Tropentag 2008
University of Hohenheim, October 7-9, 2008
Conference on International Research on Food Security, Natural Resource Management and Rural Development

Estimation of medium-term soil redistribution rates in Ibadan, Nigeria, by using the ^{137}Cs technique

Birte Junge[a]; Gerd Dercon[b]; Robert Abaidoo[a]; David Chikoye[a] and Karl Stahr[c]

a International Institute of Tropical Agriculture (IITA), PMB 5320, Oyo Road, Ibadan, Nigeria, b.junge@cgiar.org
b Institute of Plant Production in the Tropics and Subtropics, University of Hohenheim, International Atomic Energy Agency (IAEA), A-1400 Vienna, Austria
c Institute of Soil Science and Land Evaluation, University of Hohenheim, 70593 Stuttgart, Germany

Abstract
Soil erosion is a widespread and serious problem in Nigeria, West Africa. The ^{137}Cs technique is an alternative to field plots for generating data on medium-term soil redistribution. It was tested in 2007 in Ibadan, Nigeria, which means the first time in the derived savanna. To analyse the vertical and spatial distribution of this nuclide in the soil, core samples were taken either randomly or along transects in an uncultivated and a cultivated site. The study showed an accumulation of ^{137}Cs near the soil surface and a slow decrease with depth in the undisturbed site. The arable land was characterized by an almost uniform ^{137}Cs distribution within the ploughed layer. The reference inventory of ^{137}Cs determined on the uncultivated site was 569.3 ± 150.1 Bq m^{-2}; the inventory of ^{137}Cs on the field ranged from 96.9 to 1494.4 Bq m^{-2}. Comparisons with the reference inventory showed smaller values for the upper slope and higher values for the lower slope of the cultivated site, which indicated soil redistribution. The conversion of the inventories into quantitative data of erosion and deposition by a proportion model revealed, for example, that about 148.5 t ha^{-1} yr^{-1} were eroded from the cropland in furrows leading downslope. The estimated results were comparable to erosion measurements made nearby. Hence, the ^{137}Cs technique is useful as a method to generate data on soil redistribution and therefore a tool for improved natural resource management in Nigeria.

1. Background and aim of study
In Nigeria, soil degradation induced by human activity is a common phenomenon and its severity is already high or very high for about 54% of the total area (FAO 2005). Soil erosion is the most widespread type of soil degradation. Sheet erosion dominates all over the country; rill and gully erosion are common in the eastern parts and along rivers in northern Nigeria (Igbozurike et al. 1989). Fertile topsoil is removed by water and wind erosion causing the reduction of crop yields and land is lost for other uses, such as grazing for cattle. Hence, there is an urgent need to solve this problem.

The basis for improved natural resource management is the availability of information on the extent and amount of soil redistribution. The measurement of soil loss with plots is a classical measurement technique which is very time-consuming, labour-intensive, and characterized by a huge scope for faults and errors (FAO 1993). The use of the radionuclides is an alternative technique to quantify rates of soil loss and sedimentation. As fallout nuclides are quickly and strongly adsorbed by fine soil particles after deposition, they are primarily distributed by physical processes of water and wind and therefore are valuable tracers for measuring soil redistribution.

Models were developed to convert measured nuclide inventories into the quantitative rates of erosion and deposition which are required for appropriate soil management (Walling et al. 1999). This study presents the use of this tracer technique in Ibadan, Nigeria, which means the first time in the forest savanna transition zone with semi-humid tropical climate.

2. Methodology

Radionuclide: Caesium-137 (^{137}Cs) is a man-made fallout released from atmospheric nuclear-weapon tests that began in the mid-1950s. Global fallout reached its maximum in 1963 to 1964 and has decreased since then (Cambray et al. 1989). Due to its half-life of 30.2 years, it can be used to generate data on medium-term rates of soil redistribution.

