Celsius, ground, sieved (<2 mm), and homogenized. Radionuclide analysis of 137Cs was performed by gamma spectrometry using an HPGe detector (45 efficiencies) by the Centre National de l’Energie des Sciences et des Technique Nucleaires (CNESTEN), Morocco. Tennelec/Nucleus HPGe (184 cc) planar-type coaxial intrinsic germanium detector was used. The 137Cs activity was measured.
by its gamma emission at 662 keV. Background counts were
made at regular intervals to ensure the maintenance of low
background characteristics. Each soil sample was counted
for 20000 s. The Cs inventory A (Bq·m−2) was calculated
using the following equation:

\[ A = \frac{CM}{S} \]  

(1)

where C is the 137Cs activity concentration of the sample (in
Bq·kg−1), M is the total dry mass of the collected soil core (in
kg) and S is the cross-section of the sampling tube (in m2).

4. Results and Discussion

Numerous models were established to analyze soil erosion
[10]. The main postulates and necessities of the 137Cs ap-
proaches have been reported in several papers [11]. The
calculation of soil erosion and deposition rates at the un-
disturbed site is based on 137Cs inventories and the 137Cs
depth distribution. Two methods are used. The simpler
method considers the fixed 137Cs fallout input and stable
137Cs profile distribution. The depth distribution over the
soil profile is mathematically described [12]. If this distri-
bution is considered by a simple mathematical function,
then the soil loss can be estimated by the proportion of the
137Cs reference value removed at the examined site [13].
This method is used for the Profile Distribution Model (PDM).
A more widespread method takes into consideration the time-
variant processes of: (1) the 137Cs fallout and (2) the gradual
postdepositional redistribution of 137Cs within the soil
profile, which is caused predominantly by bioturbation and
several other processes. This approach is used by the Diffu-
sion and Migration Model (DMM) [14]. The calculation of
soil loss in cultivated land can be based on two theoretical
concepts. The first one called, the proportional concept, is
very simple and it presumes that the removal of soil and
137Cs are directly proportional. Models based on this con-
cept are called the Proportional Model (PM). More complex
approaches involve a mass balance concept, which considers
the temporal dynamics of 137Cs inputs and outputs resulting
in the time-variant concentration of 137Cs in soil [12]. These
changes in concentration affect considerably the relation
between the 137Cs loss and soil loss caused by erosion. The
137Cs concentration in soil is controlled by several processes
[13, 15–17]. Most important are (1) time-variable 137Cs
fallout, (2) radioactive decay of 137Cs (i.e., 30.17 years), (3)
removal of freshly deposited 137Cs by erosion prior to its
incorporation into the plough horizon by tillage, and (4)
incorporation of subsoil material free of 137Cs or having low
137Cs content into the eroded ploughed horizon by tillage
[18].

The Mass Balance Models (MBM) were developed in the
mid-1980s. Different models use different approaches to
handle the 137Cs time-variant concentration in soil and
consider some but not all processes and factors controlling it
[12, 19, 20]. Moreover, three Mass Balance Models that were
initially developed by Walling and He [10] are used, e.g.,
Mass Balance Model 1 (MBM1), Mass Balance Model 2
(MBM2), and Mass Balance Model 3 (MBM3).

In order to convert inventories or areal activities (in Bq/m2)
into soil erosion or deposition rates (in t/ha/yr), conversion
models were used. First, the Proportional Model
(PM) was used to have preliminary results about soil erosion,
in accordance with equations (2), (3), and (4) obtained from
references [12, 21].

The basic equation (2) of the Proportional Model [10]
can, therefore, be represented as follows:

\[ Y = 10 \frac{BdX}{100TP} \]  

(2)

where X is the percentage reduction in total 137Cs inventory
(defined as (Aref - A)/A * 100), d is the depth of the plough
or cultivation layer (m), B is the bulk density of the soil
(kg·m−3), T is the time elapsed since the start of 137Cs
accumulation (yr), Aref represents the local reference inven-
tory (Bq·m−2), and A is the total inventory measured at the
sampling point (Bq·m−2). P represents the particle size
correction factor for erosion. This model does not require
many parameters, but it is not realistic as he neglected some
processes or phenomena related to 137Cs behavior and
erosion processes in cultivated sites.

