WORKING MATERIAL

Assess the Effectiveness of Soil Conservation Techniques for Sustainable Watershed Management Using Fallout Radionuclides

Report of the Third Research Coordination Meeting of the FAO/IAEA Coordinated Research Project held in Vienna, Austria, 27-30 March 2006

Reproduced by the IAEA
Vienna, Austria, 2006

NOTE
The material in this document has been agreed by the participants and has not been edited by the IAEA. The views expressed remain the responsibility of the participants and do not necessarily reflect those of the government(s) of the designating Member State(s). In particular, neither the IAEA nor any other organization or body sponsoring this meeting can be held responsible for any material reproduced in the document.
EDITORIAL NOTE

In preparing this publication for press, staff of the IAEA have made up the pages from the original manuscripts as submitted by the authors. The views expressed do not necessarily reflect those of the governments of the nominating Members States or of the nominating organizations.

Throughout the text names of Member States are retained as they were when the text was compiled.

The use of particular designations of countries or territories does not imply any judgment by the publisher, the IAEA, as to the legal status of such countries or territories, of their authorities and institutions or of the delimitation of their boundaries.

The mention of names of specific companies or products (whether or not indicated as registered) does not imply any intention to infringe proprietary rights, nor should it be construed as an endorsement or recommendation on the part of the IAEA.

The authors are responsible for having obtained the necessary permission for the IAEA to reproduce, translate or use materials from sources already protected by copyrights.
# TABLE OF CONTENTS

1. INTRODUCTION
2. THE CO-ORDINATED RESEARCH PROJECT
3. THE THIRD CO-ORDINATED RESEARCH MEETING
   3.1 Work accomplished
   3.2 Results achieved in the implementation of the CRP
   3.3 Results of the Proficiency test for $^{137}$Cs and $^{210}$Pb
   3.4 Collecting the quantitative data on soil erosion rates and on efficiency of selected soil conservation measures
   3.5 Planning of publications
   3.6 Preparation of new CRP
4. CONCLUSIONS AND RECOMMENDATIONS
5. FOLLOW-UP

Annex 1 - List of participants to the third RCM
Annex 2 - Programme of the meeting
Annex 3 - Progress reports
Annex 4 - Publications related to the CRP
1. INTRODUCTION

Accelerated soil erosion and associated land degradation represent a major threat to sustainable intensification of agricultural production, conservation of natural resources and protection of the environment. There is an urgent need to obtain reliable quantitative data on the extent and rates of soil erosion and sedimentation, under varied agri-environmental and land use conditions, to provide a comprehensive assessment of the magnitude of these problems and underpin the selection of effective soil conservation measures. The quest for alternative techniques for assessing water soil erosion to complement classical methods has directed attention to the use of fallout radionuclides (FRNs) as tracers to obtain quantitative estimates of water soil erosion and deposition on agricultural landscapes.

\(^{137}\)Cs has been particularly used for soil erosion/sedimentation studies, as reflected by the important bibliography compiled by Ritchie and Ritchie (2006) who recorded some 3600 publications on the topic. More recently, the potential of \(^{210}\)Pb\textsubscript{ex} and \(^{7}\)Be for establishing rates and spatial extent of soil erosion/deposition was demonstrated. \(^{210}\)Pb\textsubscript{ex} measurements may quantify the soil movement rates that took place over a period of some 100 years. It also offers an alternative to \(^{137}\)Cs where the fallout of this isotope were too low for precise determinations. \(^{7}\)Be, with its short half-life of 53 days, offers a mean of assessing rates and spatial patterns of soil erosion and deposition, on a rainfall event basis, thus providing a way to evaluate the short-term impact of conservation practices or shifts in land use on soil movements.

In continuation of previous activities on this topic, The CRP D1.50.08 on “Assess the effectiveness of soil conservation measures for sustainable watershed management using fallout radionuclides” was initiated in 2003.

2. THE CO-ORDINATED RESEARCH PROJECT

The CRP on “Assess the effectiveness of soil conservation measures for sustainable watershed management using fallout radionuclides” from the Joint FAO/IAEA Division and the Physical and Chemistry Division is being implemented over a period of 5 years (2003-2007). The project document (revised) was included in the report of the first Research Co-ordination Meeting (RCM) (www-naweb.iaea.org/nafa/swmm/crp/fallout-crp-first.pdf).

The overall aim of the projects conducted under CRP D1.50.08 is to develop diagnostic tools for assessing soil erosion and sedimentation processes and effective soil conservation measures for sustainable watershed management. The specific research objectives are: i) to further develop FRN methodologies, with particular emphasis on the combined use of \(^{137}\)Cs, \(^{210}\)Pb\textsubscript{ex} and \(^{7}\)Be for
measuring soil erosion over several spatial and time scales, ii) to establish standardized protocols for the combined application of the above techniques, and iii) to utilise these techniques to assess the impact of short-term changes in land use practices and the effectiveness of specific soil conservation measures.

Twelve research contract holders: A. Bujan (Argentina), O. Bacchi (Brazil), P. Schuller (Chile), Y. Li (China PR), X. Zhang (China PR), M. Benmansour (Morocco), M. Rafiq Sheikh (Pakistan), W. Froehlich (Poland), N. Popa (Romania), V. Golosov (Russia), S. Haciyakupoglu (Turkey) and H. S. Phan (Vietnam); two technical contractors: D.E. Walling (UK) and A. Klik (Austria), and five agreement holders: P. Wallbrink (Australia), D. Lobb (Canada), Y. Onda (Japan), H. Liniger (Switzerland) and J. Ritchie (USA), are currently participating in the project. The participants are representing multi-disciplinary and inter-institutional teams involved in soil erosion/sedimentation research in their countries. Contact information for the participants is provided in Annex 1.

The first RCM of the CRP (www-naweb.iaea.org/nafa/swmn/crp/fallout-crp-first.pdf) was held on 19-23 May 2003, in Vienna, Austria. The second RCM was in Istanbul, Turkey, from 4 to 8 October 2004 (www-naweb.iaea.org/nafa/swmn/crp/fallout-crp-secondversion.pdf).

The activities carried out during the meeting, and their results, are described in this report. The programme of the meeting, the progress reports from the participants and a list of publications related to the CRP since 2003 are included in Annexes 2, 3 and 4 respectively.

3. THE THIRD CO-ORDINATED RESEARCH MEETING

The third RCM of the CRP was held from 27 to 30 March 2006, at IAEA’s Headquarters, in Vienna, Austria. All the participants to the CRP attended the meeting (Figure 2).

![Figure 2. Participants to the 3rd RCM](image)

The objectives of this meeting were to review the progresses achieved by the participants in the implementation of their respective objectives and work plan and to discuss and agree on the follow-up of experimental work until the fourth and final RCM.
3.1 Work accomplished

In the first three days of the meeting (27-29 March), all the participants reported on their work, the progress accomplished, the difficulties encountered and the implemented solutions to overcome these difficulties. These presentations provided an excellent opportunity for participants to share their experience and discuss their results with the other researchers. The progress reports of the participants are included in Annex 3.

A presentation was also made by a representative of the World Overview of Conservation Approaches and Technologies (WOCAT) on the tools available from WOCAT for the dissemination of information on soil and water resource conservation issues.

Three technical communications were also done in the meeting.

Mr Abdulghani Shakhashiro, of the Chemistry Unit of the Agency's Laboratories in Seibersdorf made a presentation on the first results of a proficiency test which was organized among the participating laboratories to the CRP. Mr Shakhashiro presented the objectives of this exercise, the procedure to prepare the samples for the test, the statistical parameters used to analyze the results provided by the participating laboratories. He also presented and discussed the results obtained for $^{137}$Cs and $^{210}$Pb determinations. The draft report of this proficiency test is available from the following address: www.iaea.org/programmes/aqcs/icpt/icpt_pb_cs.htm.

Mr Lionel Mabit and Ms Maitane Melero Urzainqui, of the Soil Science Unit of the Agency's Laboratories in Seibersdorf, made a presentation on the use of geostatistics to improve the spatialization of FRN punctual data and thus produce improved maps of FRN redistribution, which can be translated into maps of soil movements. The introduction of these techniques in FRN-based studies could also help to improve soil sampling strategies and the accuracy of soil movement budgets established from FRN spatial redistribution.

Finally, a presentation was done by Dr Walling, from Exeter University (UK), on the latest developments on new conversion models for the use of FRNs ($^{137}$Cs, $^{210}$Pbex and $^{7}$Be) for erosion/sedimentation studies and on the latest version new software that includes these models. Several models have been developed in recent years. They were grouped in an Excel-based Add-in, which make their use more user-friendly and takes advantage of the Windows environment. Dr Walling’s presentation also focused on how to select/establish local values for the input variables of the most commonly used conversion models.

During the final session of this third RCM, an assessment of the work accomplished so far and of the progresses achieved was presented and discussed with the participants.

3.2 Results achieved in the implementation of the CRP

At the first RCM, a set of methodological issues, related to the expected outputs of the CRP, had been identified. An assessment of the degree of achievement for these issues was done at the meeting. Table 1 reports the results of this evaluation.
Table 1. Assessment of the progress achieved on the different issues related to the CRP.

<table>
<thead>
<tr>
<th>Approaches</th>
<th>Achievements</th>
</tr>
</thead>
</table>
| Use of detailed measurements of $^{137}$Cs depth distributions and inventories to establish changes in soil redistribution rates over the period covered by bomb fallout in response to a major change in land management. The report presented by Schuller et al. usefully exemplified the potential of this approach. It should be noted however, that the change in land use/management has to date back to many years to apply successfully this approach | • The work of Schuller et al in Chile (papers in 2004 and 2006) that has investigated the impact of the change from conventional to no-till management has successfully developed this approach.  
• Conversion models were improved for expressing the erosion rates at undisturbed land.  
• In the Diffusion model, the concept of depth distribution of $^{137}$Cs was incorporated to conversion models in terms of diffusion model.  
• The Mass Balance model should include the diffusion coefficient to express the diffusion of Cs below the plowed layer caused by bioturbation and migration. |
| Combined use of Chernobyl and bomb $^{137}$Cs to investigate changes in soil redistribution rates associated with the post Chernobyl period. The utilization of this approach was likely to be limited primarily to those areas of Europe where bomb and Chernobyl fallout inventories were of similar magnitude. | • A great advance was achieved. Firstly there is a great advance in understanding the spatial distribution of Chernobyl fallout. There are maps of overall spatial distribution of Chernobyl fallout available.  
• The Chernobyl fallout was incorporated to conversion models to consider this input in erosion calculations.  
• The Chernobyl Cs is very valuable for dating the sediments in reservoirs and at alluvial planes. The value of Chernobyl fallout is now higher since there is more time elapsed from the Chernobyl fallout.  
• Work undertaken in Poland has successfully demonstrated the potential for using Chernobyl fallout to compare erosion and sediment redistribution rates pre-1986 and post 1986. |
| Time series measurements of $^{137}$Cs inventories aimed at quantifying changes in soil redistribution rates during specific periods, as proposed by Lobb. It was clear that the application of this approach would be constrained by the need for periods of sufficient duration between measurement campaigns to ensure that the change in inventory was greater than the uncertainty associated with the sampling and laboratory measurement procedures. Its application was therefore, likely to be restricted to areas with relatively high | • Several groups are intending to use this approach and have established baseline inventories for future comparison. However there are some concerns regarding the period of time required to produce a reliable estimate of redistribution rate. The reliability of the $^{137}$Cs analysis is a key constraint and the approach will probably only work in areas where erosion rates are quite high and inventories are relatively high. Some time interval between two samplings will need to be respected so that difference in inventories |
erosion rates. This need to undertake an initial measurement campaign to provide a baseline against which to compare future measurements meant that in general it was unlikely to be possible to obtain results from this approach during the duration of the CRP. However, there are a few detailed data sets in existence, which could be used to provide an existing baseline.

- Use of $^7$Be appears a promising approach for short-term comparisons and measurements. The successful use of $^7$Be measurements to quantify erosion rates during individual events or short periods had been reported by Wallbrink et al. and Walling. The approach clearly involved a number of complexities and would require careful application. In addition an appropriate experimental design would be required to ensure that meaningful results were obtained. For example, in determining the effectiveness of soil conservation measures it will be necessary to have a control area for comparison purposes.

- $^7$Be is currently being used in several participating countries e.g. Pakistan, Vietnam, Poland, UK, Chile, China, Morocco, to investigate short-term erosion rates and sediment transfers with promising results.

- In some environments further work is required to refine sampling frequencies and to provide further information on the behavior of fallout inputs.

- This method is good for undisturbed land, but it can be used also at arable land in periods when no plowing is done. The basic condition is that we need exact data on precipitations.

- Most groups are attempting to use at least 2 radionuclides in conjunction to obtain information on erosion history, to compare short-term and longer-term erosion rates and to provide information on erosion processes/mechanisms.

- They proved that conjunctive use is useful.

- The limiting factor is the interpretation of berilium and the difficulty to compare with

<table>
<thead>
<tr>
<th>Use of $^7$Be measurements. There was still a need to explore more fully the potential for using $^{210}$Pb measurements to estimate soil redistribution rates but potential was felt to exist for such work. The concerns raised for $^{137}$Cs in point 3 above also apply for $^{210}$Pb.</th>
<th>2$^{10}$Pb is being successfully used for documenting sedimentation rates and as a source fingerprint, but less success has been obtained with its use for assessing erosion rates.</th>
</tr>
</thead>
</table>
| 1. Problems/Issues that need to be solved for increased use for erosion studies:  
- measurement problems, i.e. lack of low energy detectors;  
- high radium 226 levels in granite soils;  
- freshly deposited $^{210}$Pb has bigger impact on inventory than older because of radioactive decay; it is not clear how to express this issue mathematically;  
- long land use history is needed, which is often not available; if it is missing, there is problem of interpretation. |  |
**Source fingerprinting procedures.** The studies reported by Wallbrink and Onda had clearly demonstrated the potential for using fingerprinting techniques for discriminating and identifying suspended sediment sources. Coupled with an appropriate experimental design this approach could afford a powerful tool for assessing changes in sediment sources resulting from the introduction of soil conservation measures. This would be valid in cases where the sites with conservation measures and the control area exhibit contrasting fingerprint characteristics.

- In some cases we are not sure whether the values can be considered as absolute values or rather as relative values.
- The fingerprinting procedure is a mature technique Japan, Pakistan, Vietnam, Poland, UK are successfully developing the use of sediment source fingerprinting techniques for which environmental radionuclides have proved very valuable as source discriminators.
- This work has involved suspended sediments, reservoir sediment deposits and depositional patterns and fine sediment accumulation in river gravels.
- Most success has been obtained in using radionuclides to distinguish source types (ie surface or subsurface sources) rather than spatial sources.

**Explore the potential to use FRNs to assess or predict losses of carbon, nutrients, pesticides, etc. from the watershed.**

- The use of FRNs to assess the Carbon is commonly used. Less contribution was made to nutrients and pesticides assessment.
- One group (UK) has successfully used FRNs to support investigation of P mobilization and delivery from watersheds

**Challenges:**

Global location and environmental conditions: the environmental conditions under which fallout radionuclides (FRNs) are currently being applied vary considerably – a variety of climates, soils, topographies and land uses. One of the most significant consequences is the variety of FRN deposition histories and current inventory levels (can be quite low or highly variable). Uncertainties still exist as to the inventories to be expected in some areas of the world (e.g. $^{137}$Cs inventories in tropical areas, excess $^{210}$Pb inventories in coastal areas with prevailing onshore winds, and high levels of supported $^{210}$Pb relative to excess $^{210}$Pb in areas such as Vietnam). In some circumstances low FRN levels can be dealt with by analysing samples for greater durations (requiring more detectors, longer studies, or alternate sampling strategies--bulking) or using more efficient detectors (requiring more capital investment), but practical limits may exist.

- Current work indicates that FRN approaches are generally applicable in most environments
- There should be more attention paid to investigate the role of geomorphic factor in radionuclide and soil redistribution.
- The environmental conditions are very complex and it will stay always a challenge.
- IAEA should encourage the member countries to incorporate the monitoring of $^7$Be and $^{210}$Pb to atmospheric and rain monitoring.
**Reference sites:** reliable reference sites can be difficult to establish due to the high degree of variability in local precipitation and the difficulty of identifying undisturbed stable sites. In this respect, it is essential that utmost care be taken by the researchers to establish the reference inventory of FRN in their study area. Finding suitable reference sites was a particular problem in mountain areas and areas with intensive cultivation. In studies covering large areas, the use of a single value for reference inventory may be inappropriate.

- Locating good reference sites continues to be a key problem in many studies, particularly those in mountainous and hilly areas. It is important to ensure that the reference site is fully representative of the study site e.g. altitude, aspect etc.
- The experience showed that for reference site the undisturbed land is not needed. The cultivated land is suitable when situated at flat landscape positions. In some areas it is even much better than undisturbed land. There is a lot of variability of undisturbed land (forests, grasslands) due to bioturbation.
- There should be agreed some standardised approach, at least the minimum number of samples, statistical evaluation, etc.
- In the case of $^7$Be it is possible to prepare a local reference site.

**Fate of FRNs:** there are still some uncertainties associated with the behaviour of fallout FRNs in the soil and related environments e.g. plant interception, preferential adsorption/desorption mechanisms within the soil, and plant uptake. These uncertainties require further elucidation. There is scope for exchange of information with other groups concerned with radioecology etc (role for IAEA).

- The behaviour of $^{137}$Cs was studied at Exeter University (UK) using the rain simulators.
- Experimental studies are providing useful information on the characteristics of initial depth distributions of fresh fallout but these need to be extended to a wider range of soils. A more comprehensive understanding of Be fallout is required.
- Some studies were done with aggregates, but more research on this topic should be done by special group of chemists and/or radioecologists.

**Use of $^7$Be:** many projects proposed to use $^7$Be. The use of $^7$Be involves considerably more complexity than the traditional $^{137}$Cs method (e.g. the need to monitor fallout inputs). Further work and testing of this approach was required before it could be widely adopted with confidence.

- The presented studies showed that it can be used if the methodological procedure is carefully followed. Monitoring of fallout inputs is necessary.
- In some studies more attention needs to be given to the timing of sampling in relation to fallout inputs and the interpretation of the results.

**Quality assurance / Quality control / Technical support:** Several issues were identified under this broad topic: (a) need for training to establish a minimum skill set in field procedures, analytical procedures and data interpretation; (b) access to standards for calibration; (c) sample exchange programmes (d) analytical support for some CRP members. The IAEA’s role has been developed as Recommendations for IAEA (in a separate section).

- The Proficiency Test recently organised by IAEA has proved very valuable. It should probably be repeated.
- Provision of accurate mixed standards would be of value for many CRP members. A $^7$Be standard would also be valuable.
New technologies: gamma spectrometry undergoes regular “advances” (new hardware such as in-situ detectors and software), which may or may not afford new opportunities for the use of FRN in soil erosion studies. These advances need to be rigorously tested to assess their value in our studies (possible role for IAEA). Clearly defined testing strategies are required.

