VN0400032

VAEC-AR 01/02--30

ESTABLISHMENT OF THE RELATIONSHIP BETWEEN ^{137}CS LOSS AND SOIL EROSION RATES

Phan Son Hai

Nuclear Research Institute

INTRODUCTION

In recent years, ^{137}Cs technique has been widely and successfully applied in estimation of soil erosion in many developed countries. In comparison with conventional methods, the ^{137}Cs technique can meet requirements which are needed for a method of soil erosion assessment. The following potential advantages of the technique have been summarized: (i) the technique permits assessment of the average soil erosion rate in the period of 40 years; (ii) the application of the technique requires only one field visit and the results can be provided within a relatively short time; (iii) the soil erosion rates estimated represent an average for the last 40 years, and are therefore less influenced by extreme events; (iv) the rates estimated represent the sum of all erosive processes; (v) the technique can estimate soil erosion rates, sediment deposition rates, pattern of soil redistribution and net rates of soil export from the field; (vi) the spatial resolution of the data obtained is defined by the sampling strategy.

However, the utilization of ^{137}Cs technique in studies of soil erosion is still unheard-of for many developing countries. The objective of this project is to carry out necessary researches in order to be able to use the technique for estimation of soil erosion in Vietnam. Therefore, the following matters have been performed: (i) studying the method of assessment of soil erosion rates based on ^{137}Cs inventory in the soil, consisting of the basis of the technique, sample collection methods, sample analysis and methods for interpretation of the data; (ii) development of "calibration" relationship between the degree of increase or depletion of the soil ^{137}Cs inventory relative to the reference inventory and total soil loss or gain; (iii) application of the technique in a pilot study.

EXPERIMENT

1. Determination of optimal parameters in analysis

The rates of erosion or deposition are assessed upon measurement of ^{137}Cs. Therefore, the precision of analytical data plays an important role in decrease of the uncertainty of results estimated. The mothod for analysis of ^{137}Cs based on gamma spectrometry has been described somewhere by the author. Only some parameters directly related to analysis of ^{137}Cs for soil erosion study are investigated in this work.

1.1. Determination of optimal sample weight

In nuclear analysis the number of counts increases with the increase of sample weight. However, this proportion is not linear in a wide range. Consequently, there is a need of investigation of the relationship between the counts acquired and sample weight. In this study two sample geometries in the form of well with wall thicknesses of 1.5cm and 2.0cm were used. A fixed count time of 30 hours was selected. The study of variation in percent error of the peak area at 662 keV with sample weight showed that the significant improvement in precision with increased sample mass up to 650g for the small well and 900g for the large well, and smaller improvement with further increase in sample mass.

1.2. Determination of count time

The analytical precision of measurements is dependent upon the count time. In order to investigate this relationship, two soil samples with ^{137}Cs concentrations of 1.36 Bq/kg and 2.40 Bq/kg, which are the common levels in cultivated lands in Viet Nam, were measured in a period of 240 ksec. The result showed that the analytical error decreases in the exponent law with increase of count time; that the error only decreases considerably within first 90 ksec (from 19% down to 9% for sample of 1.36 Bq/kg and 7% down to 4% for level of 2.40 Bq/kg); and that in the period of time from 100 – 240 ksec the error reduces very slowly (from 8.7% down to 6.5% and 3.8% to 2.8% for two levels of ceasium, respectively). From the results of this study, a count time of 85 ksec should be chosen to get the analytical error of about 8 – 9% for the level of concentration of about 1.3 Bq/kg.

For the level of concentration of about 2 – 2.5 Bq/kg, a count time of 30 – 40 ksec is enough for the requirement of error of about 7%. However, in measurements with smaller errors required, the count time needs to be increased, for instance 80 – 90 ksec to get the error of 4%.

2. Establishment of procedures for assessment of soil erosion

The ^{137}Cs technique is based upon the following fundamental assumptions: (a) the distribution of total atmospheric fallout ^{137}Cs may be considered uniform in the area of about $1 \div 2^0$ latitude; (b) the deposited ^{137}Cs is rapidly and strongly adsorbed by mineral soil; (c) subsequent redistribution of ^{137}Cs only takes place in association with soil erosion and deposition. If the validity of these assumptions is accepted then ^{137}Cs redistribution will mirror soil redistribution and that ^{137}Cs measurements may be used in erosion assessment.

In order to apply ^{137}Cs for estimation of soil erosion, five key stages should be followed: (i) establishment of a reference fallout inventory for the study site; (ii) measurement of the current spatial redistribution of ^{137}Cs inventories at the study site; (iii) evaluation of the pattern of ^{137}Cs redistribution at the study site; (iv) development of a calibration relationship between ^{137}Cs loss and gain and rates of soil erosion and deposition; (v) use of the calibration procedure to estimate rates of soil erosion and deposition at the study site.