In addition, the Chernobyl contribution was not in-
cluded when applying this model. In this case, Mass Balance
Models were used (equation (3)) and, more specifically, the
Mass Balance Model 2, which can describe suitably the real
situation and therefore was also applied (equation (4)). It has
to be noted that the file for the annual deposition of 137Cs
was modified to take the Chernobyl contribution into ac-
count. The results given by both models for both sites 1 and 2
are reported in Table 1 and Table 2.

\[ \frac{dA(t)}{dt} = (1 - \Gamma)(t) \left( \lambda + \frac{P R}{d} \right) A(t), \]  

(4)

where A (t) = cumulative 137Cs activity per unit area (Bq/
m2); R = erosion rate (kg/m2·yr); d = cumulative mass depth,
representing the average plough depth (kg/m2·yr); \( \lambda \) = decay
constant for 137Cs (yr−1); \( \Gamma(t) \) = annual 137Cs deposition flux
(Bq/m2·yr); \( \Gamma \) = percentage of the freshly deposited 137Cs
fallout removed by erosion before being mixed into the
plough layer; P = particle size correction factor.

The inventories of the samples were calculated from the
137Cs concentration (in Bq/kg), the bulk density of the
sample, and the depth of the core. An average bulk density
was calculated for each type of site. There are about 1160 kg/
m3, 1240 kg/m3, and 1190 kg/m3 for a reference site, site 1,
and site 2, respectively.

The results of all inventories (Bq/m2) are given in Table 3.
For the reference site, the inventories ranged between 2927
and 4086 Bq/m2. The average value of the reference site is
3315 ± 410 Bq/m2, which corresponds to a coefficient of
### Table 1: Soil erosion rates in t/ha/yr associated with site 1 for different points of the transects using the Proportional Model (PM) and Mass Balance Model 2 (MBM2).

| Distance from the top (m) | Foot slope site 1 | Terraced site 1 | Foot slope site 1 | Terraced site 1 |
|--------------------------|-------------------|-------------------|-------------------|-------------------|
|                          | PM T1 | T2 | T3 | T1 | T2 | T3 | T1 | T2 | T3 |
| 0                        | 9.6  | 18.8 | 8.7 | 10.9 | 26.7 | 9.6 |
| 1.5                      | 11.1 | 7.1  | 9.5 | 13.0 | 7.7  | 10.7 |
| 3                        | 7.4  | 15.6 | 7.7 | 8.1  | 20.3 | 8.4 |
| 4.5                      | 11.5 | 8.1  | 7.3 | 13.6 | 8.9  | 7.9 |
| 6                        | 17.4 | 8.1  | 9.3 | 23.9 | 8.9  | 10.5 |
| 7.5                      | 16.7 | 5.4  | 8.2 | 22.4 | 5.7  | 9.0 |
| 9                        | 5.9  | 10.0 | 6.6 | 6.2  | 11.4 | 7.1 |
| 10.5                     | 11.1 | 7.2  | 9.5 | 12.9 | 7.8  | 10.7 |

### Table 2: Soil erosion rates t/ha/yr associated with site 2 for different points of the transects using the Proportional Model (PM) and Mass Balance Model 2 (MBM2).

| Distance from the top (m) | Foot slope site 1 | Terraced site 2 | Foot slope site 1 | Terraced site 2 |
|--------------------------|-------------------|-------------------|-------------------|-------------------|
|                          | PM T1 | T2 | T3 | T1 | T2 | T3 | T1 | T2 | T3 |
| 0                        | 22.9 | 23.5 | 10.0 | 40.0 | 42.4 | 12.0 |
| 1.5                      | 22.3 | 16.5 | 9.4 | 38.2 | 23.3 | 11.2 |
| 3                        | 21.8 | 10.9 | 12.0 | 36.6 | 13.3 | 15.2 |
| 4.5                      | 23.3 | 9.4  | 25.3 | 41.5 | 11.1 | 49.4 |
| 6                        | 22.7 | 12.9 | 24.9 | 39.6 | 16.6 | 47.8 |
| 7.5                      | 22.6 | 11.4 | 25.4 | 39.1 | 14.2 | 49.8 |
| 9                        | 23.4 | 10.0 | 24.5 | 41.8 | 12.1 | 46.1 |
| 10.5                     | 23.0 | 10.0 | 23.6 | 40.6 | 12.0 | 42.7 |