- The new detection technologies are developed by nuclear physicists and usually are out of the scope of CRP.
- These new developments need to be monitored and integrated in the CRP.
- Improvements of sampling methods for depth distribution: a sampling device allowing to take very thin slices of soil, especially for $^7$Be and $^{210}$Pb sampling, was developed in UK. Detailed information can be obtained from D. Walling.
- In situ measurements should be further investigated, to establish their actual potential.
- The main advantages are:
  - The detector covers a large area (several square meters), integrating the local variability;
  - collecting time is relatively short (1 to 2 hours/spectrum); several spectra can be collected per day;
  - permits a screening of large areas in order to optimize the sampling strategy, (selecting the sampling points, number of samples etc).
- The main limitations are:
  - depth distribution of the radionuclide of interest is not known a priori;
  - amount of water in soil is not known (it affects the detection efficiency);
  - amount of vegetation over the field is not known (it affects the detection efficiency);
  - effective depth from which the net signal is coming depends on energy (low energy gamma rays comes from thin surface layer, high energy gamma rays come from thick layers of soil);
  - not applicable in some area, e.g. gullies, narrow terraces, etc;
  - not applicable in wet or very cold conditions.

Appropriate technologies: this issue was raised with regard to the analysis of $^{210}$Pb e.g. appropriate Ge detectors and the use of alpha spectrometry as an alternative method.

- Following the results of the Proficiency Test, standard protocol for $^{210}$Pb measurements should be prepared.

Conversion models: further development and validation of existing (and development of new) conversion models is required. Uncertainties associated with these models need to be better

- Great advance was done in development of conversion model. They are now at good level and they are providing reliable data.
- The development of models is close to final
understood (e.g. grain size effects). There is a need for standardization of methods, although with the development of new approaches the potential for standardisation was bound to reduce. Circulation of models and guidelines for their application within the CRP members was proposed.

<table>
<thead>
<tr>
<th>Source fingerprinting: although basic procedures were now well established, there was a need to explore the application of new fingerprint properties capable of providing improved discrimination between potential sources and to develop rigorous statistical/numerical procedures for establishing the relative importance of the sources considered. Again, an appropriate and rigorous experimental design was essential to ensure the generation of meaningful results.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Progress has been made in obtaining improved source discrimination. Both radionuclides and other geochemical properties are needed. Reliable mixing models are now available and progress has been made in incorporating particle size corrections.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Climatic changes (extreme events or storms): it was important that any attempt to quantify changes in soil redistribution rates resulting from changes in land management should be able to distinguish from those changes arising from climate change alone (frequency and intensity of extreme events or storms). Such considerations should be incorporated in the experimental design for a study.</th>
</tr>
</thead>
<tbody>
<tr>
<td>All scientists should consider the potential of climate change in their experimental design.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Closer linking of the two components of the CRP: although there were close links between the two components of the CRP, it was important that these links should be further strengthened to ensure that the results obtained from the CRP were applicable at both the field and watershed scales. This would also promote the integration of studies focusing on either on-site or off-site effects.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good integration of the two components has been achieved. Further attention could be given to sediment control strategies linked to sediment source tracing to parallel the links between erosion assessment and soil conservation techniques.</td>
</tr>
</tbody>
</table>

From the table it can be concluded that significant advances were achieved in the development of the FRN technique, in the application of the technique and on the development of conversion models and of the software to run these models.

FRNs are being used under a variety of agri-environmental conditions, demonstrating the applicability of the approach under contrasted conditions. Several types of land use and/or conservation practices are under investigation using FRN measurements. In some cases, actual measurements from erosion plots provide an opportunity to confirm the reliability of the FRN-based approach. In many studies, the conjunctive use of two, or even three isotopes provide new evidence on the potential of the FRN approaches to document erosion/deposition processes at different time scales. Finally, this CRP integrates both erosion (sediment source) and deposition (sediment sinks).
measurements, highlighting how FRNs can be used in an integrated approach considering sediment budgeting at the regional or watershed scale.

Some methodological and application aspects still require additional consideration and development. These aspects can be summarized as:

1. The use of sequential sampling of $^{137}$Cs could be an interesting approach. However, some uncertainties remain concerning the time interval that should separate two sampling. This interval should obviously be a function of the initial $^{137}$Cs inventory, the rate of erosion/deposition, the precision of the detection of $^{137}$Cs etc. Few participants can investigate these aspects in a near future.

2. $^{7}$Be shows promising possibilities to assess the impacts of changing land use/management practices. Some aspects of the technique need further development. It was also pointed out that care should be taken to measure the FRN in precipitation and report correctly the period covered by the measurements.

3. $^{210}$Pb can be most interesting in areas where the $^{137}$Cs inventories are low. However, the results of the Proficiency test indicate that there are some measurement problems and it was suggested that standardized protocol should be developed to help solve these problems. Documenting the management history of the study site over a period of some 100 years can also be a challenge.

4. Locating appropriate reference sites still remains a challenge under some environmental conditions. This step is important, being at the base of the use of FRN for erosion/sedimentation studies. Level grassland and even cultivated land could be suitable for that purpose, if it did not experienced erosion or deposition since the beginning of the fallout period. There is also a concern that a sufficient number of samples should be collected in the reference site to reduce the variability around the reference value.

3.3 Results of the Proficiency test for $^{137}$Cs and $^{210}$Pb

A proficiency test on $^{137}$Cs and $^{210}$Pb was organized and conducted by the Chemistry Unit of the IAEA's Laboratories located in Seibersdorf (Austria), following a request from the participants of the CRP. The soil test material was prepared according to a validated procedure by the Chemistry Unit staff.

A soil from China was used to prepare a spiked mineral matrix with $^{137}$Cs and $^{210}$Pb. This matrix of Chinese soil was characterised and the results have shown that the material is free from manmade radionuclides, except for $^{137}$Cs, which was present at $2.6 \pm 0.2$ Bq/kg and $^{210}$Pb at $48 \pm 1.5$ Bq/kg (based on dry weight; reference date: 2006-01-01).

This soil was used to prepare two sets of duplicated spiked samples. One set presented activity levels $\sim 10$ times that of the blank for $^{137}$Cs; and $\sim 5$ times for $^{210}$Pb. Another set had activity levels of $^{137}$Cs and $^{210}$Pb $\sim 2$ times that of the first set of spiked of samples. The target values of the matrix soil and the spiked samples are presented in table 2.

Some 90 test samples (reference materials) were distributed to the participating laboratories in January 2006. From the 18 initially registered laboratories, 14 reported to the IAEA their results. The analytical results of the participating laboratories were compared with the reference values assigned to the reference materials, and a rating system was applied.
Table 2. Target values of the matrix and spiked soil samples used for the proficiency test (adapted from Shakhashiro et al., 2006)

<table>
<thead>
<tr>
<th>Sample code</th>
<th>Target value (Bq kg$^{-1}$)$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$^{137}$Cs</td>
</tr>
<tr>
<td>03 (matrix soil)</td>
<td>$2.6 \pm 0.2^b$</td>
</tr>
<tr>
<td>01, 05</td>
<td>$20.3 \pm 0.5$</td>
</tr>
<tr>
<td>02, 04</td>
<td>$38.4 \pm 0.8$</td>
</tr>
</tbody>
</table>

$^a$ activities on a dry weight basis
$^b$ 1 σ uncertainty

In the case of $^{137}$Cs, the analytical results were satisfactory, while the $^{210}$Pb analysis indicated the need for corrective actions in the analysis process (Figure 3). The analytical uncertainties associated with the results were, in general, appropriate for the analytes and matrices considered in the current proficiency test.

Full technical details of the proficiency test set of materials are described in the report.

![Figure 3. Distribution of the results of the proficiency test (from Shakhashiro et al., 2006).](image)

The problems associated with $^{210}$Pb measurements do not preclude its use for erosion studies. These results are the reflection of the present situation. It should be remembered that a similar tested on for $^{137}$Cs measurements and done in the previous CRP had produced similar results. In this new test, 95% of the participating laboratories produced good results. Therefore, the present results for $^{210}$Pb highlight the need to pay attention to the measurement techniques for this FRN. As indicated before, a standardised measurement protocol should be developed by the IAEA. It is believed that such a protocol should help to improve the quality of measurements.

3.4 Collecting the quantitative data on soil erosion rates and on efficiency of selected soil conservation measures

Apart of the achievements related to development of methodology the CRP brought also large amount of quantitative data on soil erosion rates and efficiency of soil conservation. FRN techniques were used by CRP for estimation of soil erosion rates in wide geographical extent, covering countries distributed across the whole world (Table 3).
Table 3. Soil erosion rated measured by $^{137}$Cs and $^{210}$Pb methods in selected countries.

<table>
<thead>
<tr>
<th>Country</th>
<th>Erosion (t.ha$^{-1}.y^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>50 to 65.7</td>
</tr>
<tr>
<td>Brazil</td>
<td>100 to 120</td>
</tr>
<tr>
<td>China</td>
<td>6 to 110</td>
</tr>
<tr>
<td>Morocco</td>
<td>4 to 30</td>
</tr>
<tr>
<td>Romania</td>
<td>0.03 to 31.9</td>
</tr>
<tr>
<td>Russia</td>
<td>14.2 to 78.9</td>
</tr>
<tr>
<td>Turkey</td>
<td>0.92 to 17.1</td>
</tr>
<tr>
<td>USA</td>
<td>13.5</td>
</tr>
<tr>
<td>UK</td>
<td>0.4 to 9.1</td>
</tr>
<tr>
<td>Vietnam</td>
<td>4.5 to 27.8</td>
</tr>
</tbody>
</table>

The wide geographical variability of participating countries is reflected by great interval of measured erosion rates from (0.4 to 120 t.ha$^{-1}.y^{-1}$). The highest rates were measured in Brasil (120 t.ha$^{-1}.y^{-1}$) and in China (110 t.ha$^{-1}.y^{-1}$) and the lowest in UK (0.4 to 120 t.ha$^{-1}.y^{-1}$). The erosion rates depends on several key factors: kinetic energy of rain soil resistance against erosion (texture and OM contents), slope length and inclination, soil protection effect of crops and effect of conservation measures (if implemented). In Brazil they are determined by high energy rainfall typical for tropical climate. In China they are caused by twofold effect of poor soil stability and cultivation of land with steep slopes. The lowest values measured in UK are influenced by low energy of rainfall and more regular seasonal rainfall dynamics.

The soil conserving efficiency was assessed for several selected soil conservation measures, especially for non-till management (Tab 4). The tested soil conserving practices reduced erosion rates by $\geq 20\%-90\%$. The no-till practice reduced the erosion rates by 63% (from 16.0 to 6.0 t.ha$^{-1}.y^{-1}$) in Morocco, 25.8% (from 9.3 to 6.9 t.ha$^{-1}.y^{-1}$) and 61.5% (from 13.5 to 5.2 t.ha$^{-1}.y^{-1}$) in Chile. Grass strips reduced the erosion rate in Vietnam by 89.2% (from 32.4 to 3.5 t.ha$^{-1}.y^{-1}$). Terracing reduced the erosion rate by 54.8% (from 23 to 10.4 t.ha$^{-1}.y^{-1}$) and in Russia terracing combined with forest strips by 42.2% (from 46.9 to 27.1 t.ha$^{-1}.y^{-1}$). Apart of these major soil conserving practices also the impact of land use change and the soil conserving crop rotation were assessed. In Chile the change of land use from crop land to grassland reduced erosion rate by 78.7% (from 12.7 to 2.7 t.ha$^{-1}.y^{-1}$) in case of subsistence management and by 68.8% (from 9.3 to 2.9 t.ha$^{-1}.y^{-1}$) in case of commercial management. In China the reforestation of watershed damaged by timber over harvesting reduced the erosion rate by 81.1% (from 32.3 to 6.1 t.ha$^{-1}.y^{-1}$). The impact of crop rotation can be demonstrated by great differences of soil erosion rated under wide row crops such as maize and narrow row crops such as cereals. In Romania the erosion rate under maize was about 18 times higher than under wheat.

Table 4. The efficiency of soil conservation.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Country</th>
<th>Land management practice</th>
<th>Soil erosion (t.ha$^{-1}$)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Romania</td>
<td></td>
<td>Grassland (Bromus)</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Winter wheat</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soya been</td>
<td>7.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Beans</td>
<td>5.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maize</td>
<td>7.2</td>
<td></td>
</tr>
<tr>
<td>Non-till management</td>
<td>USA</td>
<td>Conventional tillage</td>
<td>9.3</td>
<td>25.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-till management</td>
<td>6.9</td>
<td></td>
</tr>
<tr>
<td>Measure</td>
<td>Country</td>
<td>Land management practice</td>
<td>Soil erosion (t.ha(^{-1}))</td>
<td>Efficiency (%)</td>
</tr>
<tr>
<td>---------</td>
<td>---------</td>
<td>--------------------------</td>
<td>-----------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>3</td>
<td>Morocco</td>
<td>Conventional tillage</td>
<td>16.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-till management</td>
<td>6.0</td>
<td>72.5</td>
</tr>
<tr>
<td>4</td>
<td>Chile</td>
<td>Conventional tillage</td>
<td>13.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-till management</td>
<td>5.2</td>
<td>61.5</td>
</tr>
<tr>
<td>5</td>
<td>Chile</td>
<td>Non-till management with</td>
<td>16.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>burning</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-till management without</td>
<td>13.0</td>
<td>19.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>burning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grass strips</td>
<td>6</td>
<td>Vietnam</td>
<td>Conventional tillage</td>
<td>32.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Grass strips</td>
<td>3.5</td>
</tr>
<tr>
<td>Terracing</td>
<td>7</td>
<td>Romania</td>
<td>Conventional management</td>
<td>23.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Terracing</td>
<td>10.4</td>
</tr>
<tr>
<td>8</td>
<td>Russia</td>
<td>Conventional tillage</td>
<td>46.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contour terraces and forest strips</td>
<td>27.1</td>
<td>42.2</td>
</tr>
<tr>
<td>Grassland</td>
<td>9</td>
<td>Chile</td>
<td>Cropland with subsistence</td>
<td>12.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>management</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grassland with subsistence</td>
<td>2.7</td>
<td>78.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>management</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cropland with commercial</td>
<td>9.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>management</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grassland with commercial</td>
<td>2.9</td>
<td>68.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>management</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reforestation</td>
<td>10</td>
<td>China</td>
<td>overharvesting of forest</td>
<td>32.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>restauration of forest</td>
<td>6.1</td>
<td>81.1</td>
</tr>
</tbody>
</table>

The data on soil erosion rates help to improve the picture on distribution of soil erosion over the world, to demonstrate its variability controlled by geographical conditions and thus they contribute to understanding the magnitude of land degradation caused by of soil erosion. The data on soil conservation efficiency are valuable for developing regional targeted soil conservation strategies adopted for different geographical conditions. However, it should always be kept in the mind that all these data represent results from specific study areas and are determined by local geographical conditions. They should not be interpreted or generalized mechanically in order to avoid misinterpretation.

After all both data on erosion rates and on efficiency of soil conservation are available for IAEA Member Countries participating in CRP and are ready to be used as background information for implementing of soil conservation policies.

3.5 Planning of publications

Considerable part of the results was already published by CRP participants in wide range of publications and disseminated at national and international level. In total 28 papers were published, 17 of that in international peer-reviewed journals and 11 in proceedings of international conferences and in national scientific journals. As the research is still on-going, next publications are in preparation or under expectation. The further publishing strategy will focus to three major issues: (1) preparation of IAEA TECDOC, (2) preparing of special issue of international scientific journal, (3) updating the handbook on FRN-techniques published as outcome of CRP D15005 in 2002.

The plan for publications summarizing the results of the CRP was discussed:
1) The overall results of the CRP will be published as an IAEA TECDOC. The participants agreed on the following points:

a) every participant to the CRP, either contract or agreement holder, is required to produce at least one paper for inclusion in the TECDOC;

b) the participants will send in advance a tentative title for each paper to the Technical Officer of the CRP, Mr Emil Fulajtar (E.Fulajtar@iaea.org), in order to make sure that all the aspects of the CRP are addressed. Mr Fulajtar will notify the participants of the date when these tentative titles should be submitted;

c) the participants will produce their manuscript(s) using the IAEA’s template for individual papers for TECDOCs. This template will be included on the CD-ROM collecting the material presented at the 3rd RCM. This CD-ROM will be produced in a short interval after the RCM and will be distributed to all the participants to the CRP;

d) the manuscripts will be submitted to the Technical Officer at the 4th and final RCM the latest. Participants were encouraged to send their documents before the RCM so the revision process can be initiated as soon as possible.

2) The major scientific results of CRP should be published also in special issue of a selected international scientific journal. Although the IAEA TECDOC will provide a comprehensive summarization of all CRP’s results, it is important also to disseminate the CRP’s outcomes towards the whole international scientific community. The best approach is through scientific papers assembled to special issue of scientific journal. This would help to present the CRP’s results at high scientific level and to increase its impact. The following conclusions were reached:

a) The TO contact different journals to ask about their interest for a special issue focused on the objectives of the CRP. For this step, he will consult with experienced agreement holders participating in CRP. The following journals were suggested:
   - Catena
   - Hydrological Processes
   - Geomorphology
   - Soil and Tillage research
   - Journal of Environmental Radioactivity
   - Journal of Radioecology
   - Journal of the Total Environment

b) If there is interest from some publishers to produce such special issue, the CRP participants will be informed about this possibility so they prepare their paper(s) for the special issue. It will be not obligatory for all participants to contribute but it would be highly recommended. The papers will be evaluated and selected on the basis of scientific quality.

c) The TO will inform participants on further steps and the timetable for preparation of the papers for the special issue.

3) Handbook for the assessment of soil erosion and sedimentation using environmental radionuclides, edited by F. Zapata, in 2002 should be updated. The discussion on this issue was resulting in the following conclusions:
a) There is a consensus on the need to proceed with this update, since significant new developments in the applications of FRNs have taken place since 2002 and that these developments should be integrated to the new edition of the Handbook.

b) It was discussed which issues should be added and which chapters should be reworked. The following issues were mentioned and should be integrated somehow to the new edition of the Handbook; some of them are included in the present edition and need an update, others are new issues:
   - origin of radionuclides
   - measurement of radionuclide deposition – e.g. for $^7$Be
   - selection of reference site
   - use of geostatistics for spatialization of data
   - new conversion models and software
   - quality assurance, precision of measurements
   - new equipments
   - validation of FRN data - interpretation
   - production of sediment budgets
   - fingerprinting approaches
   - relationship with other parameters - e.g. SOC
   - more emphasis on Pb and Be
   - limitations of each method
   - challenges and future developments

c) An editorial board, which will lead the updating process, was composed with the following persons:
   - E. Fulajtar
   - L. Mabit
   - D. Walling
   - M. Benmansour
   - P. Wallbrink
   - V. Golosov
   - D. Lobb

4) The TO informed all participants about the intention to build up a database of scientific publications of CRP participants related to results of CRP. This database should serve as tool for further dissemination of CRP results and radionuclide techniques in general. He asked the participants for assistance. The following tasks should be completed:

a) CRP participants should provide TO with electronic copies of their papers which contain some results related to CRP.

b) TO will compile the publication lists of each participant using the data from CRP progress reports and from bibliography published by Ritchie and Ritchie (2005). He will send these lists for update to each participant.

c) The publications collected from participants will be used for further dissemination of CRP’s results. First presentations based on these data will be probably presented at COST 634 International Conference: Remote Sensing and Spatial Analysis Tools for Erosion Processes. Samos Island, Greece, 26-28 May 2006 and at 1st International Sediment Initiative Conference in 27-30 November 2006 in Khartoum, Sudan.
3.6 Preparation of new CRP

The future development of the FRNs methods (spatialisation using geostatistics, initial fallout assessment), will be part of the objectives of new proposed study focussed to integrated approach of soil and water management at watershed scale.

Since the CRP D1.50.08 has reached the third RCM and that it will reach conclusion in the 3rd quarter of 2007, preparatory work for a new CRP has already been initiated by the technical staff of the Soil sub-programme. C. Bernard and M.L. Nguyen presented to the participants the main lines of this new CRP.