2.1 Determination of reference inventory

The integrated deposition density of fallout ^{137}Cs is used as the reference value to define erosion or deposition areas. If total fallout ^{137}Cs is retained in surface soil, the total input of ^{137}Cs can be determined by measuring the ^{137}Cs inventory in soil samples. The site which is known to have suffered no erosion or disturbance during the period of ^{137}Cs deposition is called the reference site, and ^{137}Cs inventory at this site is termed the reference inventory.

This study is to attain two aims: (i) understanding the distribution of ^{137}Cs in the soil profile for some soil kinds in Lamdong province; (ii) determination of reference inventories at sites around Lamdong and the mean value for this area which are being used in the future.

a. Distribution of ^{137}Cs in soil profile

The depth distribution of ^{137}Cs has investigated at five reference sites: Dalat (LD1), Dilinh (LD2), Baoloc (LD3), Dateh (LD4) and Donduon (LD5). At each site incremental samples with 1 – 2 cm intervals and 10 cm diameter were collected down to 35cm. The results obtained from the study showed that ^{137}Cs activity decreases with the increase of depth; the maximum penetration depths of ^{137}Cs vary between 20 and 25cm (Fig. II.1); and that most of ^{137}Cs activity (more than 80%) is in a 15cm top layer. Therefore, the necessary depth for sampling is ranged from 25cm to 30cm.

b. Determination of the mean reference inventory for Lamdong area

In principle, the reference site should be next to the study site to avoid possible local variations in the density of fallout ^{137}Cs. However, it is not easy to find the reference site proximate to the study site, in practice. In many cases the mean value of reference inventories for the larger area is used instead of the reference value for the study site. The mean reference inventory determined for Lamdong area will be used for such cases in the future.

Reference inventories were estimated at 11 reference sites around Lamdong area. At each site, 4 – 6 soil samples with 10 cm diameter and 30cm depth were collected, and then these samples were mixed to make one sample for gamma measurement. The average value for 11 reference sites is 331Bq/m^2 with the standard deviation of 67 Bq/m^2. In the area of about 10.000 km^2 the variation of 20% about the mean for the ^{137}Cs inventory is acceptable in practice.

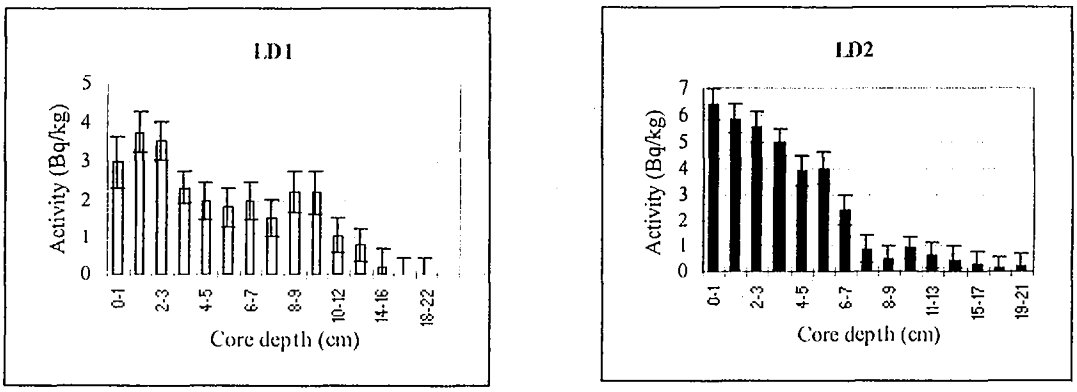

Figure.1. The depth distribution of ^{137}Cs at two reference sits in Lamdong

c. Determination of the number of samples required

Due to the probabilistic nature of fallout ^{137}Cs deposition and ^{137}Cs adsorption by mineral soil, the inventory is little different from point to point in a reference site. Meanwhile, a sampling area is not large enough, for instance 78.5 cm^2 in the study case, resulting in the variation in inventory at each sampling point. The question is that how many samples need to be collected to obtain the mean 137Cs inventory with a given confidence and allowable error.