### Table 3: Inventories (B/m²) associated with all points collected at reference and study sites.

| Sample code | Inventory | Sample code | Inventory | Sample code | Inventory |
|-------------|-----------|-------------|-----------|-------------|-----------|
| R101        | 3804      | PE101       | 2492      | SD101       | 1278      |
| R102        | 4086      | PE102       | 2366      | SD102       | 1328      |
| R103        | 3543      | PE103       | 2678      | SD103       | 1374      |
| R104        | 3511      | PE104       | 2332      | SD104       | 1239      |
| R105        | 3564      | PE105       | 1823      | SD105       | 1289      |
| R106        | 3675      | PE106       | 1886      | SD106       | 1303      |
| R107        | 3790      | PE107       | 2812      | SD107       | 1232      |
| R108        | 2965      | PE108       | 2370      | SD108       | 1264      |
| R109        | 3800      | PE109       | 1707      | SD109       | 2617      |
| R110        | 2864      | PE110       | 2704      | SD110       | 1217      |
| R111        | 2791      | PE111       | 1983      | SD111       | 1846      |
| R112        | 3003      | PE112       | 2623      | SD112       | 2345      |
| R113        | 3250      | PE113       | 2623      | SD113       | 2481      |
| R114        | 3069      | PE114       | 2850      | SD114       | 2167      |
| R115        | 2979      | PE115       | 2463      | SD115       | 2296      |
| R116        | 2944      | PE116       | 2701      | SD116       | 2420      |
| R117        | 2499      | PE117       | 2574      | SD117       | 2428      |
| R118        | 2840      | PE118       | 2504      | SD118       | 2478      |
| R119        | 3108      | PE119       | 2656      | SD119       | 2242      |
| R120        | 3135      | PE120       | 2693      | SD120       | 1057      |
| R121        | 3616      | PE121       | 2522      | SD121       | 1092      |
| R122        | 3014      | PE122       | 2615      | SD122       | 1050      |
| R123        | 3369      | PE123       | 2749      | SD123       | 1128      |
| R124        | 2927      | PE124       | 2504      | SD124       | 1210      |
variance of about 12%. This coefficient of variance can be considered as low, confirming the low variability and low disturbance of the selected reference site. The high inventory associated with the reference site suggests that the fallout 137Cs deposited in this region is the result of both old nuclear weapon tests conducted in the 1950s–1960s and the Chernobyl disaster that occurred in 1986. Taking into account the average rainfall in this region (Jenin Province) of about 300 mm, the inventory estimated by prediction using conversion models is about 897 Bq/m². It means that the contribution of Chernobyl is about 2418 Bq/m², which represents around 73% of the total reference inventory. Concerning study site 1 and site 2, the inventories are significantly lower than those of the reference site (see Table 1), especially for site 2, indicating that these sites are eroded. Figure 2 shows the distribution of 137Cs inventory along 3 transects for each site and the mean reference inventory value. For site 1, inventories are found between 1707 and 2749 Bq/m², while for the site 2, inventories are found between 1050 and 26117 Bq/m². In comparison, all the inventories obtained are lower than the reference value (Figure 1), indicating that there is no depositional area at both sites.

As previously reported by Nouira et al. [19], the Proportional Model does not take into account the dilution of 137Cs concentrations in the soil within the cultivated layer, resulting from the assimilation of soil from below the originally cultivated depth due to surface lowering by erosion; thus, the results obtained by this model in the present study likely underestimate the actual rates of soil loss. The Mass Balance approach that takes into account the effect of mixing the subsoil containing no 137Cs from below the plough depth into the plough layer gave higher values for soil loss rate, as is observed in some other reports [19, 22].