The intensification of agriculture has resulted in increased pressures on land, soil and water. Inappropriate land use and management practices can lead to different forms of soil degradation, among which erosion is a major one. Erosion results in a reduction of the soil productivity (on-farm impact) and environmental pollution through the loss of associated pollutants such as nutrients, pesticides, micro-organisms, etc.(off-farm impacts). In this way, soil and water degradation are closely interrelated problems which need to be addressed simultaneously.

The objective of the new CRP will thus be to develop tools to establish complete sediment budgets at the watershed scale. These budgets should make possible to:
   a) identify and localize the diverse sources of soil erosion and sediment production at the watershed scale; locate, in the watershed, the areas responsible for the highest unit loads of sediments
   b) assess soil erosion and sediment production from these sources;
   c) trace sediments along their transit through the watershed;
   d) identify areas and rates of deposition of sediments (between fields and the drainage network, within the drainage network);
   e) quantify the net output of sediments from the watershed;
   f) investigate the relationships between sediment production and transfer and the fate of associated pollutants.

Following such analysis, corrective actions can be prioritized, and the nature of these actions can be adapted to the characteristics of the source areas. In this way, the best and most cost-effective conservation practices can be identified, for a maximum efficiency in terms of soil conservation at the minimum cost.

From the work accomplished under the past CRP D1.50.05 CRP on “Assessment of soil erosion through the use of \(^{137}\)Cs and related techniques as a basis for soil conservation, sustainable production and environmental protection” and the on-going CRP D1.50.08 on “Assess the effectiveness of soil conservation measures for sustainable watershed management using fallout radionuclides”, fallout radionuclides have proven to be very efficient to localize and quantify soil erosion and sediment deposition at various spatial and time scales. They are also used very successfully in fingerprinting approaches, to identify the spatial origin of sediments.

It was felt by the participants of the meeting that the idea of targeting the future CRP on sediment production and transfer through watersheds responds to a high priority. It is acknowledged that sediments are probably the single most important pollutant originating from agricultural nonpoint sources. Sediments per se can degrade water habitats, by creating turbidity and sedimentation problems. Sediments are also a major carrier for several pollutants, including phosphorus, pesticides, heavy metals, microbiological agents, etc. It was mentioned that developing tools and approaches to route sediments from their point of production through watersheds and to their “final” destination would make a very significant contribution in view of improved resource conservation.
4. CONCLUSIONS AND RECOMMENDATIONS

The following recommendations were addressed to the IAEA:

1) Certified values for the material prepared for the Proficiency Test on $^{137}$Cs and $^{210}$Pb should be established by the IAEA. This way these samples could be used by the participants as standards.

2) Following the results of the Proficiency Test on $^{210}$Pb, a standardised protocol for measuring this isotope should be developed by the Seibersdorf laboratory.

3) Since the monitoring of FRN in precipitation is an important step in the use of $^{7}$Be and $^{210}$Pb for erosion/sedimentation studies, the IAEA should encourage the measurement of these two isotopes in precipitation in environmental monitoring programs.

4) IAEA should initiate a new CRP on the use of FRNs to assess complete sediment budgets at the watershed scale. Given the importance of soil erosion in the global soil degradation problem, and the importance of sediments as pollutant *per se* and as carrier of other agricultural pollutants, this new CRP would make a major contribution for improved soil and water conservation.

The following conclusions may be drawn from this third RCM:

1) The participants are conducting relevant experimental work, in keeping with the objectives of the CRP and their respective work plan. Reliable erosion/sedimentation rates under a variety of agri-environmental conditions are being generated.

2) The three major radioisotopes identified for this purpose ($^{137}$Cs, $^{210}$Pb$_{ex}$ and $^{7}$Be) are being used to assess erosion/deposition rates under varied conditions of climate, soil, slope, land use with/without conservation practices. Most researchers use more than one isotope. This way, erosion data on different time and spatial scales will be generated.

3) A detailed assessment of the degree of achievement of methodological issues, related to the expected outputs of the CRP, has been done. This assessment shows that significant advances were achieved under all the identified issues. Section 3.2 of the report provides detailed comments on these achievements.

5) The soil erosion rates measured in participating countries range from (0.4 to 120 t.ha$^{-1}$.y$^{-1}$). This large fluctuation is determined by great variability of geographical conditions and land management practices implemented. The highest values were measured in tropical countries such as Brasil (120 t.ha$^{-1}$.y$^{-1}$) and the lowest in temperate areas (0.4 to 9.1 t.ha$^{-1}$.y$^{-1}$).

6) The tested soil conserving practices reduced erosion rates by $\approx$ 20-90%. The no-till practice, to which several studies were focused, reduced the erosion rates by $\approx$ 25-70%.

7) Publications, to report the results of the CRP were discussed. It was agreed to produce a TECDOC with at least one contribution from each participant to the CRP. The possibility of producing a special issue in a scientific journal was raised. The idea will be further developed by the Technical Officer. The need to update the Handbook on the use of FRNs for erosion/sedimentation studies was acknowledge. Issues to be updated or introduced in the new version were discussed and an editorial board was formed.
8) A set of recommendation to the IAEA were expressed.

9) It was proposed and accepted that the fourth and final RCM of this CRP is held in October 2007, in Vienna, Austria.

5. FOLLOW-UP

After the meeting, a CD-Rom including the following elements was produced:
   1) the electronic version of all the presentations made at this third RCM;
   2) the report of the third RCM;
   3) the template for formatting documents to the TECDOC format;
   4) the preliminary report of the proficiency test on $^{137}$Cs and $^{210}$Pb;
   5) the complete files to run the add-in application with conversion models.

A copy of this CD-Rom was sent to each participant to the RCM.
Annex 1 - List of participants to the third RCM

Andreas Klik  
BOKU - University of Natural Resources and Applied  
Life Sciences Vienna  
Institute of Hydraulics and Rural Water Management  
Muthgasse 18  
A - 1190 Vienna  
Austria  
Phone: +43-1-36006-5472  
Fax: +43-1-36006-5499  
E-mail: andreas.klik@boku.ac.at

Desmond Eric Walling  
Department of Geography,  
School of Geography, Archaeology and Earth Resources  
University of Exeter  
Amory Building  
Rennes Drive  
Exeter, EX4 4RJ  
UK  
Phone: +44 1392 264345  
Fax: +44 1392 263342  
E-mail: d.e.walling@exeter.ac.uk

Alfonso Bujan  
Comision Nacional de Energia Atomica (C.N.E.A)  
Unidad de Actividad: Aplicaciones Tecnologicas y  
Agropecuarias  
Gerencia Centro Atómico Ezeiza  
Av. Libertador 8250 - (Cp:1429)  
Buenos Aires  
Argentina  
Phone: +54 (11) 6779-8316  
Fax: +54 (11) 6779-8322  
E-mail: bujan@cae.cnea.gov.ar

Osny Oliveira Santos Bacchi  
Centro de Energia Nuclear na Agricultura /  
Universidade de São Paulo (CENA/USP)  
Ave. Centenario 303  
Caixa Postal 96  
13400-970 Piracicaba (SP)  
Brazil  
Phone: +55-(019)34294600  
Fax: +55-(019)34294610  
E-mail: osny@cena.usp.br
Paulina Schuller  
Universidad Austral de Chile  
Facultad de Ciencias  
Instituto de Fisica  
Independencia 641  
Casilla 567, Valdivia  
Chile  
Phone: +56-63-221585  
Fax: +56-63-221585  
E-mail: porschulle@uach.cl

Yong Li  
Institute of Agricultural Environment and Sustainable Development  
Chinese Academy of Agricultural Sciences (CAAS)  
No. 12 Zhongguancun South Street, Beijing 100081  
P.R. China  
Phone: +86-10-68919584 ext 3606  
Fax: +86-10-62137112  
E-mail: yongli32@hotmail.com

Xinbao Zhang  
Institute of Mountain Hazards and Environment, Chinese Academy of Sciences and Ministry of Water Resources  
P.O. Box 417, Chengdu,  
Sichuan, 610041,  
P.R. China  
Phone: +86 2885229235  
Fax: +86 2885222258  
E-mail: zxbao@imde.ac.cn

Moncef Benmansour  
Centre National de l'Energie, des Sciences et des Techniques Nucléaires (CNESTEN)  
B.P 1382, RP 10001  
Rabat  
Morocco  
Phone: +212 37 81 97 50  
Fax: +212 37 80 32 77  
E-mail: benmansour@cnesten.org.ma

Muhammad Rafiq Sheikh  
Pakistan Atomic Energy Commission  
Pakistan Institute of Nuclear Science and Technology  
Radiation and Isotope Applications Div.  
P.O.Box 1114, Nilore  
Islamabad - Pakistan  
Phone: +92-51 9290261  
Fax: +92-51 9290275  
E-mail: manzoor@pinstech.org.pk
Wojciech Froehlich  
Institute of Geography and Spatial Organization  
Polish Academy of Sciences (PAN)  
HOMERKA Laboratory of Fluvial Processes  
Frycowa 113, P.O. Box 2  
33-335 Nawojowa  
Poland  
Phone: +48 18 4436791  
Fax: +48 18 4436791  
E-mail: watroehlich@pro.onet.pl

Nelu Popa  
Central Research Station  
For Soil Erosion Control  
BARLAD  
P.O. Box 1,  
PERIENI - 6400 Barlad,  
Romania  
Phone: +40 235 413770  
Fax: +40 235 412837  
E-mail: perieni@spectral.ro

Valentin Golosov  
Faculty of Geography  
Moscow State University  
Leninskie Gory, 119992,  
GSP-2 Moscow  
Russian Federation  
Phone: +7 095 9395044  
Fax: +7 095 9395044  
E-mail: river@river.geogr.msu.su

Sevilay Haciayakupoglu  
Istanbul Technical University  
Institute of Energy  
34469 Maslak, Istanbul,  
Turkey  
Phone: +90-212-2853887  
Fax: +90-212-2853884  
E-mail: haciayakup1@itu.edu.tr

Hai Son Phan  
Viet Nam Atomic Energy Commission  
Nuclear Research Institute  
Dept. for Nuclear Physics and Techniques  
01 Nguyen Tu Luc Street  
Dalat  
Viet Nam  
Phone: +84 63 829436  
Fax: +8463821107  
E-mail: phansh_nri@vnn.vn
Peter John Wallbrink  
CSIRO  
Division of Land and Water  
P.O. Box 1666  
Canberra ACT 2601  
Australia  
Phone: +61 2 6246 5700  
Fax: +61 2 6246 5800  
E-mail: Peter.Wallbrink@csiro.au

David Lobb  
University of Manitoba;  
Dept of Soil Science  
Winnipeg, R3T 2N2  
Canada  
Phone: +1 204 474 9319  
Fax: +1 204 474 7642  
E-mail: lobbd@ms.umanitoba.ca

Yuichi Onda  
University of Tsukuba  
Institute of Geoscience  
Tsukuba  
Ibaraki 305-8571  
Japan  
Phone: +81 298 53-4226  
Fax: +81 298 53-4226  
E-mail: onda@atm.geo.tsukuba.ac.jp

Gudrun Schwilch  
Centre for Development and Environment (CDE)  
Institute of Geography  
Bern University  
Steigerhubelstrasse 3  
CH-3008 Bern  
Switzerland  
Phone: +41 31 631 88 45/22  
Fax: +41 31 631 85 44  
E-mail: gudrun.schwilch@cde.unibe.ch

Jerry C. Ritchie  
USDA Agriculture Research Service  
Hydrology and Remote Sensing Laboratory  
BARC-West Bldg-007  
Beltsville, MD 20705  
USA  
Phone: +1-301-504-8717  
Fax: +1-301-504-8931  
E-mail: jritch@hydrolab.arsusda.gov
Observer
Romulus Margineanu
National Institute of RD for Physics and
Nuclear Engineering - "Horia Hulubei" IFIN-HH,
Dept. of Life and Environmental Physics
407 Atomistilor street, R-077125, Magurele, jud. Ilfov
Romania

IAEA Participants
Minh-Long Nguyen, Emil Fulajtar
Soil and Water Management and Crop Nutrition Section
Joint FAO/IAEA Programme on Nuclear Techniques in Food and Agriculture
A-1400 Vienna
Emails: M.Nguyen@iaea.org
E.Fulajtar@iaea.org

Gudni Hardarson, Lionel Mabit, Joseph Adu-Gyamfi, Maitane Melero Urzainqui, Adelaide Gondin
Da Fonseca
Soil Science Unit
FAO/IAEA Agriculture and Biotechnology Laboratory
A-2444 Seibersdorf, Austria
Emails: G.Hardarson@iaea.org
L.Mabit@iaea.org
J.Adu-Gyamfi@iaea.org
M.Melero.Urzainqui@iaea.org

Abdulghani Shkhashiro
Chemistry Unit
Physics, Chemistry and Instrumentation Laboratory
A-2444 Seibersdorf, Austria
Email: A.Shkhashiro@iaea.org

Scientific Secretary
Claude Bernard
Soil and Water Management & Crop Nutrition Section
Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture
P.O. Box 100
Wagramer Strasse 5
A-1400 Vienna
Austria
Phone: +43 1-2600 21693
Fax: +43 1-2600 7
Email: C.Bernard@iaea.org
Annex 2 - Programme of the meeting

Third Research Co-ordination Meeting of the Co-ordinated Research Project D1.50.08

“Assess the effectiveness of soil conservation techniques for sustainable watershed management using fallout radionuclides”

27 to 30 March 2006

Vienna International Centre
Meeting Room F0513

P R O G R A M M E

**27 March 2006**

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
<th>Presenter</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:00</td>
<td>Welcome</td>
<td>L. Nguyen – IAEA, Head SWMCN Section</td>
<td>Welcome address</td>
</tr>
<tr>
<td>09:15</td>
<td>Opening</td>
<td>C. Bernard – IAEA</td>
<td>Opening remarks and overview of the meeting</td>
</tr>
<tr>
<td>09:45</td>
<td>Session 1 – Progress reports</td>
<td>O. Bacchi – Brazil</td>
<td>Use of $^{137}$Cs fallout redistribution analysis for the determination of optimal width of riparian forests for erosion control</td>
</tr>
<tr>
<td>10:30</td>
<td>Break</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11:00</td>
<td>Session 1 – Progress reports</td>
<td>P. Schuller – Chile</td>
<td>Use of fallout radionuclides to estimate soil redistribution rates in south-central Chile</td>
</tr>
<tr>
<td>11:45</td>
<td>Session 1 – Progress reports</td>
<td>A. Bujan – Argentina</td>
<td>Soil erosion and sedimentation study by $^{137}$Cs, $^{210}$Pbex and $^7$Be techniques in Pampa Ondulada region, Argentina</td>
</tr>
<tr>
<td>12:30</td>
<td>Lunch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14:00</td>
<td>Session 2 – Progress reports</td>
<td>V. Golosov – Russia</td>
<td>Assessment of soil losses within conservation agrolandscapes of Central Russia using fallout radionuclides and other methods</td>
</tr>
<tr>
<td>14:45</td>
<td>Session 2 – Progress reports</td>
<td>N. Popa – Romania</td>
<td>Evaluating the effectiveness of soil conservation measures on sloping cropland in Romania using fallout radionuclides</td>
</tr>
<tr>
<td>15:30</td>
<td>Break</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16:00</td>
<td>Session 2 – Progress reports</td>
<td>W. Froehlich – Poland</td>
<td>The use of $^{137}$Cs, $^{210}$Pbex and $^7$Be for investigations of soil erosion to assessment the impact of land use changes and the effectiveness of soil conservation in the Polish Carpathians</td>
</tr>
<tr>
<td>16:45</td>
<td>Discussion on papers of the day</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- 24 -
**Session 3 – Progress reports**

*Chair: X. Zhang – China*

08:30 - 09:15 D. Walling – UK
*Development, validation and documentation of improved conversion models for use in deriving estimates of soil redistribution rates from $^{137}$Cs, excess $^{210}$Pb and $^7$Be measurements*

09:15 - 10:00 A. Klik – Austria
*Soil quality evaluation of agricultural soils under conventional, conservation and no tillage systems using the concept of a Soil Quality Index (SQI)*

10:00 - 10:30 Break

10:30 - 11:15 S. Haciyakupoglu – Turkey
*The use of $^{137}$Cs, $^{210}$Pb and $^7$Be measurements for assessing soil erosion and sedimentation in the Riva Basin (Istanbul, NW Turkey)*

11:15 - 12:00 M. Benmansour – Morocco
*Use of radionuclides to investigate soil erosion in agricultural fields and to evaluate soil conservation measures in Morocco*

12:00 - 13:30 Lunch

**Session 4 – Progress reports**

*Chair: V. Golosov – Russia*

13:30 - 14:15 J. Ritchie – USA
*Measuring redistribution of soils and soil organic carbon on small research watersheds with Cesium-137*

14:15 - 15:00 D. Lobb – Canada
*Impacts of soil erosion on soil biophysical properties and processes with agricultural landscapes: assessment of soil erosion process as affected by land management practices using $^{137}$Cs and $^{210}$Pb distributions and dynamics*

15:00 - 15:30 Break

15:30 - 16:15 Y. Onda – Japan
*Fingerprinting the sources of fluvial sediment using fallout radionuclides in forested watershed in Japan*

16:15 - 17:00 Y. Li – China
*Using fallout radionuclides to assess effectiveness of soil conservation measures in reducing soil erosion and improving soil quality in China*

17:00 - 17:30 Discussion on papers of the day
29 March 2006

Session 5 – Progress reports
Chair: O. Bacchi – Brazil

08:30 - 09:15 X. Zhang – China
Investigation of soil erosion and sedimentation by using nuclide tracers of $^{137}$Cs, $^{210}$Pb, and $^7$Be in the upper Yangtze River basin of China

09:15 - 10:00 M. Sheikh – Pakistan
Field investigations for sediment fingerprinting and assessment of erosion and sedimentation remediation strategies using nuclear techniques

10:00 - 10:30 Break

10:30 - 11:15 H. Phan – Vietnam
Assessment of soil erosion rates and the effectiveness of soil conservation measures using fallout radionuclides and plots

11:15 - 12:00 P. Wallbrink – Australia
Using tracers to assist in the planning and design of erosion mitigation strategies for dam sustainability

12:00 - 13:30 Lunch

Session 6 – Technical issues related to the use of FRNs
Chair: P. Wallbrink – Australia

13:30 - 14:15 L. Mabit – IAEA
Study of $^{137}$Cs redistribution at the field scale using geostatistics

14:15 - 15:00 A. Shakhashiro – IAEA
Data evaluation of the proficiency test on the determination of $^{137}$Cs and $^{210}$Pb in soil, within the frame of IAEA CRP DI.50.08

15:00 - 15:30 Break

15:30 - 17:30 D. Walling – UK
Use of conversion models

17:30 - 18:15 G. Schwilch – Switzerland
World Overview of Conservation Approaches and Technologies

30 March 2006

Session 7 – Implementation of the CRP
Chair: C. Bernard – IAEA

08:30 10:00 Discussion on implementation of the CRP

10:00 - 10:30 Break

10:30 - 11:30 Discussion on implementation of the CRP

11:30 - 12:00 Planning for publications

12:30 - 13:30 Lunch

13:30 - 14:00 Update of handbook on the use of FRNs for erosion studies

14:00 - 14:30 New CRP

14:30 - 15:30 Conclusions and recommendations of the meeting

15:30 - End of the meeting
Annex 3 - Progress reports

Use of $^{137}$Cs fallout redistribution analysis for the determination of optimal width of riparian forests for erosion control

Osnys Bacchi
Centro de Energia Nuclear na Agricultura – Universidade de São Paulo
Piracicaba., SP. Brazil

Contract number BRA/12320

Objectives of the project
The purpose of this project is to evaluate quantitatively the efficiency and suitability of riparian forests (RF) as part of the erosion control measures at the watershed scale and to predict the optimal width of riparian forests, considering only their soil conservation function in the watershed. The assessment will be made through the combination of a GIS supported soil erosion prediction model using WEPP (USDA-Water Erosion Prediction Project) which allows expeditious large scale surveys, validated and calibrated by the $^{137}$Cs technique. The $^{137}$Cs technique is being applied to quantify the erosion and sediment deposition rates in sugarcane cultivated areas and in selected riparian forests. These measures are being compared with estimates made by the WEPP prediction model.