In this study the sampling area is in the flat top of a hill of about 7000 m^2 located in Lacduong district. Twenty five soil samples were collected in a square grid with the distance of 15m between sampling points. The mean inventory and variance are 339 Bq/m^2 and 52 Bq/m^2, respectively. The number of samples can be estimated based on Student distribution when using the expression for the confidence limits of the true value μ (A. Hald, 1952):

$$\left\{\bar{x} - t_{\alpha/2}\frac{s}{\sqrt{n}} < \mu < \bar{x} + t_{\alpha/2}\frac{s}{\sqrt{n}}\right\} = 1 - \alpha \qquad (2.1)$$

where, n – number of samples. If the variance s is constant, the number of samples required to estimate the mean inventory at the 95% confidence level with allowable errors of ± 10%, ± 15% and ± 20% is 11, 6 and 4 samples, respectively.

2.2 Development of 'calibration' procedures

The procedures utilized in the estimation of erosion rates from ^{137}Cs inventories are usually termed calibration. The existing approaches may be divided into two broad groups: empirical relationships and theoretical models.

Empirical relationships between soil loss and ^{137}Cs loss are commonly established using direct plot measurements. Therefore there are some characteristics for these relationships: (i) because the relationship is dependent on local conditions, in particular the plough depth, the problem may be raised when it is applied to another place; (ii) the experimental data used for establishment of the relationship are obtained in a specific time, the equation is valid to the date of sample collection. Because of these characteristics, there is a need of development of relationships for assessment of erosion rates in Vietnam.

a. Development of empirical relationship

In order to estimate soil erosion rates empirical relationship is typically expressed as follows:

$$Y = a.X^b \qquad (2.2)$$

where: Y – total soil loss; X – loss of ^{137}Cs (%); a, b – constants.

The constants were determined using data collected from 4 plots (the area of 405 m^2 for each plot) located in Baoloc, Lamdong in the period of 2001 – 2002. The expression obtained as follows:

$$Y = 19,667.X^{1,1086} \qquad (2.3)$$

where: Y – total soil loss (t/ha); X – loss of ^{137}Cs (%) and determined by following expression:

$$X = \frac{I_p - I_r}{I_r}.100 \qquad (2.4)$$

where: I_p – inventory at study site; I_r – reference inventory.

b. Theoretical model

Apart from the empirical relationship mentioned above, theoretical models can be applied for assessment of soil loss from ^{137}Cs data. The simplest and most widely used theoretical model is the proportional method. This model is based on the assumption that soil loss is directly proportional to the amount of ^{137}Cs removed from the soil. It is suitable to cultivated soil where ^{137}Cs is well mixed in the plough depth. The relationship is expressed in the following form:

$$Y = \frac{D.B.X}{T} 10^4 \qquad (2.7)$$

where: Y – annual mean soil loss (t ha^{-1} y^{-1}); D – plough depth (m); B – bulk density (t m^{-3}); T – period of time from the beginning of ^{137}Cs fallout deposition to the investigation time(year); X – loss of ^{137}Cs and determined by:

$$X = \frac{I_p - I_r}{I_r} \qquad (2.8)$$

where: I_p – inventory at study sites; I_r – reference inventory.

In comparison with empirical relationships, the proportional model has significant advantages such as participation of a time component, local plough depth and bulk density in the expression. These characteristics make the model to be used over a wide range of conditions and time-scales.

3. Pilot application of ^{137}Cs technique

3.1 Experiment area

The ^{137}Cs technique was used to estimate soil erosion rates for the mulberry field of about 20 ha in Baoloc. The study site has a simple topography with the slope of 10^0 - 15^0 and parallel contours in South-North direction.

3.2 Determination of reference inventory

The reference site is about 1.5 – 2 km far from the study site. Eleven samples were collected at the reference site for determination of inventory. The mean value is 400 ± 41 Bq/m^2.

3.3 Sample collection

In order to investigate the depth distribution of ^{137}Cs in soil at the study site, two samples were collected in incremental depth intervals of 1 – 2 cm. The study result showed that ^{137}Cs is present and distributed rather homogeneously in the 25cm top layer. Therefore, the sampling depth of 30cm was chosen for bulk samples.

Bulk samples were collected along two slope transects, which are parallel and about 30m far from each other, with the slope length of about 220m. On each transect, 17 samples were collected with 10m – 15m distance between sampling points. The samples collected in such a way can provide following information: (i) rates of soil erosion or deposition; (ii) the distribution of ^{137}Cs along contour-lines.

3.4 Spatial distribution of ^{137}Cs

After sample analysis, the inventory of ^{137}Cs at sampling points is determined. The relative ^{137}Cs loss was estimated and illustrated on Figure II.2. The results showed that the distribution of ^{137}Cs along two transects are similar. Therefore, the rates of erosion or deposition for the study area can be estimated upon data obtained from one or two transects.