5. Conclusions

137Cs distribution at the sites confirmed that the 137Cs tracking procedure can be effectively used to assess soil erosion and deposition rates. The application of the 137Cs tracking system enabled us to quantify the extent of soil erosion in the Northern Palestine region. For the reference site, the inventories ranged between 2927 and 4086 Bq/m². The average value of the reference site is 3315 ± 410 Bq/m², which corresponds to a coefficient of variance of about 12%, suggesting that the fallout 137Cs deposited in this region is a result of both old nuclear weapon tests conducted in 1950s–1960s and the Chernobyl disaster that occurred in 1986.

Finally, the 137Cs tracking technique is a useful erosion model for the Northern Palestine region. This data can be used to refine erosion control guidelines influencing the selection of a vast array of management practices by an agricultural producer, such as tillage, fertilizer application, crop rotation, plant population, and structures. Thus, the future work, which will be carried out in phase–II of the project, highly recommends the selection of more locations in Gaza and the West Bank in order to generate a soil erosion map of Palestine. This result will also be presented to legislators and decision makers within the government to implement appropriate soil erosion solutions.

Data Availability

All data has been included.

Conflicts of Interest

The authors declare that there are no conflicts of interest.
Authors’ Contributions

Orwa Houshia is the project P.I. and coordinator who oversees the project and is responsible for grant and funding acquisition from the IAEA. Also, Orwa Houshia wrote the draft of the manuscript and is the corresponding author of the article. Benmansour Moncef ran samples and interpreted data using Gamma HPGeD spectroscopy. Lionel Mabit, the IAEA Technical Officer, helped to revise the proposal for phase-1 and also edited manuscripts and facilitated funding. Emil Fulajtár, IAEA Technical Officer, helped in revising the manuscript, specifically the abstract and title, and facilitated a scientific visit. Sample collection and preparation were done by Saber Abu-Jabal. Ismail Hroub carried out the sample preservation, shipping and handling, and logistics. Procurement and sample analysis follow-ups were done by Rafat Odeh.

Acknowledgments

This research has been made possible through the generous donation and support from the IAEA. The authors also express their gratitude to NARC for providing transportation, especially Dr. M. AbuEid (former DG of NARC), Mr. Motasem Zaid, and Mr. Oday Zaid.