Theoretical approach
The conceptual framework for the definition of the optimal width of riparian forests (RF) for sediment trapping was proposed by Sparovek et al. (2001). The hypothesis is that the amount of sediment retained in a RF is defined mainly as a function of its width ($W_f$). Increasing $W_f$ extends the relative area where sediments can be trapped due to runoff kinetic energy reduction, high surface roughness as a result of permanent residue cover, and high soil water infiltration. Considering a constant sediment inflow, an increase of $W_f$ would result in continuously increasing amounts of trapped sediments. At the same time, due to the much lower erosion rates in forests as compared to agroecosystems, the increase of $W_f$ also decreases the mean sediment generation, reducing the amount of sediments available to be trapped. Thus, the increase of $W_f$ will increase sediment deposition (extension of trapping area) but decrease erosion (less sediment to be trapped). A narrow RF strip results in low sediment deposition ($S_d$) due to the absence of sufficient trapping area and intense sediment flow into the RF. If the RF is extremely wide, enough trapping area will be present, but sediment generation is reduced as a result of the mean soil erosion reduction, again yielding low $S_d$ values.

It is assumed that the relation between $W_f$ and the $S_d$ can be well described by a quadratic function (equation 1) and has a maximum value ($dS_d/dW_f = 0$) expressed by equation 2:

$$S_d = a W_f^2 + b W_f + c$$

$$W_{max} = -b / 2a$$

Where: $a$, $b$, $c$ are regression constants.

In this project, $S_d$ is being evaluated simultaneously by both WEPP and $^{137}$Cs methods, in at least four different conditions. The results will be compared to validate the proposed above theoretical approach as well as to check and adjust some WEPP model parameters.
The study sites
Four selected riparian forests are being studied where sampling transects were established and all field work was already performed. Two transects are in reforested riparian areas of Iracema Sugar Mill (22°35' S; 47°33' W) and the other two in natural riparian forests, one located in the same sugar mill and the other at Moema Sugar Mill (20°14’ N; 49°21W). Near the two natural riparian forests, two sugarcane areas very close to the forest transects and positioned at similar topographic conditions were also selected in order to compare the sediment redistributions inside and outside the forest. In these areas parallel sampling transects in relation to the forest transects were also established. Figure 1 shows the three selected areas and respective positions of the transects.

![Figure 1: Selected riparian forests and position of established sampling transects. a) reforested riparian area - Iracema Sugar Mill; b) natural riparian forest – Iracema Sugar Mill and c) natural riparian forest area – Moema Sugar Mill](image)

Research carried out during the period
According to the last report; the following activities were planed to be developed in this period:

- Sampling complementation and $^{137}$Cs analysis up and down-slope in the transect B (figure 1b);
- Recalculation of sugarcane crop sediment delivery and sediment deposition in the riparian forest;
- Phytosociological survey and analysis of the reforested area;
- Morphological and micromorphological analysis of a more extended forest transect;
- Analysis of samples and data interpretation of other selected riparian forests.

All the previewed activities were fully completed for one natural riparian forest of Iracema Sugar Mill (transects A and B - figures 1b) and the two transects on the riparian reforested area (transects...
E and F – figure 1a). It was not possible to finish sample analysis and data interpretation for the two transects (C and D) of the last selected natural riparian forest (figure 1a) of the Moema Sugar Mill. However, most of the sample analysis and field work has been done. The following main activities and results were achieved in the period.

**Complementary topographical studies**

Some of the differences between the first observed results on erosion and sedimentation rates estimated by the WEPP and \(^{137}\)Cs methods, presented in the second report, were attributed to the lack of more confident input parameters used in the WEPP model, mainly those related to the shape of the studied slope. Initially the topographic profile of the transect B was determined by the available 1:10.000 topographic chart. Since WEPP model is very sensitive to relief variations, it was decided to take more detailed slope topographic profiles of all transects using a Total Station TPS equipment.

**Morphological and micro-morphological analysis**

The quantification of the total porosity, shape and size distribution of pores was performed in all horizons and pits of the natural riparian forest transects B and C (Iracema and Moema Sugar Mills). High contrasts of these parameters were observed between the sediments and the original soil horizons. Differences were also observed between the new A horizons formed from the sediment and the sediment in both sequences.

As shown in the second report, the sediment layer becomes thinner as it enters the riparian forest, being thicker close to the edge of the forest and thinner around 20m from the edge, in both study areas. This densification phenomenon is more pronounced where the sediment is thicker, closer to the edge of the forest. This shows that most of the filtering effect of the riparian forest, at least for physical interception of sediments, occurs in the first meters from the edge.

**New erosion and deposition rates estimated by WEPP and \(^{137}\)Cs models**

After the complementary topographic surveys of the transects, described previously, and complementary sampling for \(^{137}\)Cs analysis in the transects B and C, new calculations of soil erosion and deposition were made for the transects A, B, E and F using the WEPP and \(^{137}\)Cs models. It was observed a lower discrepancy of results between both methods than observed before. As an example, figure 2 shows the new estimated values for the transect B.

![Erosion and deposition rates estimated by WEPP and \(^{137}\)Cs models](image)

Figure 2- Erosion and deposition rates estimated by WEPP and \(^{137}\)Cs models - segment of transect B
The main differences between WEPP and \(^{137}\)Cs estimates were observed in the riparian forest segment of the transect. The \(^{137}\)Cs technique did not indicate the same abrupt and large deposition of sediments in the first meters of the forest segment and showed a trend of increasing sediment deposition rates with the increase of the forest width, on the contrary as estimated by WEPP. The complementary \(^{137}\)Cs analysis as well as the detailed slope topographic profile survey of the transect B and new adjusted WEPP input parameter did not change the general tendencies and main results presented before in the second report.

A better agreement of estimated values was obtained for the transects E and F of the reforested area as shown in figure 3.

![Figure 3: Erosion and deposition rates estimated by WEPP and \(^{137}\)Cs models – transect E. (\(^{137}\)Cs estimates corrected by the age of the reforested vegetation).](image)

**General discussion of the main results**

As mentioned before one of the most important objectives of our project is to use the \(^{137}\)Cs technique and micro-morphological analysis to validate and calibrate the WEPP model, which would allow expeditious large scale surveys and could be an easy and useful tool for estimations of optimal width of riparian forests for sediment trapping as proposed by Sparovek et al. (2001). Despite of some known restrictions, the \(^{137}\)Cs technique has proved to estimate confident results of erosion and deposition rates in a large variety of environmental conditions in different countries. Even in the southern hemisphere, despite of the very low \(^{137}\)Cs activity found in the soil, the isotopic technique yielded confident results, comparable to those obtained by the traditional direct measurements on long term runoff plots (Correchel et al. 2006).

It is therefore expected that the results of this project can effectively produce basic supports for the improvement of input parameters and the validation of the WEPP model for the proposed objectives.

A general analysis of the results obtained up to now allows presenting some conclusions and some new actions in order to achieve the original objectives.

Some important questions regarding the differences of erosion and deposition rates estimated by both models still need to be investigated such as the possibility of a selective transport of fine sediments inside the forest and in situ determination and adjustment of other WEPP input parameters. It is important to emphasize that both models were not originally developed to be used in soils covered by forest and therefore the adjustment and adaptation of input parameters is essential for its validation in this situation.

Although WEPP and \(^{137}\)Cs techniques estimated similar trends of erosion and deposition along the transects and values of the same order of magnitude, WEPP model estimated lower erosion rates for

- 30 -
almost all points situated in the sugarcane crop transects. Considering that in our project the WEPP model produce estimates for the points situated just on the slope lines of the transects and that the $^{137}$Cs inventories of each point of the transect was an average of five profiles taken from perpendicular lines of the transect, some of the observed differences can be attributed to this fact. Some improvement in the results can be achieved running the WEPP model for different parallel slope lines of the same transects and taking the averages of such values for the comparisons with the $^{137}$Cs model estimates.

Other improvements on WEPP estimates can also be tried by using more adapted input parameters related to climate, soil management and soil characteristics. Many of the input parameters can be improved for each specific local condition by their in situ measurement.

The most divergent results estimated by both models are for the natural riparian forest segment of the transect B. The models estimates are not agreeing both in the deposition rates and in the trend of the deposition along the transect. According to the $^{137}$Cs results there is a trend of increase in the deposition rates down to 110m along the forest transect while the WEPP results shows a decrease in the deposition rate in the same range. Since the morphological analysis of soil profiles in the transect are shown the same trend indicated by WEPP, it will be important to investigate more details about $^{137}$Cs redistribution inside the forest. It is possible that the new results that are being processed for the transects C and D can give some answers for this question. More detailed investigations about selective transport of fine particles inside the forest need to be carried on.

**Main activities for the next period**

Complementary analysis ($^{137}$C, WEPP, micromorfology, Phytosociological) and data interpretation of transects C and D (Moema Sugar Mill) – the same work already done and reported for the transects A, B, E and F (Iracema Sugar Mill) will be completed for the two remained transects originally proposed for the study.

Selection, and detailed study of extra transects in one agricultural area of Goiatuba – Goiás (18° 02’ S; 49° 37’W). Transects in three situations will be selected: pasture, annual crop rotation (normal tillage) and annual crop rotation in direct seeding (zero tillage). In the three situations the lower part of the transects would also be crossing riparian forests. Although these study areas belong to another investigation project about soil management effects on soil erosion, the inclusion of these new situations in the present project would generate more interesting data which can help the interpretation, calibration of parameters and validation of both models.

For the transects where the $^{137}$Cs inventories are showing increasing trends along the forest, investigations about selective transport of fine particles will be performed. More detailed sediment textural analysis and micromorfoligical studies will be carried out.

In order to help better understanding the sediment redistribution inside the forest and the contribution of the upland delivered sugarcane crop sediment, some complementary investigation will be conducted using the $^{13}C/^{12}C$ ratio in the riparian forest soil organic matter. The sediments and organic matter delivered by the sugarcane crop, which is a C4 plant, are probably changing the $^{13}C/^{12}C$ ratio of the forest organic matter along the transect, mainly in the range of forest width where the deposition of the upland sediment is more significant.

**Determination of optimal width of riparian forests for the studied watershed**. After the validation and adjustments of the WEPP model for each watershed, the next step to achieve the main objective of the project will be the application of the procedure proposed by Sparovek et al. (2001) (item 2) in each watershed and to present some estimates for the optimal width of riparian forests for each situation. Some simulations of the procedure are already being done in the three studied watersheds. For this, all the needed spatial information (relief, soil type, soil management, climate) were already processed by GIS (TNT Mips, version 6.8).

**References**

Correchel, V., Bacchi, O.O.S., De Maria, I.C., Reichardt, K. & Dechen, S.C.F. Primeira aproximação de um estudo sobre as atividades de $^{137}$Cs em áreas de referência (Compact disc).


Sparovek, G.; Ranieri, S. B. L.; Gassner, A.; De Maria, I. C.; Schnug, E.; Santos, R. F.; Joubert, “A conceptual framework for the definitions for the optimal width of riparian forests”.


Use of fallout radionuclides to estimate soil redistribution rates in south-central Chile

Paulina Schuller
Universidad Austral de Chile, Facultad de Ciencias
Instituto de Física, Casilla 567
Valdivia, Chile

Contract number: CHI-12321

Use of a simplified $^{137}$Cs method to evaluate the change in soil redistribution rates associated with the shift from conventional to reduced tillage system

The main objective of this research was to assess the efficiency of reduced tillage as compared to traditional tillage system in reducing soil erosion using a simplified $^{137}$Cs approach developed previously (Schuller et al., 2004). The results obtained for the study field located at Buenos Aires farm, in south-central Chile, showed that the implementation of no-till practice, including crop residue management, reduced the net erosion rate by about 89% and therefore significantly decreased soil and nutrient loss. The reduced soil loss has important benefits for the sustainable use of the soil resource and the reduced sediment delivery ratio will result in a reduction in sediment transfer to the local watercourses. These changes clearly demonstrate the potential environmental benefits of a shift from conventional tillage to a no-till system.

The use of conversion models to estimate the rate of soil redistribution during the conventional tillage period necessitates specifying a value for the parameter representing the relaxation mass depth ($h_o$, Bq m$^{-2}$) of the initial distribution of the fallout $^{137}$Cs in the soil profile, prior to the incorporation into the plough layer by tillage. The experimentally established value of this parameter, $h_o = 6.2$ kg m$^{-2}$, is representative of local conditions (Araucano series Ultisol and intense rainfall during winter).

The results and conclusions obtained in the above described research are summarized in the manuscript:

Use of $^7$Be to estimate short-term soil redistribution associated with high erosive events
Use of $^7$Be to document soil redistribution following forest harvest operations

Rapid and reliable methods for documenting soil erosion associated with forest harvest operations are needed to support the development of best management practices for soil and water conservation. To address this need, the potential for using $^7$Be measurements to estimate patterns and amounts of soil redistribution associated with individual post-harvest events was explored. The $^7$Be technique, which was originally developed for use on agricultural land, was employed to estimate soil redistribution associated with a period of heavy rainfall within a harvested forest area located in the Lake Region of Chile (39°44´7´´S, 73°10´39´´W; 22% slope; mean annual rainfall 2300 mm yr$^{-1}$). The results provided by the $^7$Be technique were validated against direct measurements of soil gain or loss during the same period obtained using erosion pins. The information produced by the two approaches was very similar. The results of this study, which demonstrate the potential for using $^7$Be measurements to document event-based erosion rates in recently harvested forest areas, are summarized in the manuscript:
Use of $^{7}$Be for estimating soil redistribution associated with a period of very intense rainfall at a site managed with reduced tillage and burning of crop residues

For many years, the site located at Buenos Aires farm, selected by our research group for studying the change in soil redistribution rates associated with the shift from conventional tillage to reduced tillage, was managed with reduced till and no burning of crop residues. However, after harvesting in 2005 and shortly before the rainy season began, the crop residues remaining on the field were burnt. The $^{7}$Be method (Walling et al., 1999) was applied at this field to investigate whether the burning of harvest residues caused a change in the soil redistribution rates established for the period prior to the introduction of burning using $^{137}$Cs measurements (Schuller et al., 2004). The experiment also provided an opportunity to test the application of the $^{7}$Be method for estimating soil redistribution rates associated with high magnitude events in this environment.

After a period with an unusually high amount of precipitation during May 2005 (401 mm month$^{-1}$ in an area characterised by a mean annual precipitation of about 1100 mm $^{-1}$), which was preceded by a prolonged period of low precipitation (Fig. 1), the field was sampled for $^{7}$Be measurements. Eighteen cylindrical bulk cores were collected from a flat area located at the top of the field, in order to determine by sectioning the cores at the Laboratory the $^{7}$Be reference inventory and the relaxation mass depth. Additionally, bulk soil cores were collected at 15 m intervals along three slope transects spaced 15 m apart, using a corer 11 cm in diameter and 4 cm in length, to determine the soil redistribution along the slope based on the $^{7}$Be content of the samples.

Fig. 1. The precipitation events during May 2005 affecting the bare soil associated with reduced tillage and burning of crop residues practice at Buenos Aires farm.
Fig. 2 (a) depicts the depth distribution of the mean $^7$Be mass activity density, $C(x)$, at the undisturbed reference site and Fig. 2 (b) shows the depth distribution of the mean $^7$Be areal activity density, $A(x)$. The depth distributions are based on mass depth, $x$. The relaxation mass depth, estimated using a linear regression between $\text{Ln}[A(x)]$ and $x$ is $3.2 \pm 0.2$ kg m$^{-2}$ ($r = 0.995^{**}$). The calculated functions describing the downward decrease of the $^7$Be mass activity density [$C(x) = 158 e^{-x/3.2}$] and the areal activity density [$A(x) = 511 e^{-x/3.2}$] at the reference area are also represented by the continuous curves shown on Fig. 2 (a) and (b), respectively.

The total areal activity density calculated using the linear regression is $A_{\text{ref},c} = 511 \pm 60$ Bq m$^{-2}$ and the total areal activity density measured at the reference area is $A_{\text{ref},m} = 465 \pm 43$ Bq m$^{-2}$. Both values are consistent considering their uncertainty intervals. Nevertheless, if the areal activity density contained in the tail of the calculated $^7$Be downward distribution (where the $^7$Be concentration was below the detection limit, i.e. below 10 kg m$^{-2}$) is subtracted from the total calculated $A_{\text{ref},c} = 511$ Bq m$^{-2}$, the result obtained is in very close agreement with the measured $A_{\text{ref},m} = 465 \pm 43$ Bq m$^{-2}$:

$$511 - \int_0^\infty 158 e^{-x/3.2} dx = 511 - 23 = 488 \text{ Bq m}^{-2}$$

Based on these calculations, a reference areal activity of 488 Bq m$^{-2}$ and a relaxation mass depth of 3.2 kg m$^{-2}$ were used for applying the $^7$Be model.

Table 1. Comparison of the soil redistribution rates at the study site associated with the period of intense rainfall in May 2005 and management under reduced tillage and burning of harvest residues, estimated using $^7$Be measurements, with previous estimates of soil redistribution under reduced tillage without burning of crop residues practice based on $^{137}$Cs measurements (Schuller et al. 2006)

<table>
<thead>
<tr>
<th>Zone</th>
<th>Reduced till without burning of crop residues (16 y-annual mean)</th>
<th>Reduced till with burning of crop residues (event related)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Eroding zone</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean erosion (kg m$^{-2}$)</td>
<td>1.3±0.2</td>
<td>1.6±0.3</td>
</tr>
<tr>
<td>Fraction of total area (%)</td>
<td>57</td>
<td>75</td>
</tr>
<tr>
<td><strong>Aggrading zone</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean sedimentation (kg m$^{-2}$)</td>
<td>1.4±0.2</td>
<td>0.8±0.3</td>
</tr>
<tr>
<td>Fraction of total area (%)</td>
<td>43</td>
<td>21</td>
</tr>
<tr>
<td><strong>Total area</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net erosion (kg m$^{-2}$)</td>
<td>0.1±0.2</td>
<td>1.0±0.3</td>
</tr>
<tr>
<td>Sediment delivery ratio (%)</td>
<td>16</td>
<td>86</td>
</tr>
</tbody>
</table>
Surprisingly high rates of net soil loss were estimated for the period of intense rainfall using the $^7$Be measurements, as compared to the soil redistribution rates documented by Schuller et al. (2006) for the previous 16-y period under reduced tillage without burning of crop residues (Table 1). According to Kaste et al. (2002) $^7$Be$^{+2}$ ions reaching the soil surface are extremely competitive for cation exchange sites because of their high charge density, and they are therefore rapidly sequestered by exchange sites. After burning of the crop residues, the upper 2 mm of the soil was characterised by a bulk density 60% higher than the soil below. The reduction of the pore space in the surface soil layer could act as a surface seal reducing the infiltration of water into the soil and promoting the mobilization and downslope transport of ash containing $^7$Be. The burning may also have promoted hydrophobic conditions at the soil surface, thereby further increasing surface runoff and erosion. Changes in the bulk density distribution and the infiltration capacity of the soil before and after burning of the crop residues are being investigated, to provide a better understanding of the high rates of soil redistribution associated with the period of heavy rainfall.