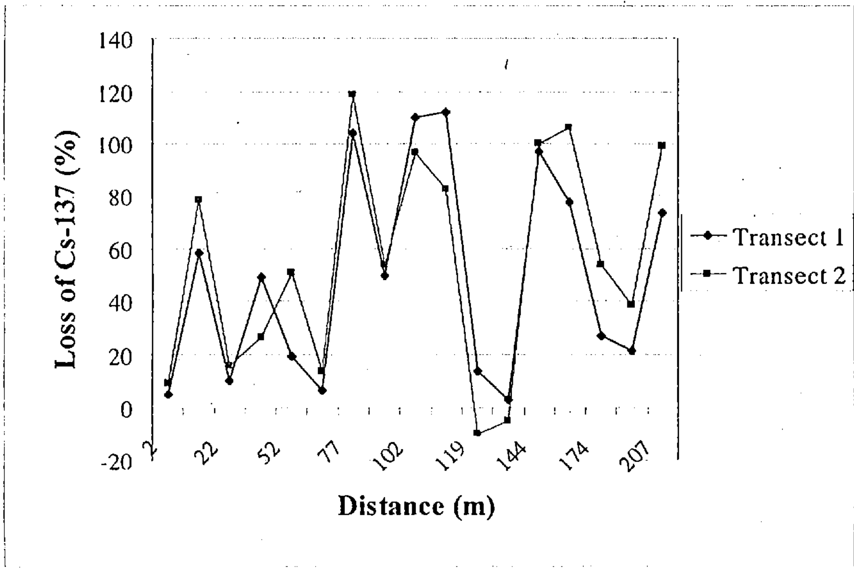

Figure .2. The distribution of ^{137}Cs along transects

3.6 Assessment of soil erosion rates

Soil erosion or deposition rates at sampling points have been estimated using the empirical relationship and proportional model established. In the proportional model the depth plough of 30 cm was used. The net soil loss or gain for each transect was obtained by integrating over the transect. The calculation for transect 1 showed that the total soil gain is 157.7 kg/m^2 according to empirical relationship and 158.1 kg/m^2 according to proportion model. The similar result is also obtained for transect 2 with 167.5 kg/m^2 (empirical relationship) and 178.6 kg/m^2 (proportion model).

The soil redistribution rates at each sampling sites on the same contour-lines vary between 6% and 13%. This implicated that the soil redistribution along the contour-line, to a certain extent, is identical. This allows to assess the total amount of erosion or deposition based upon data of individual transects. The estimate of soil deposition rate for the study area using data of transects gave the value of 38 t ha^{-1} y^{-1}. For study sites with the complicated topography the study area can be marked off into simple zones for which the individual transect method will be utilized.

CONCLUSIONS

The key stages involved in the use of ^{137}Cs in soil erosion assessment have been studied and successfully applied in pilot scale to mulberry land in Baoloc province. These main stages can be summarized as follows: (i) selection of reference sites next to the study site and establishment of a reference fallout inventory for the study site; (ii) measurement of the current spatial distribution of ^{137}Cs inventory; (iii) evaluation of the pattern of ^{137}Cs redistribution at the study site; (iv) development of a calibration relationship between ^{137}Cs loss and gain and rates of soil erosion and deposition; (v) estimation of soil redistribution rates using the calibration relationship.

The agreement of soil deposition rates obtained from the empirical relationship and the proportional model implicated that the proportional model can be used to assess erosion rates in a wide range of conditions for cultivated lands. This method has a special precedence for the study sites without empirical relationships. However, the validation of this method should be verified in many areas in the country where the run-off lots are available.

With the results obtained from the project's activities, the ^{137}Cs technique can be utilized for assessment of soil erosion rates for some regions in the Central Highland. However, it is necessary to continue using run-off plots available to validate the empirical relationship in the future.

REFERENCES

1. Fredericks, D.J., S.J. Perrens (1988). Estimating Erosion Using Cs-137: II. Estimating Rates of Soil Loss. *Sediment Budgets (Proceeding of the Porto Alegre Symp., Dec. 1988), IAHS Publ. no. 174, pp. 233-240.*
2. Hald A. (1952). Statistical Theory with Engineering Applications, *NXB John Wiley & Sons, Inc., 1952.*
3. Hai, P.S. et al. (2003). Report of the national project in the period of 2001-2002.
4. Quine, Timothy A. (1995). Estimation of Erosion Rates from Cs-137 Data: the Calibration Question. *In: "Sediment and Water Quality in River Catchments" (Edited by I.D.L. Foster, A.M. Gurnell and B.W. Webb), John Wiley & Sons Ltd., pp. 307-329.*
5. Walling D.E., T.A. Quine (1990). Calibration of Cs-137 Measurements to Provide Quantitative Erosion Rate Data. *Land Degradation & Rehabilitation, Vol. 2, pp. 161-175.*