References

[1] A. A. Hammad, L. E. Haugen, and T. Børresen, “Effects of stonewalled terracing techniques on soil-water conservation and wheat production under Mediterranean conditions,” Environmental Management, vol. 34, no. 5, pp. 701–710, 2004.
[2] S. Alkhouri, Monitoring of Land Condition in the Occupied Palestinian Territory, Applied Research Institute—Jerusalem/Society [ARIJ], Bethlehem, State of Palestinian, 2010.
[3] A. A. Hammad and T. Børresen, “Socioeconomic factors affecting farmers’ perceptions of land degradation and stonewall terraces in Central Palestine,” Environmental Management, vol. 37, no. 3, pp. 380–394, 2006.
[4] H. A. Elwell, “Sheet erosion from arable land in Zimbabwe: prediction and control,” in Challenges in African Hydrology and Water Resources, D. E. Walling, Ed., pp. 429–438, IAHS Press, Wallingford, UK, 1984.
[5] R. Lal, “Soil erosion and the global carbon budget,” Environment International, vol. 29, no. 4, pp. 437–450, 2003.
[6] L. Mabit, M. R. Laverdière, and S. Wicherek, Césium-137 et érosion des sols Cah, Agric, vol. 7, no. 3, 1998.
[7] M. Ben Mansour, M. Ibn Majah, H. Marah, T. Marfak, and D. Walling, “Use of the Cesium 137 technique in soil erosion investigation in Morocco-case study of the Zitouza basin in the north,” in Proceeding of the International Symposium on Nuclear Techniques in Integrated Plant Nutrient, Water and Soil Management, AIEA/FAO, pp. 308–315, Vienna, Austria, October 2000.
[8] L. Ivan, Q. Laura, P. Leticia, G. Leticia, and N. Ana, “Enhancing connectivity index to assess the effects of land use changes in a Mediterranean catchment,” Land Degradation & Development, vol. 29, no. 3, pp. 663–675, 2018.
[9] L. Mabit, K. Meusburger, E. Fulajtár, and C. Alewell, “The usefulness of 137Cs as a tracer for soil erosion assessment: a critical reply to Parsons and Foster (2011),” Earth-Science Reviews, vol. 127, pp. 300–307, 2013.
[10] D. E. Walling and Q. He, “Improved models for estimating soil erosion rates from 137Cs measurements,” Journal of Environmental Quality, vol. 28, Article ID 61112262, 1999.
[11] A. Navas, J. Machín, and J. Soto, “Assessing soil erosion in a Pyrenean mountain catchment using GIS and fallout 137Cs,” Agriculture, Ecosystems & Environment, vol. 105, no. 3, pp. 493–506, 2005.
[12] A. Navas and D. E. Walling, “Using caesium-137 to assess sediment movement on slopes in a semi-arid upland environment in Spain,” in Erosion, Debris Flows and Environment in Mountain Regions, pp. 129–138, IAHS Press, Wallingford, UK, 1992.
[13] A. Navas, L. Gaspar, M. López-Vicente, and J. Machín, “Spatial distribution of natural and artificial radionuclides at the catchment scale (South Central Pyrenees),” Radiation Measurements, vol. 46, no. 2, pp. 261–269, 2011.
[14] A. Navas, T. A. Quine, D. E. Walling, L. Gaspar, L. Quijano, and I. Lizaga, “Relating intensity of soil redistribution to land use changes in abandoned pyrenean fields using fallout caesium-137,” Land Degradation & Development, vol. 28, no. 7, pp. 2017–2029, 2017.
[15] E. Fulajtár, “Assessment of soil erosion through the use of 137Cs at jaslovske bohunice, western Slovakia,” Acta Geologica Hispanica, vol. 35/3, pp. 291–300, 2000.
[16] A. Navas, M. López Vicente, L. Gaspar, and J. Machín, “Assessing soil redistribution in a complex karst catchment using fallout 137Cs and GIS,” Geomorphology, vol. 196, pp. 231–241, 2013.
[17] A. Navas, M. López-Vicente, L. Gaspar, L. Palazón, and L. Quijano, “Establishing a tracer-based sediment budget to preserve wetlands in Mediterranean mountain agro-ecosystems (NE Spain),” Science of the Total Environment, vol. 496, pp. 132–143, 2014.
[18] L. Mabit, C. Bernard, and M. R. Laverdiere, “Quantification of soil redistribution and sediment budget in a Canadian watershed from fallout cesium137 (137Cs) data,” Canadian Journal of Soil Science, vol. 82, 2002.
[19] A. Nouira, E. H. Sayouty, and M. Benmansour, “Use of Cs technique for soil erosion study in the agricultural region of casablanca in Morocco,” Journal of Environmental Radioactivity, vol. 68, pp. 11e26–137, 2003.
[20] A. Navas, D. E. Walling, T. Quine et al., “Variability in 137Cs inventories and potential climatic and lithological controls in the central Ebro valley, Spain,” Journal of Radioanalytical and Nuclear Chemistry, vol. 274, no. 2, pp. 331–339, 2007.
[21] E. Fulajtár, L. Mabit, and C. S. Renschler, “Use of 137Cs for soil erosion assessment,” 2017, https://www.fao.org/3/18211EN/i8211en.pdf.
[22] X. B. Zhang, D. L. Higgitt, and D. E. Walling, “A preliminary assessment of the potential for using caesium-137 to estimate soil erosion in the Loess plateau of China,” Hydrological Sciences Journal, vol. 35, Article ID 267e276, 1990.