Based on the current results, it would seem that burning of crop residues in the autumn could promote soil loss during the following rainy season, especially if high magnitude erosive events occur. Such burning may therefore be an undesirable component of reduced tillage management practices.

References
Soil erosion and sedimentation study by $^{137}$Cs, $^{210}$Pbex and $^7$Be techniques in Pampa Ondulada region, Argentina


# : chief scientific investigator
*CNEA, **Facultad de Agronomía. Univ. de Buenos Aires., **Autoridad Regulatoria Nuclear.

Contract number ARG/12318

**Introduction**

Soil erosion is the most important degradation process in Argentina and also in most countries of the world. It has been estimated that from 4.9 million ha in Pampa Ondulada Region, 1.600.000 ha (36% of agricultural soils) are affected by the erosion process (SAGyP 1995). Although the slope gradients are relatively low in this region, the soil erosion rate has exceeded two or more times the recommended tolerance. Recently the $^{137}$Cs technique was utilized successfully in order to assess soil erosion/deposition in arable lands in Pampa region (Bujan et al. 2003)

Knowledge of soil redistribution rates in the long term should be complemented with continuous monitoring of short term erosion/deposition processes which may allow to measure the effect of land use changes and the efficiency of soil conservation practices like no tillage, terraces etc. The objective of study is the combined utilization of $^{137}$Cs, with $^{210}$Pb and $^7$Be to investigate soil erosion and sedimentation in two areas with contrasting geomorphological and land use/management conditions.

- Standardizing methodologies for using $^{137}$Cs, with $^{210}$Pb and $^7$Be to study soil erosion and sedimentation,
- Developing and testing conversion models to estimate soil losses/deposition from the excess $^{210}$Pb and $^7$Be measurements,
- Testing and validation of models to predict long term and short term soil losses in cultivated land, and to predict sediment yields from small watersheds,
- Evaluating the effectiveness of soil conservation measures on reducing soil loss and sediment yields in the basin.

**Materials and Methods**

Fallout radionuclides techniques: For the soil erosion study in the basin the $^{137}$Cs technique was used, which is based on the comparison between the $^{137}$Cs inventories, measured in the suspected eroded or deposited sites in the landscape and a reference $^{137}$Cs inventory normally established at a long-term undisturbed site (Quine, 1995).

Fallout $^{210}$ Pb (half life 22 years, also known as $^{210}$Pb excess, $^{210}$ Pbex) is generated from the decay of $^{222}$Rn in the atmosphere. It is continually supplied to the soil surface with rainfall and is usually defined as the excess of $^{210}$Pb activity over the amount that is directly supported from in situ decay of its parent $^{226}$Ra.

Maximum concentration of $^{210}$Pb ex in undisturbed soils occur at the surface, decreasing approximately exponentially with depth and typically reaching undetectable levels at depths of 100 mm.

$^7$Be is a cosmogenic radionuclide which shows interesting characteristics for soil erosion studies in the short term and is considered an adequate tool for the evaluation of conservation practices (He et al., 2002).

General characteristics of the Tala’s basin: The climate is temperate with an average annual temperature of 16.9 °C. The region has an annual average rainfall of 1069 mm (mean of 50 years).
The general topography is undulated with slopes between 0 and 3%. The slope length is variable and sometimes is over 400 m.

Within the Tala’s basin the main soil type is classified as a Vertic Argiudoll, and its eroded phases. Due to their high silt content these soils are very susceptible to the impact of the raindrops resulting in crusting and sealing of the soil surface (FAO, 1980).

Soybean is the most important crop grown in rotation with cereals such as maize and wheat. During the last years direct drilling technique became widespread in this basin.

Selected study area: For this study two small watersheds under no tillage agriculture about 300 ha each, with differences in slope length and gradients, were selected located in the medium and lower basin of the Tala river (Arroyo del Tala) respectively, within the "Partido of San Pedro" in the province of Buenos Aires, Argentina, (33°50’ S latitude, 59°52’ W longitude).

$^{210}\text{Pb}$ is being used to determine soil redistribution process in medium and long term scale. The spatial scale is watershed level. $^7\text{Be}$ is being used for the estimations of soil erosion-sedimentation in short-term scale in order to evaluate the efficiency of conservation practices and landscape positions. The spatial scale is plot level.

The radionuclide measurements are being made with a hyperpure Germanium detector Canberra, Model GC2518, with a relative efficiency of 25% and a resolution of 1.8 keV (FWTM) at 1.33 MeV, with a 6 inches led shield, connected to Multichannel Ortec 919 in the Laboratory of Nuclear Regulatory Authority in the Ezeiza Atomic Center, National Atomic Energy Commission, Argentina. The soil/sediment samples were placed in plastic containers of 7 cm diameter and 4 cm height, the lid of which was firmly sealed at least 21 days prior to analysis, in order to ensure equilibrium between $^{226}\text{Ra}$ and its daughter $^{222}\text{Rn}$. Each sample was counted for 90000 seconds. The total concentration was determined from the 46.5-keV gamma ray for $^{210}\text{Pb}$ and the $^{226}\text{Ra}$ concentration from the 351.9-keV gamma ray for $^{214}\text{Pb}$, a short-lived daughter of $^{226}\text{Ra}$. The $^{210}\text{Pb}_{ex}$ concentration was calculated by subtracting the $^{226}\text{Ra}$-supported $^{210}\text{Pb}$ concentration from the total $^{210}\text{Pb}$ concentration. It must be indicated that the capacity of production of data of this laboratory is relatively low since it is only one affected equipment to this project and measurement time allow to analyze a single sample per day. A portable Hyperpure Germanium Detector Canberra GC4019 associated to a integrated portable multichannel analyzer Canberra Model Inspector with software Gennie 2000, was used for $^7\text{Be}$ field conditions counting.

Soil Sampling procedure: In order to establish reference profile inventories in each watershed, five profiles in an 20 square meters area were sampled getting incremental depth layer samples of: 0-2 cm, 2-5 cm, 5-10 cm, 10-20 cm, 20-30 cm and 30-40 cm. For $^{137}\text{Cs}$ and $^{210}\text{Pb}$ studies transect strategy was performed for soil loss/sediment assessment in the two whole watersheds. Soil samples were obtained separated 50 m along the transect.

$^7\text{Be}$ activities were obtained in two forms: a) Counting soil samples in the laboratory. b) Counting soil activity in situ with a portable detector. The experiment was sequentially done in small plots under contrasting soil surface cover in different positions along the watershed a) shoulder/high backslope position (SH), b) mid backslope position (MB) and c) low backslope position (LB). Slope length for the three sites were ca. 150 m, 300 and 600 m respectively while slope gradients was smaller than 2%. In each position the following land use situations were analyzed: a) natural grassland (G), b) soil kept continuously bare by herbicide application (B) and c) annual cropping rotation with wheat/soybean or corn under no tillage (N). In the study sites the samples were obtained at 0-2 cm depth and 0-5 cm depth (at the same time identical samples were taken in de reference site). Six sample procedures were carried out in the following dates: August 3, 2004, November 18, 2004, December 15, 2004, February 15, 2005, July 22, 2005 and October 4 2005.

Additional instrumental facilities: 1) pluviograph instrument, 2) limnigraph instrument, 3) neutron probe and aluminum access tubes for soil moisture measurements, 4) instruments topographic survey

Results and Discussion

Reference sites in connection with $^{137}\text{Cs}$, $^{210}\text{Pb}_{ex}$ and $^7\text{Be}$
In Figure 1 we present the reference profiles of $^{137}$Cs and $^{210}$Pbex corresponding to the reference sites of Los Patricios and La Esperanza watersheds expressed in areal activity (Bq.m$^{-2}$). These graphics show a similar exponential distribution and accumulation of $^{137}$Cs and $^{210}$Pb respectively in the different layers surveyed. It is necessary to highlight that the presence in depth of $^{137}$Cs is superior to the development of the $^{210}$Pbex profiles which shows no contents so far of 20 cm depth. In Los Patricios $^7$Be reference site, at the moment of this sample procedure, showed in the first 2 cm layer mean values about 446,25 Bq.m$^{-2}$ from 2 cm to 5 cm 186,75 Bq.m$^{-2}$ and no presence under 5 cm depth which shows the shape of the $^7$Be profile.

Results In connection with $^7$Be

In the reference site the measured activities was about 20 Bq.kg$^{-1}$ in the first 2 cm depth in the profile, diminishing strongly to the 5 cm depth and becoming no measurable at 10 cm depth which shows the shape of the $^7$Be profile. The studied period was unusually dry, as for the 17 months period the total recorded rainfall amount was 964 mm, similar to the annual mean value for this region in normal periods. Consequently, only 4 measurable runoff events were registered of less than 7 mm/day each. The areal activity (Bq m$^{-2}$) registered in the three sampling sites under different soil surface cover for the studied period that were measured at the laboratory showed better correlation with climate, topography and/or land management than field measurements probably due to the large variability of these data. These results suggest the need of enlarging the time of field measurements in further surveys.

Figures 2 show the linear regression models that were fitted between relative areal inventories (means of the three land use types for each topographic position and sampling date) and the cumulative antecedent rainfall for each sampling date. Higher $R^2$ values were obtained when using the meteorological data from larger periods of time (e.g. three months vs one month). Significant differences were observed between the areal activity from the higher and more stable position: shoulder (SH), and the lower and less stable position: low backslope (LB). These differences can be related to soil erosion due to the influence of the slope length increasing the hazard of rill erosion processes (Bujan et al. 2003).

![Reference profile: Los Patricios $^{137}$Cs](image1)

![Reference profile: Los Patricios $^{210}$Pbex](image2)

![Reference profile: La Esperanza $^{137}$Cs](image3)

![Reference profile: La Esperanza $^{210}$Pbex](image4)

Figure 1: Reference profiles of $^{137}$Cs and $^{210}$Pbex in Los Patricios and La Esperanza watersheds

![Values of SH site / reference site and LB site / reference site (Bq m$^{-2}$) related to cumulative rainfall 90 days before each measurement](image5)

Figure 2. Relative $^7$Be areal inventory of the shoulder and the low backslope positions in relation to cumulative rainfall
Table 1 shows a tendency towards lower relative areal inventories under the bare condition (B) and annual cropping (N) compared to the natural grassland (G) condition. The lack of statistical significance can be ascribed to the high variability of the plant and residue surface cover and soil crusting throughout the studied period.

Table 1. Mean, standard deviation and variation coefficient of the relative areal inventory (in Bq m$^{-2}$) calculated as land use type / reference site

<table>
<thead>
<tr>
<th>Land use type</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Variation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual cropping (N)</td>
<td>0.816</td>
<td>0.320</td>
<td>0.392</td>
</tr>
<tr>
<td>Natural grassland (G)</td>
<td>0.872</td>
<td>0.205</td>
<td>0.235</td>
</tr>
<tr>
<td>Bare surface (B)</td>
<td>0.817</td>
<td>0.219</td>
<td>0.269</td>
</tr>
</tbody>
</table>

An attempt was made in order to estimate soil erosion rates using the data gathered in the present investigation through the methodology proposed by He et al. (2002). However, the results obtained were not satisfactory because they overestimated the erosion rates expected for this watershed employing $^{137}$Cs (Bujan et al. 2003).

Results in connection with $^{137}$Cs and $^{210}$Pb in the suspected eroded-deposited area

The inventories in four transects in Los Patricios watershed ranged between a maximum of 1755 to a minimum of 391 Bq.m$^{-2}$ for $^{137}$Cs and a maximum of 8816 to a minimum of 0 Bq.m$^{-2}$ for $^{210}$Pbex. The estimated soil loss/deposition rates ranged between -65.7 and +27.8 t/ha/yr employing mass balance model for $^{137}$Cs.

It is possible to observe a rather acceptable correlation between the $^{210}$Pbex and $^{137}$Cs inventories in each point and in some portions of the studied transects the values fit well with the topographic position along the slope (Figure 3).

Likewise is observable a direct relationship between both inventories ($^{137}$Cs and $^{210}$Pbex) and the location of the transects in the watershed. In general view the inventories decrease from the higher positions to the lower positions. Nevertheless some inconsistencies are shown in the areas suspected of erosion-deposition processes near the waterway where the slope shape becomes concave and the slope gradient diminishes.

Figure 3 shows the data obtained in four transects in high, medium and low positions in La Esperanza watershed. Inventories values range from 4551 to 0 Bq.m$^{-2}$ for $^{210}$Pbex and 1337 to 149 Bq.m$^{-2}$ for $^{137}$Cs. The relative data in these transects show some points with no detectable $^{210}$Pbex mainly in the medium backslope position, where the kinetic energy of runoff is highest. Further work is required to refine the correlation of the inventories values of $^{210}$Pbex. Perhaps we must consider the fact that $^{210}$Pbex is refreshing by constant fallout. Next step will be to test and validate models to estimate soil loss-deposition from $^{210}$Pbex measurements. The estimated soil loss/deposition rates ranged between -50.3 and +38.2 t/ha/yr employing mass balance model for $^{137}$Cs.

Taking into account that previous reports showed that the $^{137}$Cs inventories were good estimators of erosion processes, an attempt to employ the inventory ratio methodology proposed in the Handbook for the assessment of soil erosion and sedimentation using environmental radionuclides of Zapata F. (ed.) was carried out. However, no good correlations were found when this technique was applied. Only few parts of the transects showed an acceptable correlation between $^{137}$Cs and $^{210}$Pb inventories. In Figure 4 we illustrate the distribution of all pair of data obtained in Los Patricios watershed and the correlation of inventories of $^{137}$Cs and $^{210}$Pb in both, left and right hillslopes, in the lower part of the Los Patricios watershed. Further studies will be necessary to explain the obtained results, particularly the points where $^{210}$Pb was undetectable.
Figure 3: Areal activities of $^{210}\text{Pb}$ and $^{137}\text{Cs}$ in Los Patricios and La Esperanza watersheds

Los Patricios watershed transects

La Esperanza watershed transects
Conclusions
The reference site in Los Patricios and La Esperanza watershed for $^{137}$Cs and $^{210}$Pb$_{ex}$ had been described and showed similar characteristics: exponential distribution and $^{137}$Cs and $^{210}$Pb$_{ex}$ inventories mean values respectively. The studied transects in two studied watershed show a rather acceptable correlation between the $^{137}$Cs and $^{210}$Pb$_{ex}$ inventories, especially in the slope parts with erosion processes. The correlation appears not so clear in areas with sedimentation processes. In La Esperanza watershed with higher slope gradients the $^{210}$Pb$_{ex}$ inventories were not detectable in areas suspected to suffer high erosion rates within the lower section of this watershed. The application of $^7$Be technique in order to assess soil erosion-sedimentation processes in short time scale have begun in cultivated soils under no tillage system. The $^7$Be activity obtained showed differences between three topographic locations in Los Patricios watershed. The use of a portable Canberra detector is being tested with high variability results. The major limitation for using $^{137}$Cs, $^{210}$Pb$_{ex}$ and $^7$Be techniques is the low analytical capacity for a great number of samples.

References
Bujan, A; O.J. Santanatoglia; C.I, Chagas; M. Massobrio; M. Castiglioni; M Yañez; H. Ciallella and J. Fernandez. 2003. Soil erosion evaluation in a small basin through the use of $^{137}$Cs technique. Soil and Tillage Research 69 (1-2):127-137.
Assessment of soil losses within conservation agrolandscapes of Central Russia using fallout radionuclides and other methods

Valentin Golosov, M.V. Lomonosov
Moscow State University,
Faculty of Geography, Laboratory for Soil Erosion and Fluvial Processes

Contract No 12329

Introduction
During period November 2004 – February 2006 investigation was continued within Novosil experimental station (Orel region). Also new study was started on the field site of All-Russian Scientific Institute of Farming and Soil Protection from Erosion (Kursk region). According work plan till the beginning of spring 2006 we should complete evaluation of sediment redistribution within Orel key site. Sediment redistribution within three pair slopes should be evaluated using different methods. Effectiveness of soil conservation measures should be evaluated. The field works and sample analysis were completed for the pair slopes of the Novosil experimental station. Soil redistribution rates were calculated for different time intervals using results of radionuclide (Chernobyl-derived $^{137}$Cs and $^{210}$Pb$_{ex}$) techniques. Also soil morphological method and modified version of USLE were applied for evaluation of soil erosion rates for each slope. Results of soil redistribution calculations were compared with evaluation of soil quality, which was undertaken for slope with traditional cultivation and for slope with soil conservation measures. Detail information about Kursk site was collected. Also some data about erosion rate and soil quality for Kursk region was found. Sampling and analysis of reference samples was made for area, located in several kilometres to north-east from study site (territory of the Central Chernozem Reserve). The most part of planning work is completed now.

Results
Results have shown that slopes with soil-protective measures are characterized by a 25-80% reduction of average soil redistribution rates, as shown by soil profile morphology and $^{137}$Cs methods (Table 1 and Table 2). Application $^{210}$Pb$_{ex}$ method for evaluation of sediment redistribution allows to receive similar with $^{137}$Cs technique spatial distribution of erosion and depositional zones along the slope.

Mean values of net erosion received by using $^{210}$Pb$_{ex}$ technique are in range 2-15 tha$^{-1}$year$^{-1}$. Good coincidence of spatial patterns of soil redistribution rates provided by different techniques suggests general reliability of results. Discrepancy in values obtained can be attributed to differences in temporal resolution of methods as well as to possible influence of individual extreme events on results yielded by the $^{137}$Cs method. On the other hand, more significant decrease of average soil degradation rates on slopes with soil conservation (up to 70-75% for each pair of slopes) was predicted by the results of calculation using erosion model. This substantial difference between predicted and directly measured values is attributed to a high degree of soil degradation prior to introduction of protective measures (reflected by the soil-morphological method) and lack of funding for maintaining the appropriate conditions of terraces and forest shelter belts after collapse of the former Soviet Union (reflected by the $^{137}$Cs technique). The $^{137}$Cs method overestimates gross and net soil redistribution rates as a result of the influence of extreme erosion prior to tillage mixing of a fresh fallout isotope, not accounted for by calibration models used. Another shortcoming of the estimations obtained is that sediment re-deposition directly within forest belts was not taken into account. Therefore, net erosion rates obtained for slopes with forest belts should be regarded as highest possible estimates only. Nevertheless, it can be generally concluded that the multi-technical approach has allowed acquiring much more detailed information on temporal and spatial variability of soil redistribution rates than single method-based studies.
Table 1. Gross and net soil redistribution rates calculated for the studied slope transects from $^{137}$Cs data (upper figures – proportional model, lower figures – mass balance model).