Study area: The study sites were located on the campus of the International Institute of Tropical Agriculture in Ibadan, Nigeria. The reference site (7°50'N 3°89 E) was a secondary forest not used for about 50 years and situated in a flat area. The cultivated site (7°48'N 3°89 E) was regularly ploughed and had been mainly used for growing cassava since 1970.

Sampling and Analysing: A core with an internal diameter of 11.8 cm was used for sampling. To describe the vertical distribution of radionuclides in the soil profile, samples were taken for depth-incremental sectioning (interval 5 cm). The analysis of the spatial ^{137}Cs distribution required random sampling on the reference sites (depth 30 cm) and sampling along transects running downslope on ridges and in furrows on the cropland (depth 30 to 60 cm). In addition, topsoil and sediment samples from different slope positions were collected for the analyses of the particle sizes. All samples were analyzed by gamma spectrometry using a high-purity Germanium (HPGe) detector (662 keV peak, counting time 45.000 s) at the Institute of Physics and Meteorology, University of Hohenheim, Germany.

Conversion Model: The proportion model presented by Walling and He (1997) was used to convert inventories of ^{137}Cs into rates of soil loss and deposition.

$$Y = 10 \frac{BdX}{100TP} \qquad Y' = 10 \frac{BdX'}{100TP'}$$

B = soil bulk density (kg m^{-3})
d = depth of cultivation layer (m)
P = ratio of ^{137}Cs in mobilized sediment to that of original soil
P'= ratio of ^{137}Cs in deposited sediment to that of mobilized sediment
T = time elapsed since the initiation of ^{137}Cs accumulation (yr)
X = % reduction in total ^{137}Cs inventory (Bq m^{-2})
X'= % increase in total ^{137}Cs inventory (Bq m^{-2})
Y = mean annual soil loss rate (t ha^{-1} yr^{-1})
Y'= mean annual deposition rate (t ha^{-1} yr^{-1})

3. Results and Discussion

Vertical distribution of ^{137}Cs: In the reference site, the peak of ^{137}Cs concentration was determined close to the surface, and the maximum of 5.6 ± 0.6 Bq kg^{-1} was found at the depth of 5 to 10 cm. The concentration declined exponentially with depth as a result of the fallout origin of the nuclides and because of the slow migration within the undisturbed soil. In the cultivated site, the ^{137}Cs concentration was almost uniform within the top 30 cm because of the mixing effect of ploughing (Figure 1). The ^{137}Cs depth distributions conformed to profiles reported for undisturbed and disturbed sites by Walling et al. (1999) or Wallbrink et al. (1999).

Spatial distribution of ^{137}Cs: In the reference site, the ^{137}Cs inventory ranged from 403.0 to 839.6 Bq m^{-2} (average value 569.3 ± 150.1 Bq m^{-2}). The inventory of ^{137}Cs in the field was 96.9 to 1494.4 Bq m^{-2} (average value 496.3 ± 272.5 Bq m^{-2}). The inventories of the uncultivated site in Ibadan were smaller and the values of the cultivated site smaller or comparable to the ^{137}Cs inventories determined by Chappell et al. (1998) in southwest Niger (943 to 4129 Bq m^{-2}). This might be an indication of the regional variability of fallout nuclides in the atmosphere and soils from the spatial influences of rainfall, wind, or harmattan that affect fallout (Chappell et al. 1998).

The variability of the ^{137}Cs inventory in the undisturbed soils was moderate (coefficient of variability (CV) 26%, n = 9) which was probably caused by the natural heterogeneity of the soil in terms of texture, bulk density, infiltration capacity, or porosity. On the field, the variability was higher (CV 35% on the upper slope, n = 20 and CV 33% on the lower slope, n = 12) owing soil redistribution (Loughran et al. 2002).