<table>
<thead>
<tr>
<th>Pairs of slopes</th>
<th>Slope transects</th>
<th>Length of erosion zones (m/%)</th>
<th>Average annual erosion within zones (t ha$^{-1}$ year$^{-1}$)</th>
<th>Gross erosion (t ha$^{-1}$ year$^{-1}$)</th>
<th>Length of deposition zones (m/%)</th>
<th>Average annual deposition within zones (t ha$^{-1}$ year$^{-1}$)</th>
<th>Gross deposition (t ha$^{-1}$ year$^{-1}$)</th>
<th>Net erosion (t ha$^{-1}$ year$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Transect 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1) Transect 1</td>
<td></td>
<td>320 / 69.6</td>
<td>62.5</td>
<td>43.5</td>
<td>80 / 17.4</td>
<td>20.6</td>
<td>3.6</td>
<td>39.9</td>
</tr>
<tr>
<td>2) Transect 2</td>
<td></td>
<td>460 / 93.9</td>
<td>58.5</td>
<td>54.9</td>
<td>30 / 6.1</td>
<td>61.0</td>
<td>3.7</td>
<td>51.2</td>
</tr>
<tr>
<td>3) Transect 3</td>
<td></td>
<td>590 / 73.8</td>
<td>19.3</td>
<td>14.2</td>
<td>60 / 7.5</td>
<td>24.9</td>
<td>1.9</td>
<td>12.3</td>
</tr>
<tr>
<td>4) Transect 4</td>
<td></td>
<td>740 / 96.1</td>
<td>61.7</td>
<td>59.3</td>
<td>30 / 3.9</td>
<td>62.3</td>
<td>2.4</td>
<td>56.9</td>
</tr>
<tr>
<td>5) Transect 5</td>
<td></td>
<td>590 / 78.7</td>
<td>30.1</td>
<td>23.7</td>
<td>80 / 10.7</td>
<td>47.3</td>
<td>5.0</td>
<td>18.7</td>
</tr>
<tr>
<td>6) Transect 6</td>
<td></td>
<td>630 / 86.3</td>
<td>30.9</td>
<td>26.7</td>
<td>100 / 13.7</td>
<td>15.9</td>
<td>2.2</td>
<td>24.5</td>
</tr>
</tbody>
</table>

1) Slope transects with contour terraces and forest shelter belts; 2) Conventionally cultivated slope transects.

Table 2. Gross and net soil redistribution rates calculated for the studied slope transects from soil profile morphology comparison data.

<table>
<thead>
<tr>
<th>Pairs of slopes</th>
<th>Slope transects</th>
<th>Length of erosion zones (m/%)</th>
<th>Average annual erosion within zones (t ha$^{-1}$ year$^{-1}$)</th>
<th>Gross erosion (t ha$^{-1}$ year$^{-1}$)</th>
<th>Length of deposition zones (m/%)</th>
<th>Average annual deposition within zones (t ha$^{-1}$ year$^{-1}$)</th>
<th>Gross deposition (t ha$^{-1}$ year$^{-1}$)</th>
<th>Net erosion (t ha$^{-1}$ year$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Transect 1</td>
<td></td>
<td>350 / 76.1</td>
<td>6.7</td>
<td>5.1</td>
<td>50 / 10.9</td>
<td>3.8</td>
<td>0.4</td>
<td>4.7</td>
</tr>
<tr>
<td>2) Transect 2</td>
<td></td>
<td>470 / 95.9</td>
<td>9.4</td>
<td>9.0</td>
<td>20 / 4.1</td>
<td>2.5</td>
<td>0.1</td>
<td>8.9</td>
</tr>
<tr>
<td>1) Transect 3</td>
<td></td>
<td>650 / 81.3</td>
<td>5.7</td>
<td>4.7</td>
<td>0 / 0</td>
<td>0</td>
<td>0</td>
<td>4.7</td>
</tr>
<tr>
<td>2) Transect 4</td>
<td></td>
<td>680 / 88.3</td>
<td>18.5</td>
<td>16.3</td>
<td>90 / 11.7</td>
<td>13.3</td>
<td>1.6</td>
<td>14.7</td>
</tr>
<tr>
<td>1) Transect 5</td>
<td></td>
<td>670 / 89.3</td>
<td>10.6</td>
<td>9.4</td>
<td>0 / 0</td>
<td>0</td>
<td>0</td>
<td>9.4</td>
</tr>
<tr>
<td>2) Transect 6</td>
<td></td>
<td>730 / 100.0</td>
<td>8.5</td>
<td>8.5</td>
<td>0 / 0</td>
<td>0</td>
<td>0</td>
<td>8.5</td>
</tr>
</tbody>
</table>

1) Slope transects with contour terraces and forest shelter belts; 2) Conventionally cultivated slope transects.
Discussion

Results of sediment redistribution evaluation for the pair slopes using $^{137}$Cs and $^{210}$Pb$_{ex}$ techniques rise several questions. In case of Chernobyl-derived $^{137}$Cs we were able to determine the initial trend of fallout, which were included in calculation. It is much more difficult to evaluate initial spatial distribution of $^{210}$Pb$_{ex}$ fallout because of several reasons. Firstly, location of forest shelter belts and contour forest seriously influence on precipitation distribution. Secondly, location of key slope nearby of the Zhusha river valley also affect on rain distribution. According observation of meteorologists in case of valley location along the main direction of wet air mass moving precipitation increase in direction of river valley. Initial distribution of Chernobyl-derived $^{137}$Cs within European part of Russia is confirmed given observation, if taking information from the Atlas of $^{137}$Cs contamination of Russia, Belarus and Ukraine (1998). However specific study should be undertaken for study local spatial distribution of precipitation depending from forested area location and relief. Thirdly, in our case it is very likely that we are overestimated the $^{210}$Pb$_{ex}$ concentration because of problem with calibration source for detector. However the latter do not influenced on the results of sediment redistribution calculation using $^{210}$Pb$_{ex}$ because it is constant systematic error. Application of Chernobyl-derived $^{137}$Cs for our slopes clearly demonstrates the influence of erosion event happen before the first cultivation after fallout. We can suggest this, because even within slopes 3 and 5, where perennial grasses is mostly growing after 1986, mean erosion rate exceed 10 t/ha. It was found from the available precipitation data that 5-10 rainfall events potentially able to generate overland flow (>10 mm) took place during the warm period of the year 1986, especially heavy was rainstorm on August 26$^{th}$ (25-35 mm at different stations). It is very likely that similar situations were very typical for some prairie regions of North America. It is certainly the reason of overestimation of erosion rates, which were shown for few sites in USA (Montgomery et al., 1997; Turn age et al., 1997; Bajracharya et al., 1998).

One more problem is connected with application radionuclide technique in areas where soil conservation measures are applying. Serious mechanical disturbance of soil because of construction field dam, terraces and so on affected on radionuclide concentration in soil more seriously if compare with soil erosion itself. From our point of view application of radionuclide (sediment) budgets for close small basin is the best site for evaluation of effectiveness of soil conservation methods on the soil erosion and sedimentation rates. Such basin was chosen as a key site in Kursk region of Central Russia.

Perspectives

Work plan till the November 2006 includes following tasks:

1. To take samples and to study sediment redistribution depositional part of key dry creek basin for evaluation of total soil losses for different time intervals: since 1986 (Chernobyl-derived $^{137}$Cs, when soil conservation system were organize within the catchment with construction of dam in the lower reach of dry creek); for period since 1954 (bomb-derived $^{137}$Cs), which is characterized by beginning of wide using of heavy machinery (tractor, combine harvester etc); for entire period of intensive cultivation (Kursk study site).
2. Construction of digital elevation model of study catchment for detail evaluation of stable, erosion and deposition zones, including location of different soil conservation measures.
3. To collect additional information about crop rotations for period since 1954 and meteorological information (Kursk study site).
4. To calculate using erosion models soil losses for different time intervals and to compare soil loss volume with soil deposition for different time intervals (Kursk study site).
5. Sample preparation and radionuclide ($^{137}$Cs, $^{210}$Pb$_{ex}$) measurements.

Conclusion

Combined application of 4 independent techniques allows acquiring much more detailed information on temporal and spatial variability of soil redistribution rates than single method-based studies do. Such a multi-technical approach also enables researchers to highlight possible
shortcomings and errors of the individual techniques employed by cross-comparison and validation of results between those. Extreme values of soil redistribution rates obtained from the $^{137}$Cs technique are believed to be overestimative, mainly as a result of the influence of erosion prior to tillage mixing of a fresh fallout isotope onto results yielded by calibration models. This problem requires further consideration and quantitative assessment. As regards the soil-protective effectiveness of contour terraces with forest shelter belts, at present stage of the research it can be concluded that 25-80% decrease of average annual net erosion rates comparatively to conventionally cultivated slopes was detected by field-based methods. The empirical model predicted the 75% decrease, comparable to a higher range of values presented above. However, much longer time of forest belts existence will be required to regain the pre-degradational soil profile characteristics. This conclusion can be drawn from comparison of average net erosion rates estimated by soil-morphological method, which are significantly affected by severe soil degradation on slopes with forest belts prior to their planting. Additional analysis should be made for results of application of $^{210}$Pb$_{ex}$ techniques.
Evaluating the effectiveness of soil conservation measures on sloping cropland in Romania using fallout radionuclides

Nelu Popa
Central research Station for Soil Erosion Control Perieni
Barlad (CRSSEC) Romania

Contract No. 12328

Objectives
- to use of $^{137}$Cs, and $^7$Be technique for measuring soil erosion over several spatial and time scales.
- to utilize these techniques to assess the impact of short-term changes in land use practices and the effectiveness of specific soil conservation measures from Romania in controlling soil erosion for sustainable crop production.

Experimental methods
In order to determine the effectiveness of the main types of soil conservation measures applied in Tutova Rolling Hills, Romania, the study was focused to find out how do they work:
- through time, in normal years concerning the level of precipitations;
- during extreme rain events;
- in comparison with the situation when none of conservation practices are applied

The study was made in three representative small watersheds that comprise a range of natural conditions and categories of soil conservation measures: stripcropping, bufferstrips, bench terraces, shelter belts and an adequate agricultural exploitation road network. In Tarnii basin, a study on runoff plots, all with a cropping history, fully instrumented for measuring runoff and soil loss under different conditions concerning vegetative cover, was also made.

The comparative study between behavior of contour system and up-and-down slope system was extended in Tutova Valley, in the neighborhood of Cuibul Vulturilor Reservoir. Here, like in many parts of the hilly area from Romania, after the revolution from 1989, the land was re-allotted to the landowners in narrow plots disposed up-and-down the slope.

The investigation has been conducted to establish relationships between soil losses, measured by combined $^{137}$Cs, and $^7$Be technique, under natural conditions and the main factors like: land use, characteristics of soils, relief and, specific conservation measures.

In order to obtain referenced data concerning $^7$Be activity, water samples from every rain event, especially in warm season, were analyzed, knowing that the peak of fallout $^7$Be is associated with precipitations.

For $^{137}$Cs "in situ" measurement a Canberra Ge HP portable detector, 18% efficiency, has been used. Concerning sampling method, a scraper device and conventional soil augers has been used. Where the depth of sediment in depositional areas was thin or in reference sites where neither soil loss nor sediment deposition occurred, the samples were collected at 1 or 2 cm intervals. In deep sediments, depth increments were usually 10 or 20 cm, depending on the auger bucket. The mass of soil collected varied between 0.5-1.5 kg and depended on the dimensions of the scraper (20 x 50cm), the bulk density and the depth increment involved.

The reference sites previously established have been maintained. They have been under continuous vegetation cover in the last 60 years and are situated on the top of the hills. The first one is an old rural burial ground and the second is an area used like a pasture.

Data referring to the aggradation of the platform of agroterraces owing to tillage translocation, were obtained by topographical measurements since 1998, made each time on 5 parallel transects at 1 m distance, whereas diminishing of errors due to roughness of soil surface.
The project has been realized in collaboration with the National Institute of Physics and Nuclear Engineering “Horia Hulubei”, IFIN-HH Magurele – Bucharest.

**Results obtained**

**$^{137}$Cs technique**

Upper Tarnii Valley (300 ha), with long and uniform slopes, is very well characterized by the transect shown in figure 1, through three agroterraces and two shelter belts. Here slope varies between 12 and 14%, and the width of stripcrops is about 100 m. It can be observed that measurements were made in the upper part, middle part and platform of agroterraces in order to determine relationships between $^{137}$Cs activity and the redistribution of eroded soil along the slope.

![Figure 1 Transect in Tarnii basin through the main conservation measures](image)

The transect is situated in the middle of the distance between the reference site no. 1 where calculated $^{137}$Cs inventory is 6.90 kBq m$^{-2}$ and the reference site no. 2 where $^{137}$Cs inventory is 4.98 kBq m$^{-2}$. In consequence, an average of 5.94 kBq m$^{-2}$ for $^{137}$Cs inventory reference was considered. However, in the neighborhood of the shelter belts, this value has to be reconsidered due to the influence of the trees on the wind velocity which, probable, influenced initial $^{137}$Cs deposition. This effect is very well illustrated during the winter when the dominant wind from NW to SE determines every year a significant snow deposition. It can be an explanation for the high values of $^{137}$Cs inventory in T-F9, T-F20 and T-F21 sampling points situated in the upper part of stripcrops, where the soil is usually affected by erosion.

$^{137}$Cs inventory for sampling points T-F1, T-F2, T-F3, T-F10, T-F11, and T-F14 presented values below the reference line because they are situated in the area where the soil loss is mostly related to erosion by water. In F8, soil loss can be explained by the influence of the tillage erosion.

The lowest value of the $^{137}$Cs activity can be observed in TF13 (1.95 kBq m$^{-2}$) where a significant part of the topsoil was removed in 1993 when a camp road was constructed.

T-F4, T-F5, T-F12, T-F15 and T-F16 sampling points are situated on the platform of agroterraces where the slope is less than 5% and the sedimentation process that is dominant is reflected in high values of the $^{137}$Cs inventory.

T-F6, T-F7, T-F17 and T-F18, which are placed inside the forest belts, have a high variability of $^{137}$Cs inventory (7.98 – 11.22 kBq m$^{-2}$) owing to canopy processing of rain and soil disturbance from root throws but the averages (11.04 kBq m$^{-2}$ for SB1 and 8.66 kBq m$^{-2}$ for SB2) are above the reference inventory. However, field observations shown that the sedimentation process inside the shelter belts is very reduced.
A transect through two agroterraces was also made in Crang Basin where some measurements concerning tillage erosion were initiated since 1998. Two lines that correspond to the shape of relief from 1998 and 2003 were determined by topographical measurements after plowing and seeding and show the modifications due mainly to tillage erosion during a period of 5 years. The method is indicated if only significant modification in micro-relief shape can be determined (e.g. platform of agroterraces), otherwise it is not enough precisely owing to the roughness of the soil surface. The site is closed to Sachelarie forest that covers the upper NW part of Crang basin. Just like in Tarnii basin where the shelter belts influenced $^{137}$Cs distribution, the reference level of $^{137}$Cs inventory is much higher than the value determined in reference site no. 2. It was estimated at 8.0 kBq m$^{-2}$, having in sight the points on the graphic where no change in altitude during the period of 1998-2003 has registered. The highest values of $^{137}$Cs inventory were determined in C-F1 and C-F6, situated on the platform of agroterraces where the sedimentation process is much evident. The low values of $^{137}$Cs activity from C-F4, C-F5, C-F9 and C-F10 confirmed that tillage erosion is much intensive in the upper part of the stripcrops. Only C-F3 point that is placed in the lower part of the stripcrop and has the lowest value of $^{137}$Cs activity is assumed to be under the influence of erosion by water.

Another transect trough two terraces from the lower part of the left hillslope was made in Gheltag Basin where reference inventory was calculated like an average between values determined in reference site No.1 and reference site no. 2.

Table 1. $^{137}$Cs inventory in 8 soil profiles from Tutova Valley

<table>
<thead>
<tr>
<th>Point</th>
<th>Distance (m)</th>
<th>Slope (%)</th>
<th>Land use</th>
<th>$^{137}$ Cs kBq m$^{-2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>TV-F1</td>
<td>0</td>
<td>12.2</td>
<td>UD</td>
<td>4.54</td>
</tr>
<tr>
<td>TV-F2</td>
<td>85</td>
<td>13.2</td>
<td>C</td>
<td>3.17</td>
</tr>
<tr>
<td>TV-F3</td>
<td>160</td>
<td>3.5</td>
<td>C</td>
<td>6.39</td>
</tr>
<tr>
<td>TV-F4</td>
<td>190</td>
<td>11.6</td>
<td>UD</td>
<td>4.44</td>
</tr>
<tr>
<td>TV-F5</td>
<td>290</td>
<td>10.4</td>
<td>UD</td>
<td>5.22</td>
</tr>
<tr>
<td>TV-F6</td>
<td>660</td>
<td>14.2</td>
<td>UD</td>
<td>2.78</td>
</tr>
<tr>
<td>TV-F7</td>
<td>760</td>
<td>14.6</td>
<td>UD</td>
<td>2.37</td>
</tr>
<tr>
<td>TV-F8</td>
<td>800</td>
<td>15.1</td>
<td>UD</td>
<td>4.25</td>
</tr>
</tbody>
</table>

UD – up and down cultivated; C – contour cultivated

On narrow terraces, redistribution of soil is mainly assigned to tillage erosion. Thus, measurements in G-F1, G-F3 and G-F4 placed in the upper part of stripcrops, from which value of $^{137}$Cs inventory are below the reference, indicated that significant erosion since 1986 occurred. Year by year, soil was translocated to the lower edge of terraces, process reflected by high values of $^{137}$Cs activity in G-F2 and G-F5 sampling points.

The comparative study related to stage of erosion process under two distinct types of soil conservation measures, situated on the same hillslope, with similar pedological characteristics, continued in Tutova Valley, near Cuibul Vulturilor reservoir.

In table 1 results concerning $^{137}$Cs inventory in different locations from Tutova Valley with and without conservation measures are presented.

Analyze of measurements on the old traditional up-and-down system used during almost 13 years, revealed that the significant higher rates of erosion and sedimentation on the up-and-down the hill disposed plots in comparison with surfaces where the contour system was applied.
I

Table 2. Results of “in situ” versus laboratory measurements of $^{137}$Cs activity

<table>
<thead>
<tr>
<th>Place of determination</th>
<th>Date</th>
<th>$^{137}$Cs inventory (kBq m$^{-2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference site No. 1</td>
<td>Mar.31, 2005</td>
<td>7.065</td>
</tr>
<tr>
<td>Reference site No. 1</td>
<td>Jul.26, 2005</td>
<td>7.36</td>
</tr>
<tr>
<td>Reference site No. 2</td>
<td>Mar.31, 2005</td>
<td>4.29</td>
</tr>
<tr>
<td>Reference site No. 2</td>
<td>Jul.26, 2005</td>
<td>4.18</td>
</tr>
<tr>
<td>Runoff plots</td>
<td>Mar.31, 2005</td>
<td>7.09</td>
</tr>
<tr>
<td>Runoff plots</td>
<td>Jul.26, 2005</td>
<td>6.28</td>
</tr>
<tr>
<td>Upper Tarnii V.</td>
<td>Apr.1, 2005</td>
<td>3.27</td>
</tr>
<tr>
<td>Tarnii V, between shelter belts, near the road camp</td>
<td>Jul.29, 2005</td>
<td>1.56</td>
</tr>
<tr>
<td>Tarnii V., near the first shelter belt</td>
<td>Jul.29, 2005</td>
<td>1.98</td>
</tr>
<tr>
<td>Tarnii V., near the second shelter belt</td>
<td>Jul.29, 2005</td>
<td>2.55</td>
</tr>
<tr>
<td>Gheltag, Sachelarie forest</td>
<td>Jul.28, 2005</td>
<td>10.51</td>
</tr>
<tr>
<td>Near Cuibul Vulturilor reservoir on the platform of an agrotace</td>
<td>Mar.31, 2005</td>
<td>3.51</td>
</tr>
<tr>
<td>Near Cuibul Vulturilor reservoir on an up-and-down plot</td>
<td>Mar.31, 2005</td>
<td>4.26</td>
</tr>
</tbody>
</table>

In table 2 results of “in situ” measurements made in spring and summer of 2005 with Canberra Ge HP portable detector, 18% efficiency, are presented. It can be observed that the major differences between $^{137}$Cs inventory values measured in-situ and those determined in laboratory on soil samples are presented in only three locations. They can be explained by the fact that the field of view of a portable detector mounted on a tripod 1 m above the ground surface is a circle of c.a. 20 m. Also, the detector is set perpendicular to the ground surface to ensure that gamma ray is collected symmetrical from the whole area. The first point is placed on a runoff plot that has 100 m$^2$ (4 x 25m) in surfaces and it is possible that value of $^{137}$Cs activity measured in-situ to be higher than the value determined in laboratory owing to surrounding area which is always covered by grass.