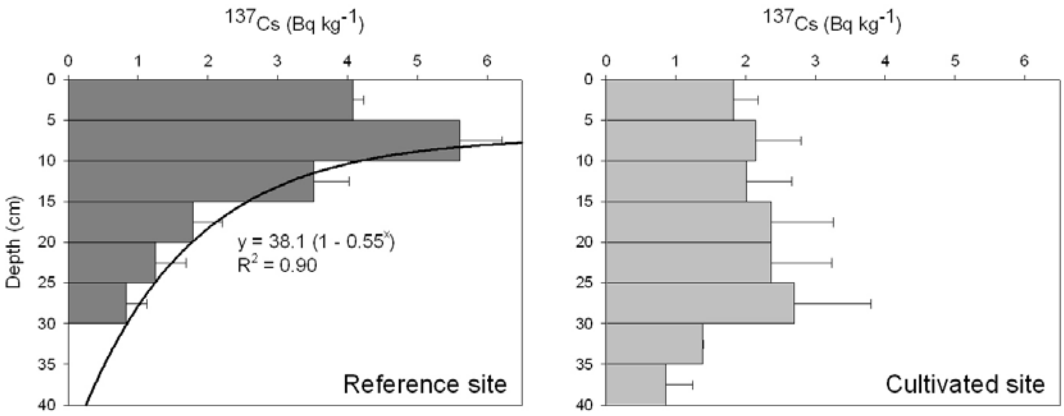

Fig. 1: Depth distribution of ^{137}Cs concentration in the reference site (28.6.2007) and cultivated site (6.7.2007).

Soil redistribution rates: The ^{137}Cs inventories of the sampling points situated on ridges or in furrows leading downslope on the cultivated site were converted into erosion and deposition rates, taking the average inventory of the reference site as the local total input of ^{137}Cs. The estimated rates showed that soil loss was highest on the upper slope and was reduced continuously downslope where soil deposition occurred (Table 1). The comparison with soil loss measurements conducted on the IITA campus by Lal (1976) revealed that the estimated soil loss rates were within the range of measured erosion rates (slope 5%: 43.5 to 156.2 t ha^{-1} yr^{-1}).

Tab.1: Estimated rates of soil eroded or deposited at selected sampling points located in a furrow leading down the slope (negative values correspond to erosion, positive values to deposition)

Sampling point	**Position**	**Rate** (t ha^{-1} yr^{-1})
1	Upper slope	–18.3
2	Upper slope	–23.9
3	Upper slope	–29.0
4	Upper slope	–19.7
5	Upper slope	–18.2
6	Middle slope	–10.6
7	Middle slope	–7.3
8	Middle slope	–3.1
9	Lower slope	–10.7
10	Lower slope	–14.8
11	Lower slope	+7.1
Total		–148.5

Particle size effect: The analyses of the topsoil and sediments collected at different slope positions showed that the mobilized and deposited sediment from the middle and lower slope included more sand (>90.0%) and less silt (<5.0%) and clay (<2.5%) than the original soil from the upper slope (86.0% sand, 9.2% silt, 4.7% clay). But the ^{137}Cs activity of the smaller particle sizes was obviously higher than from the larger sizes. For example, 79.1% of the ^{137}Cs activity was adsorbed by the clay fraction of the mobilized sediment whereas its sand fraction included only 12.8% and its silt fraction 8.2% of the total ^{137}Cs (Figure 2). This demonstrates a clear dependence of the radionuclide activity from the grain size which is caused by the increased surface area (Wallbrink et al. 1999).

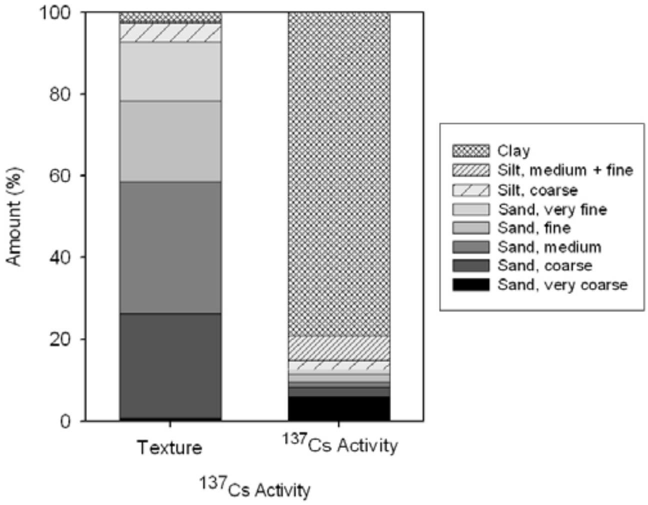

Fig. 2: Particle size fractions of mobilized sediment and their ^{137}Cs activity (9.7.2007).