The second value that is out of range refers to the point situated in Tarnii basin, near the T-F8 sampling point that indicated a value of $^{137}$Cs inventory below the reference. It is possible that downhill, the value of $^{137}$Cs inventory to be even much lower than that in T-F8 owing to increasing of the erosion process. More sampling points between T-F8 and T-F9 are needed to clarify the problem.

![Figure 2. The relationship between measured in-situ and determined in laboratory $^{137}$Cs activity](image)

The third situation refers to the platform of an agrotace, about 5 m wide, limited by a camp road. The low value of gamma ray registered by the detector owes to the surrounding area occupied by
the road. A similar situation was encountered in Crang basin and Gheltag basin when refers to in-situ measurements from the past years.

Figure 2 shows a weak relationship between values of $^{137}$Cs inventory measured in-situ and those determined in laboratory.

In order to calibrate more accurately the detector the new locations where in-situ measurements will be made have to be selected carefully.

Estimating soil redistribution rate

At this stage when many measurements have to be multiplied or refined for better understanding of processes concerning erosion and sedimentation, the proportional model for estimating soil erosion rate from $^{137}$Cs measurements on cultivated soils was used. In the next stage it is in our intent that the mass balance model incorporating the effect of tillage erosion to be used whereas, as shown above, on steep slopes and contour cultivated lands the effect of soil redistribution by tillage has also to be taken into account.

From the $^{137}$Cs measurements, the results obtained indicate that the erosion rates in the study field from Tarnii basin range between 8.6 and 31.9 $\text{t ha}^{-1} \text{y}^{-1}$ while the deposition rates are between 0.237 and 78.1 $\text{t ha}^{-1} \text{y}^{-1}$. Maximum value of sedimentation process is located on the platform of an agroterrace and is equivalent with an increasing of altitude of that point with 6.5 mm/year. Average of soil loss from all segments with erosion is 21.05 $\text{t ha}^{-1} \text{y}^{-1}$ while the average of deposition is 15.72 $\text{t ha}^{-1} \text{y}^{-1}$. It can be noticed that deposition inside of shelter belts was over-predicted owing to influence of canopy processing of rain on the accumulation of $^{137}$Cs.

In transect 2, situated in Crang basin, the erosion rates varies from 5.7 to 21.0 $\text{t ha}^{-1} \text{y}^{-1}$ and the deposition rates has a maximum of 199.7 $\text{t ha}^{-1} \text{y}^{-1}$ which corresponds to the agradation of the agroterrace with 16.6 mm yr$^{-1}$. However, in comparison with data obtained by classical methods like topographical measurements that indicated an agradation of the same point with 40.0 mm yr$^{-1}$, estimated deposition is under-predicted.

Estimated values of soil redistribution in Transect 3 through two agroterraces situated in Gheltag watershed indicated a maximum erosion of 10.4 $\text{t ha}^{-1} \text{y}^{-1}$ in the middle of a terrace and a maximum sedimentation of 70.6 $\text{t ha}^{-1} \text{y}^{-1}$ (5.9 mm yr$^{-1}$ agradation) on the edge of the terrace.

Transect 4, which is much longer than the previous transects (760 m) went both trough the cultivated lands with and without applying of conservation practices. A maximum erosion of 23.0 $\text{t ha}^{-1} \text{y}^{-1}$ was calculated for an up-and-down slope cultivated land. Average of erosion rates is 15.8 $\text{t ha}^{-1} \text{y}^{-1}$, and sediment delivery rate is 8.3 $\text{t ha}^{-1} \text{y}^{-1}$ that means that 52.5% of sediments leave the site.

Runoff plots

Analyze of data from runoff plots since 1985 on a moderately deep soil, with medium fertility (cambic chernozem), medium textured, and moderately eroded, with a 12% slope showed that through time, every plot was affected by erosion in different way. Most eroded was the plot No. 2 from which an amount of 158.078 t of soil was detached by water. Less eroded was plot No.5 from which only 19.591 t of soil was lost.
In analyzing and interpreting of data has to be considered the fact that in year of 2002 the small metallic fences that mark the limits of parcels were removed and soil surface was plough by contour, thus the soil covered by grass between plots was mixed with the soil from parcels. The need derived from the fact that a significant difference between the level of that narrow strips and the level of parcels appeared. In the same time erosion from some parcels modified the shape of the terrain that became concave.

Runoff, soil and nutrient losses have been monitored after each rainy event that produced runoff. Main results are presented in Table 3.

Soil samples were collected this year from 4 points for each plot, down to 50 cm, by 10 cm increments. All of them were sent to National Institute of Physics and Nuclear Engineering–Bucharest to be analyzed but owing to a malfunction of the detector the results were postponed for this spring when a new detector will be purchased.

\[ ^{7}\text{Be} \text{ technique} \]

\[ ^{7}\text{Be} \text{ technique} \text{ Input from rains} \]

In order to obtain referenced data concerning \(^{7}\text{Be}\) activity it was necessary to analyze the water, sampled by rain gauge during the warm season. Obtaining a supplementary quantity of water sampled from the rains to be analyzed and to provide reliable data concerning referenced \(^{7}\text{Be}\) activity was possible by using a simple device with 10 funnels, made at Perieni Station.

---

Table 3 Annual runoff, soil and nutrient losses on runoff plots during the period of 1996-2003

<table>
<thead>
<tr>
<th>Crop</th>
<th>Nutrient losses in runoff</th>
<th>Soil and nutrient losses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Runoff</td>
<td>NO(_3)</td>
</tr>
<tr>
<td>Bromus</td>
<td>23.188</td>
<td>0.067</td>
</tr>
<tr>
<td>Winter wheat</td>
<td>40.850</td>
<td>0.057</td>
</tr>
<tr>
<td>Soy bean</td>
<td>209.150</td>
<td>0.336</td>
</tr>
<tr>
<td>Beans</td>
<td>172.938</td>
<td>0.250</td>
</tr>
<tr>
<td>Corn</td>
<td>180.450</td>
<td>0.264</td>
</tr>
</tbody>
</table>
Analyze of $^7$Be activity is presented in table 4. $^7$Be activity from water of rain has a high variability and, also has a weak connection with the level of precipitation. In the last 10 years only two extreme rain events (intensity > 2 l/min, H > 50mm) that triggered a significantly erosion process, have been registered at Perieni Station. One of them occurs last year in August 27 and its effects, which were presented in the Progress Report for 2004, affected only terrains that were not covered by vegetation (at that time only small surfaces were ploughed). The other one occurred in May 7, 2005, this time when majority of terrains were just prepared for seeding.

If for the first rain event $^7$Be activity measured was 27.7 Bq m$^{-2}$, in the second case only a low value of 4.47 Bq m$^{-2}$ was determined. Maybe, it can be explained by the fact that the rain from May 2005 came after the rain from April 30, which already cleaned the atmosphere.

Measurements of “in-situ” of $^7$Be activity were done at the end of March, after the snow melting and at the end of July after a rain of 50mm but in low intensity.

$^7$Be activity measured in July on reference site No.1 was significantly higher then that from reference site No. 2 due to the fact that the last site has a convex shape. However, in March values of $^7$Be activity were almost the same because the reference site No.2 is S-E looking and the snow melted quickly thus the water flowed out. In reference site No.2 that is N looking the snow melted slowly and the water has infiltrated in soil. Generally, it can be observed that all the values from July are higher than those from March. This situation can be explained by the fact that July was a rainy month when registered 96.0mm in comparison with 17.7 mm from March.

The lowest value of $^7$Be activity was measured in the middle of Sachelarie forest maybe due to the influence of the foliage. The low activity of $^7$Be on the agroterrace from Tutova Valley, near Cuibul Vulturilor reservoirs is owing to the fact that the agroterrace is limited by a road camp were a large quantity of soil was removed. In Tarnii basin values of $^7$Be activity ranged between very close limits (313.3 – 321.9 Bq m$^{-2}$) and indicated that no significant erosion occurred.

Analyze of soil samples from reference sites, from runoff plots and from some representative terrains with and without conservation measures, showed that the level of $^7$Be activity after the rain from May 7, 2005 was under minimum detectable activity even for a collecting time of 10000 seconds, so, the measurements could not distinguish the presence of $^7$Be in the environment.

### Conclusions

- In Tarnii basin that is characterized by long slopes, $^{137}$Cs inventory for the sampling points that presented values below the reference is mostly related to erosion by water while in Gheltag basin with steep slopes the tillage erosion is dominant.
- Lowest values of the $^{137}$Cs inventory (e.g. 1.95 kBq m$^{-2}$) have been determined in places where a significant part of the topsoil was removed when camp roads were constructed. High values have been determined on points situated on the platform of agroterraces where the
sedimentation process is much evident. High values of $^{137}$Cs inventory (7.98 – 11.22 kBq m$^{-2}$) have also been observed in sample points that are placed inside of forest belts, owing to canopy processing of rain and soil disturbance from root throws. However, the distribution of $^{137}$Cs content in soil profile, as well as field observations, shown that the sedimentation process inside the shelter belts was very low.

- The comparative analyze between “in-situ” and laboratory measurements revealed that the portable detector has to be used with care, especially on slopes where many discontinuities can be met. Otherwise, “in-situ” measurements give good estimations of soil erosion and sedimentation.

- From the $^{137}$Cs measurements, using of the proportional model indicates that the erosion rates in the study field from Tarnii basin range between 8.6 and 31.9 t·ha$^{-1}$·y$^{-1}$ while the deposition rates are between 0.237 and 78.1 t·ha$^{-1}$·y$^{-1}$. In Crang basin even a rate of sedimentation of 199 t·ha$^{-1}$·y$^{-1}$ was noted.

- The maximum value of sedimentation process was located on the platform of agroterraces and it is equivalent with an increasing of altitude of those points up to 16.6 mm/yr. In comparison with data obtained by topographical measurements that indicated an agradation of the same point with 45.0 mm/yr, estimated deposition is under-predicted.

- Deposition inside of shelter belts was over-predicted owing to influence of canopy processing of rain on the accumulation of $^{137}$Cs.

- $^7$Be activity measured in water collected from rains has a high variability and, also has a weak connection with the level of precipitation.

- In most cases $^7$Be was under minimum detectable activity even for a collecting time of 10000 seconds, so, the measurements could not distinguish the presence of $^7$Be in the environment.

References
Bernard C., Duchemin M. Assessment of soil redistribution under conventional and conservation tillage practices in cool temperate regions from radiotracer measurements. First RCM of the CRP from Vienna, May 2003.


The use of $^{137}$Cs, $^{210}$Pb$_{ex}$ and $^{7}$Be for investigations of soil erosion to assessment the impact of land use changes and the effectiveness of soil conservation in the Polish Carpathians

Wojciech Froehlich
Institute of Geography and Spatial Organization
Polish Academy of Sciences,
HOMERKA Laboratory of Fluvial Processes,
Nawojowa, Poland

Contract number: POL/12327

Introduction

Studies were carried out in order to evaluate the potential use of the $^{210}$Pb$_{ex}$, $^{226}$Ra, $^{7}$Be and $^{137}$Cs techniques to assess the impact of short-term changes in land use practices and evaluate the effectiveness of soil conservation measures in the Polish Carpathians. Increase area of farmland abandonment in the last twenty-five years has introduced important soil erosion and sediment delivery processes changes. Such areas are exchanged on permanent pasture or afforested. However questions are raised concerning its effectiveness in soil erosion control and watershed management.

Description of research carried out

In the period of statement investigations focused on understanding of spatial and temporal variability of sediment mobilisation and sediment delivery dynamics during different floods generated by rainfall and snowmelt in small instrumented drainage basin of the Homerka stream. The 19,6 km$^2$ drainage basin of the Homerka stream lies at an altitude of 375-1060 m above sea level and is representative of typical land use, crop rotation and drainage basin management in the Polish Flysch Carpathians (see Froehlich et al., 1993). Sediment mobilisation and sediment delivery study were carried out on two experimental slopes with different size of plots bounded by agricultural terraces, furrows and unmetalled roads. Particular emphasis be given to the combined use of $^{210}$Pb$_{ex}$, $^{226}$Ra, $^{7}$Be and $^{137}$Cs for understanding the influence of short-term changes in land use practices for sediment mobilisation and sediment delivery dynamics in the scale of slope and small drainage basin.

The significant effort was driven to improve of the $^{7}$Be technique for understanding present day sediment mobilisation and sediment delivery dynamics during different range of rainfalls and snowmelt. Monitoring of the spatial distribution of $^{7}$Be activity immediate after each heavy rainfall and snowmelt provide a basis for the explanation of sediment mobilised by diffuse surface flow and linear flow. They were continued monitoring of the $^{210}$Pb$_{ex}$, $^{226}$Ra, $^{7}$Be and $^{137}$Cs $^{7}$Be activity in rainwater, and deposition on soil surface and also content in suspended sediment during each flood generated by rainfall and snowmelt (see as the example Fig. 1,2 and 3). A samples of wet and dry fallout were collected after each rainfall and snowfall event at meteorological station (420 m a.s.l. l.) of Homerka Laboratory of Fluvial Processes. Vertical activity distribution of $^{7}$Be has been determined of soil cores collected at different inter arrival time of heavy rainfall and snowmelt. A 75 mm diameter steel corer was used to collect soil cores to depths of 50 cm for the majority of these measurements, and in most cases the cores were sectioned at 2 cm intervals prior to analysis. Where more detailed information of the vertical distribution of $^{7}$Be within a soil profile was required, samples were collected at 5 – 10 mm depth increments using a 40 x 20 cm steel frame and scraper in order to obtain samples of adequate mass for analysis. Bulk samples of stream water were collected from gauging stations of the Homerka stream and its tributaries and within the experimental slope from outlet of unmetalled road and Holocene gully during periods of flood discharge when suspended sediment concentrations exceed ca. 20 mg l$^{-1}$. Recently deposited on streambed fine sediment samples were collected from 16 locations along the mainstream channel of the Homerka stream and its tributaries during each limb flood flow conditions. Measurements were
made on the < 63 µm size fraction.

Information on suspended sediment sources was assembled using the „fingerprinting“ approach (cf. Froehlich & Walling 1997, 2003, 2005). Samples of surface material from potential sources (forest, pasture, cultivated areas, unmetalled roads, gully walls and channel banks) were collected from an area of 1 m², using steel frame. The < 0.063 mm fraction of the source materials was therefore separated for gamma spectrometry analysis and the resultant values of radionuclide content were used for comparisons with those associated with the suspended sediment.

The water samples ranged between 200 and 1000 l in volume were withdrawn from the stream into 120 l plastic containers using an electromagnetic pump. Occasional bulk samples were also collected during flood event from sites upstream of main gauging stations of the Homerka and Bacza stream. The suspended sediment was recovered from the bulk water samples by sedimentation and centrifugation, and the <0.063 and >0.063 mm fractions were separated by wet sieving.

All soil and sediment samples were dried at 105°C, disaggregated and passed through a 2 mm sieve before being packed into 500 ml Marinelli-beakers for gamma-ray spectrometry using an ORTEC HPGe N-type coaxial detector with 45% relative efficiency, calibrated with Soil Standard Reference Materials: IAEA Soil-6; IAEA Soil-375 and IAEA Soil-327. The activities of \(^{210}\text{Pb}_{\text{ex}},^{226}\text{Ra},^{7}\text{Be}\) and \(^{137}\text{Cs}\) are determined from the photopeaks produced at 46.52; 185.99; 477.56 and 661.62 respectively. Count times were of 42 300 – 84 600 s and provided results with a precision of the order of ± 5% at the 95% level of confidence.

**Results obtained since October 2004**

In order to obtain input reference data of \(^{210}\text{Pb}_{\text{ex}},^{226}\text{Ra},^{7}\text{Be},\) and \(^{137}\text{Cs}\) samples of rainwater was processed by gamma ray spectrometry. Eight plastic containers of 60 l capacity with glass funnel of 40 cm diameter (total sampling area ca. 1 m²) were installed for sampling dry and wet fallout. The samples of rainwater were collected during each rainfall or snowfall events (cf. Baskaran, 1995; Walbrink & Murray, 1996). Due to its very short half-life, the \(^{7}\text{Be}\) activity was measured immediately after sampling. The relationship between depth of rainfall and fallout of \(^{210}\text{Pb}_{\text{ex}},^{226}\text{Ra},^{7}\text{Be},\) and \(^{137}\text{Cs}\) activity was determined (Fig. 1).

The amount of the \(^{7}\text{Be}\) deposited on the soil surface depends on the depth of rainfall. In order to compare the \(^{7}\text{Be}\) deposited within different land use with a know input, the total input of \(^{7}\text{Be}\) in wet and dry fallout to Homerka drainage basin was measured since January 2001. Individual rainfall measurements included preceding dry fallout to the collection funnels and thus represented the total fallout input. The average total annual fallout to the site was 3750 ± 150 Bq m⁻² yr⁻¹.

In this area the \(^{7}\text{Be}\) occurred on average to penetrate between 5 and 25 mm, whereas about 90% of the total \(^{137}\text{Cs}\) activity was detected in the top 5 to 20 cm of the soil profile. It is therefore capable of providing good discrimination between sediment derived from the immediate soil surface and that derived from depths >20 mm where concentrations will be effectively zero. Monitoring of the spatial distribution of \(^{7}\text{Be}\) activity across plots bounded by terraces, immediate after heavy rains provide a basis for investigating sediment mobilised by sheet and rill erosion and sediment production from unmetalled roads.

Soil particles under forest litter had lower \(^{7}\text{Be}\) activity than particles from similar depth of ploughed field, while in permanent pasture \(^{7}\text{Be}\) concentration was higher at greater depths. This is evident that canopy interception is an important factor in reducing fallout to forest soil surface. On the average, total inventories of arable soils are lower than in grass covered soils as a result of soil erosion processes linked to short time-scale of events. The results show that \(^{7}\text{Be}\) diffusion is connected with land use and soil surface cover.

In undisturbed soil profile the \(^{210}\text{Pb}_{\text{ex}},^{226}\text{Ra},^{7}\text{Be},\) and \(^{137}\text{Cs}\) activity decreased exponentially with depth. The changes in \(^{210}\text{Pb}_{\text{ex}},^{226}\text{Ra},^{7}\text{Be},\) and \(^{137}\text{Cs}\) activity during transition from diffuse wash to rill and gully erosion in unmetalled roads are find the reflection with the decrease in the \(^{210}\text{Pb}_{\text{ex}},^{226}\text{Ra},^{7}\text{Be},\) and \(^{137}\text{Cs}\) concentration in suspended sediment during each flood events (see as the example Fig. 2 and 3).
Fig. 1 The relationship between depth of rainfall and $^{210}\text{Pb}_{\text{ex}}$, $^{226}\text{Ra}$, $^7\text{Be}$ and $^{137}\text{Cs}$ activity at 420 m a.s.l.