4. Summary and Conclusion

The field trial in Ibadan, Nigeria, showed that the depth profile of ^{137}Cs was different in the uncultivated and cultivated soils. In the undisturbed site, the nuclide concentration was highest near the surface and gradually decreased with depth whereas the distribution was almost uniform within the ploughed layer of the cropland. The reference inventory for the area was 403.0 to 839.6 Bq m^{-2} (average 569.3 ± 150.1 Bq m^{-2}), and the inventory of the field ranged from 96.9 to 1494.4 Bq m^{-2} (average 496.3 ± 272.5 Bq m^{-2}). The comparisons with the reference inventory showed smaller values for the top end and higher values for the bottom end of the slope in the cultivated site, which indicated soil redistribution. Quantitative data of erosion and deposition rates estimated by a proportional model were comparable to results of measurements which show the applicability of the ^{137}Cs technique in the derived savanna of Nigeria.

5. References

Chappell, A., Warren, A., Oliver, M.A. and Charlton, M. (1998): The utility of ^{137}Cs for measuring soil redistribution rates in southwest Niger. Geoderma 81: 313-337.

Cambray, B.J., Loughran, R.J. and Elliott, G.L. (1989): Caesium-137 as an indicator of geomorphic processes in a drainage basin system. Australian Geography Studies 20: 49-64.

Igbozurike, U.M., Okali, D.U.U. and Salau, A.T. (1989): Profile on Nigeria: Land Degradation. Report submitted to Commonwealth Secretariat, London. Friedrich Ebert Foundation, Lagos, and Nigerian Environmental Study/Action Team (NEST), Ibadan. 48 pp.

FAO (1993): Field measurement of soil erosion and runoff. FAO, Rome, Italy. 30 pp.

FAO, AGL (2005): Global Assessment of the Status of Human-Induced Soil Degradation (GLASOD). Online available at: http://www.fao.org/landandwater/agll/glasod/glasodmaps.jsp (25.08.2008).

Lal R. (1976): Soil erosion problems on an Alfisol in Western Nigeria and their control. Monograph 1, IITA, Ibadan, Nigeria. 208 pp.

Loughran R.J., Pennock, D.J. and Walling D.E. (2002): Spatial distribution of Caesium-137. In F. Zapata (eds.): Handbook for the assessment of soil erosion and sedimentation using environmental radionuclides. IECA, Vienna, Austria. 215 pp.

Wallbrink, P.J., Murray, A.S. and Olley, J.M. (1999): Relating suspended sediment to its original soil depth using fallout radionuclides. Soil Science Society of America Journal 63: 369-378.

Walling, D.E. and He, Q. (1997): Models for converting ^{137}Cs measurements to estimates of soil redistribution rates on cultivated and uncultivated soils. A contribution to the IAEA Coordinated Research Programmers on Soil Erosion (D1.50.05) and Sedimentation (F3.10.01). University of Exeter, Exeter, UK, 29 pp.

Walling, D.E., He, Q. and Blake, W. (1999): Using ^{7}Be and ^{137}Cs measurements to document short- and medium-term rates of water-induced soil erosion on agricultural land. Water Resources Research 35(12): 3865-3874.

Acknowledgement

We thank the BMZ, Germany, for funding the project. We would also like to acknowledge the Institute of Physics and Metereology, University of Hohenheim, Stuttgart, Germany, for conducting the radionuclide analyses.