**Discussion of results**

In mountain environment most important for sediment mobilisation and delivery are small drainage basins in headwater areas. The relationship between erosion, sediment redistribution and storage and sediment transfer in a mountain headwater areas cover the various pathways and linkages within the fluvial system. The main problem is to identify linkages between the sediment source and the stream channel.

During extreme rainfalls, a greatly expanded contributing area could mobilise sediment in areas, which are unconnected to the stream under 'normal' events. However, there is a lack of field evidence that demonstrates sediment delivery dynamics during individual extreme rainfall.

It should also be emphasized that only samples from a single flood event should be used to examine the main sediment source of fallout $^{210}\text{Pb}_{\text{ex}}$, $^7\text{Be}$ and $^{137}\text{Cs}$ in sediment samples, because sediment deposited during different storm events may originate from various sources with different radionuclide contents. Sediment mobilised by diffuse surface flow from the surface of a forest, permanent pasture and a ploughed field will have a significantly higher radionuclide content than that derived by linear flow from unmetalled road and gullies.
Fig. 2 Variation in the $^{210}\text{Pb}_{\text{ex}}$, $^{226}\text{Ra}$, $^7\text{Be}$ and $^{137}\text{Cs}$ content of the <0.063-mm fraction of suspended sediment transported by the Homerka stream during a flood in July 2004.

Fig. 3 The relationship between discharge at main gauging station of Homerka stream and $^{210}\text{Pb}_{\text{ex}}$, $^{226}\text{Ra}$, $^7\text{Be}$ and $^{137}\text{Cs}$ activity of suspended sediment.

Concentrations of $^{210}\text{Pb}_{\text{ex}}$, $^{226}\text{Ra}$, $^7\text{Be}$, $^{134}\text{Cs}$ and $^{137}\text{Cs}$ in the < 63 μm size fraction of sediment samples collected from along the Homerka channel generally decrease towards the mouth indicating a greater contribution from hillslope sources along the stream. The contribution of hillslope and channel bank (combined roads, gully) erosion to stream sediments was assessed using activity of $^{210}\text{Pb}_{\text{ex}}$, $^{226}\text{Ra}$, $^7\text{Be}$ and $^{137}\text{Cs}$, which are concentrated in surface soil. Sediments derived from hillslope erosion by diffuse surface flow have high concentrations of these radionuclides. While
those eroded from gullies or channels have little or none. By measuring the concentration in suspended sediments transporting down the stream, and comparing them with concentrations in sediments derived by diffuse surface flow and linear erosion from hillslope and bank channel erosion we determined the contributions of each of these processes for understanding the influence of short-term land use changes.

Conclusions
The study reported confirms the capability that conjunctive use of the \(^{210}\text{Pb}_{\text{ex}}, {^{226}}\text{Ra}, {^{7}}\text{Be} \text{ and } {^{137}}\text{Cs}\) can provide additional information on the short-term sediment mobilisation and sediment delivery within a small drainage basin in Polish Flysch Carpathians. The various diffusion characteristics of the \(^{210}\text{Pb}_{\text{ex}}, {^{226}}\text{Ra}, {^{7}}\text{Be} \text{ and } {^{137}}\text{Cs}\) in undisturbed soils can be useful to identify depth of surface erosion during different events. In mountain areas, where altitudinal variations in rainfall, the importance of snow cover in distribution of the \(^{7}\text{Be}\) and the accelerated runoff generation necessitate modifications in sampling strategy. The acquaintance of the wet and dry fallout and surface deposition of the \(^{7}\text{Be}\) is an important step in a study of sediment mobilisation and sediment delivery dynamics in the scale of slope and a small drainage basin.

An improved knowledge of the soil erosion and sediment delivery dynamics of the area is required to provide a basis for developing improved land management and soil conservation strategies both for environmental protection and sustainable land use and for reducing rates of reservoir siltation. It is clear that any attempt to reduce the sediment yield of the study catchment would need to target the network of unmetalled roads in the catchment, with a view to reducing surface runoff and sediment mobilization from these sediment sources and attenuating the transfer of sediment from the roads to the stream system, by, for example, diverting runoff to temporary sinks.

References


Development, validation and documentation of improved conversion models for use in deriving estimates of soil redistribution rates from $^{137}\text{Cs}$, excess $^{210}\text{Pb}$ and $^7\text{Be}$ measurements

D.E. Walling
Sediment Research Centre,
Department of Geography,
University of Exeter, UK

Contract Number UK/12094

Conversion model validation

Further attention has been directed to the validation of existing assumptions and representations of $^{137}\text{Cs}$ behavior associated with conversion models used to estimate erosion rates, through collaboration with Dr Paolo Porto, an Italian colleague based in the University of Reggio Calabria. This work has again exploited the $^{137}\text{Cs}$ and sediment yield data available for three small uncultivated catchments (1.47, 1.38 and 1.65) located near Crotone in southern Italy, and has focused on comparing the $^{137}\text{Cs}$ content of sediment collected at the catchment outlets with that of surface soils within the catchment and the spatial pattern of sediment mobilization indicated by $^{137}\text{Cs}$ measurements undertaken on cores collected from the catchments. The data available for the Crotone catchments are also now being used to validate the use of $^{210}\text{Pb}$ measurements and associated conversion models to estimate erosion rates in these catchments. The approach being taken is similar to that used for $^{137}\text{Cs}$ in previous work within the framework of IAEA Contract 12094, since cores collected from the catchments have now been analyzed for excess $^{210}\text{Pb}$, as well as $^{137}\text{Cs}$. Further work in collaboration with Dr Paolo Porto is also in progress to use the information on the excess $^{210}\text{Pb}$ content of eroded sediment available for nine small erosion plots (3 @ 33m long and 6 @ 22m long) located near Gallina di Reggio Calabria in southern Italy to validate the use of this radionuclide and associated conversion models for estimating erosion rates. Measurements of the excess $^{210}\text{Pb}$ activity undertaken on the samples permit the relationship between excess $^{210}\text{Pb}$ and soil loss from the plots to be explored on an event basis. This affords a means of validating the basic premise underlying all conversion models i.e. that the loss of radionuclide from the soil profile is directly related to the loss of soil from the profile. This basic premise has rarely been rigorously tested to date.

Model specification

This work has focused on developing an improved understanding of the key mechanisms and process representations incorporated into existing conversion models for both $^{137}\text{Cs}$ and excess $^{210}\text{Pb}$. Recent work during the reporting period has focused on, firstly, defining the relaxation depth used to characterize the depth distribution associated with the initial distribution of fresh fallout, which is an important parameter in several conversion models, and, secondly, exploring the influence of changes in grain size and organic matter content associated with erosion and sediment transfer processes on the $^{137}\text{Cs}$ and excess $^{210}\text{Pb}$ content of that sediment. Experimental studies, involving the application of $^{134}\text{Cs}$ and $^7\text{Be}$ to a range of soils, using a rainfall simulator, are being used to establish both the form of the initial distribution and its short-term evolution and size fractionation experiments are being used to explore the effects of changes in grain size composition and organic matter content on radionuclide activities.

Model implementation

The software developed for the former CRP was restricted to conversion models for use with $^{137}\text{Cs}$ measurements. There is now a need to extend this to include excess $^{210}\text{Pb}$ and $^7\text{Be}$ measurements. In addition, there is a need to take advantage of recent developments in programming, to make the software more interactive and user-friendly and more easily coupled with other software, such as
Excel spreadsheets. This will reduce user dependence on written instructions. During the reporting period, work has been completed on updating and improving the existing conversion model software and transferring this to an improved interactive form and on developing additional software routines for the implementation of $^{210}\text{Pb}$ and $^{7}\text{Be}$ conversion models. A revised set of notes has been produced to accompany the software.

**Use of $^{137}\text{Cs}$ measurements to assess changes in soil erosion rates associated with a change from conventional tillage to no-till management**

This work has been undertaken in collaboration with Professor Paulina Schuller another member of the CRP. It addresses the potential for using $^{137}\text{Cs}$ measurements to assess the impact of a change from conventional tillage to no-till management practices on rates of soil loss. Used conventionally, $^{137}\text{Cs}$ measurements afford a means of estimating the average rate of soil loss over a period extending from the onset of $^{137}\text{Cs}$ fallout in the mid to late 1950s to the time of sampling (i.e. over ca. 45-50 years). Existing applications and procedures do not provide a basis for using $^{137}\text{Cs}$ measurements to assess changing erosion rates during this period. Working with Professor Schuller a novel procedure has been devised which permits use of $^{137}\text{Cs}$ measurements to establish erosion rates both under the period of conventional tillage and under the subsequent no-till management (Schuller et al., 2004). This procedure has been interfaced with existing conversion models. To our knowledge, this represents the first successful attempt to use $^{137}\text{Cs}$ to establish erosion rates under different management practices. Results from a study undertaken at Buenos Aires farm in Southern Chile have been submitted for publication.

**Developing appropriate and effective sampling strategies to permit the use of $^{137}\text{Cs}$ measurements in reconnaissance surveys of soil erosion rates.**

Existing sampling strategies for use in investigations aimed at using $^{137}\text{Cs}$ and excess $^{210}\text{Pb}$ measurements to estimate erosion rates are aimed primarily at individual fields or similar small areas. There is a growing interest in the potential for using $^{137}\text{Cs}$ and excess $^{210}\text{Pb}$ measurements to assess soil erosion rates over larger areas and to provide information for use in regional and national soil erosion assessments/inventories. To make this possible, there is a need to develop sampling strategies requiring smaller numbers of samples, which are more suited to reconnaissance measurements. Work has been undertaken to establish protocols for using a relatively small number of $^{137}\text{Cs}$ or $^{210}\text{Pb}$ measurements to obtain representative estimates of rates of soil loss from a landscape. The approach adopted involves the assembling of detailed information for small areas and testing the ability of a greatly reduced number of samples collected from carefully selected locations to reproduce the erosion rate values obtained from the more intensive sampling programme.

**Exploring other applications of $^{137}\text{Cs}$ measurements in soil erosion investigations.**

Most existing applications of $^{137}\text{Cs}$ measurements relate to detailed investigations of small areas and, more particularly, estimation of point erosion rates from $^{137}\text{Cs}$ measurements undertaken on individual cores. The work undertaken within (5) above represents one attempt to use $^{137}\text{Cs}$ measurements in a reconnaissance mode. Another rather different approach developed in collaboration with Professor Xinhao Zhang, who is also a member of the CRP, attempts to assemble more generalized information on surface erosion rates within an area by exploiting the potential for using $^{137}\text{Cs}$ measurements undertaken on lake and reservoir deposits to characterize erosion rates in the contributing catchment. By documenting the rate of decrease of $^{137}\text{Cs}$ activity with depth in a lake sediment core, it is possible to derive an estimate of the average rate of surface lowering or erosion within the catchment contributing to the lake or reservoir from which the sediment core was collected. A key advantage of this approach is that a small number of measurements undertaken on a sediment core can provide estimates of the average erosion rate in the entire catchment draining to the lake or reservoir. In addition the estimated erosion rate represents the average rate of surface lowering from the eroding areas within the catchment. It is well known that soil erosion will
frequently only affect parts of a catchment and this approach provides a means of estimating the average rate of soil loss from those areas, rather than the average rate of soil loss from the entire catchment. The latter value will frequently underestimate on-site erosion problems, since erosion rates could exceed the soil loss tolerance in the eroding areas, but be significantly less than the soil loss tolerance when averaged over the entire surface area of a catchment.

Results obtained and discussion

Model validation

Some results from the validation work undertaken in the Crotone catchment in southern Italy were presented at the International Symposium on Sediment Budgets held in Foz do Iguacu, Brazil in April 2005 and included in the paper: Investigating sediment sources within a small catchment in southern Italy, that was recently published in IAHS Publication no. 291 (pp. 113-122). The results provide clear evidence of the consistent relationship between the spatial variability of the $^{137}$Cs content of surface soils and the spatial distribution of erosion rates within the catchment and in turn provide valuable confirmation of both the key assumptions of sediment source fingerprinting investigations and the use of $^{137}$Cs as an important fingerprint property. Some results of the ongoing work aimed at comparing the estimates of net soil loss from the Crotone catchments, based on excess $^{210}$Pb measurements, with the measured sediment yields from the catchments were presented at the IASWS Symposium in Slovenia in early September 2005. This study provides a much-needed empirical validation of the use of excess $^{210}$Pb measurements for estimating erosion rates and to the author’s knowledge it is the first attempt to provide such empirical validation.

Model Specification

As indicated above, work on this topic during the reporting period has focused on two areas. The first involved establishing an improved basis for deriving the estimates of relaxation depth for the initial depth distribution of fresh fallout required by several of the conversion models. This has involved a series of experiments aimed at simulating the response of a range of soil types to fresh fallout of $^{134}$Cs and $^{7}$Be. Some results of these experiments undertaken with $^{134}$Cs are presented in Figures 1 and 2. These relate to a single soil and represent the depth distribution of $^{134}$Cs measured shortly after a simulated rainfall event (Figure 1) and 10 days later (Figure 2). Both Figures 1 and 2 emphasize the shallow nature of the initial distribution of fallout and thus the low values of the relaxation depth parameter involved and the need for precise estimates of this important parameter. However, it is clear that some redistribution of $^{137}$Cs has occurred during the period prior to the determination of the second depth distribution. These results are being combined with other experimental results and existing empirical information to develop improved guidelines for establishing appropriate values of relaxation depth for the initial distribution of recent fallout for use with $^{137}$Cs, $^{7}$Be and excess $^{210}$Pb conversion models. The second area has involved experimental investigations of the effects of grain size selectivity and organic matter enrichment/depletion, associated with sediment mobilization and transport and their influence on radionuclide activities. This has again led to improved characterization of particle size/organic matter correction factors for use in existing conversion models.

Model implementation

The initial stage of developing conversion models for application to excess $^{210}$Pb and $^{7}$Be measurements, to complement the suite of $^{137}$Cs conversion models developed under the previous CRP has been completed. For $^{210}$Pb, these models include a mass balance models equivalent to MBM2 and MBM3 for use for cultivated sites and a diffusion and migration model for use for uncultivated sites. For $^{7}$Be, a single conversion model, applicable to both cultivated and uncultivated sites, has been provided. The software for implementing these new models for use with excess $^{210}$Pb and $^{7}$Be measurements has been produced as an Addin to run within Excel and has been designed to be more user friendly than the software formerly developed for the $^{137}$Cs conversion models. The $^{137}$Cs conversion models have also been updated (e.g. to include Chernobyl
inputs) and transferred to this new Addin software package so that the models for all three radionuclides are fully compatible and integrated. By incorporating ‘Help Information’ into the programme, by restricting the range of values that can be input for specific parameters to ensure that the programme is not run with unrealistic values and by avoiding ‘hard-coded’ folder paths and data file locations, the software is considerably more flexible and easy to use. The notes originally produced to accompany the 

\[ ^{137} \text{Cs} \]

software have been fully revised and updated, to include information on all three radionuclides and to reflect the new interactive form of the software.

Figure 1 The depth distribution of \n\[ ^{134} \text{Cs} \]

in a soil monolith shortly after a simulated rainfall event.

![Figure 1](image1.png)

Figure 2 The depth distribution of \n\[ ^{134} \text{Cs} \]

in a soil monolith 10 days after the same simulated rainfall event.

**Use of \n\[ ^{137} \text{Cs} \]

measurements to assess changes in soil erosion rates associated with a change from conventional tillage to no-till management**

The procedure for using \n\[ ^{137} \text{Cs} \]

measurements to assess changes in soil erosion rates associated with a change from conventional tillage to no-till management, developed in collaboration with Professor Paulina Schuller, was initially tested using data from a field at Buenos Aires farm near Carahue in the 9th region of Chile. Further sampling in the same study area has since been undertaken, with a view to obtaining a more definitive assessment of the impact of the shift from conventional tillage to no-till management, on both gross and net erosion rates. The results of this work have been submitted for publication. The key findings presented here as Table 1 indicate that in the field investigated, the switch to no-till management reduced the overall net soil loss by nearly 90%, from 1.1 to 0.12 kg ha\(^{-1}\) year\(^{-1}\). This was achieved by a major change in the sediment delivery ratio. Previously all of the eroded soil was exported from the area investigated, whereas after the conversion to no-till, significant deposition occurred over 43% of the area. Erosion rates were found to increase slightly on the eroding areas, but their areal extent was greatly reduced. The reduced eroding area, coupled with the increased deposition account for the greatly reduced net soil loss.

**Developing appropriate and effective sampling strategies to permit the use of \n\[ ^{137} \text{Cs} \]

measurements in reconnaissance surveys of soil erosion rates.**

Emphasis has been placed on testing the viability of using a small number of samples collected from a carefully positioned transect within a field, to obtain an estimate of the gross and net erosion rate in that field. By focusing on fields with relatively simple topography (i.e. parallel contours), it
is possible to assemble information from a wide range of landscape types, in order to assess the influence of soil type, slope angle, slope length (field size), land use, management practice etc. To a degree, this approach to assembling information on erosion rates could be seen as analogous to the establishment of erosion plots at a wide range of locations, to sample soil types, slope angles etc. However, it exploits the key advantages of the $^{137}$Cs approach, namely the ability to obtain retrospective information on medium-term average erosion rates from a single site visit and the ability to sample representative ‘natural’ field units, rather than artificially defined plots, as well as avoiding the need for costly installations and long-term operation.

Table 1. Soil redistribution rates estimated for the two contrasting management periods using the simplified approach.

<table>
<thead>
<tr>
<th>Eroding zone:</th>
<th>Conventional tillage period</th>
<th>No-tillage period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean erosion rate (kg m$^{-2}$ y$^{-1}$)</td>
<td>1.1 ± 0.2</td>
<td>1.3 ± 0.2</td>
</tr>
<tr>
<td>Fraction of total area (%)</td>
<td>100</td>
<td>57</td>
</tr>
<tr>
<td>Mean sedimentation rate (kg m$^{-2}$ y$^{-1}$)</td>
<td>0.0</td>
<td>1.4 ± 0.2</td>
</tr>
<tr>
<td>Fraction of total area (%)</td>
<td>0.0</td>
<td>43</td>
</tr>
<tr>
<td>Net erosion rate (kg m$^{-2}$ y$^{-1}$)</td>
<td>1.1 ± 0.2</td>
<td>0.12 ± 0.2</td>
</tr>
<tr>
<td>Sediment delivery ratio (%)</td>
<td>100</td>
<td>19</td>
</tr>
</tbody>
</table>

The ability of reconnaissance sampling to provide reliable/meaningful estimates of erosion rates for particular fields is demonstrated by the data presented in Table 2, which compares erosion rate estimates for a range of fields in southern England, derived from detailed $^{137}$Cs sampling (e.g. grid sampling with ca. >150 samples per field), with those obtained using the reconnaissance transect approach (e.g. ca. 12 samples). These results indicate that the estimates of both gross soil loss and net soil loss obtained using the reconnaissance sampling protocols are closely similar and fully consistent with those obtained using more intensive sampling programmes. Work on applying the reconnaissance sampling protocol is in progress, with a view to assembling a representative data base on rates of soil loss in southern England, which can in turn be used to support the development of soil erosion indicators, as well as a more general assessment or inventory of soil erosion and associated on-site and off-site impacts.

Table 2 A comparison of erosion rate estimates for selected fields obtained using a reconnaissance sampling protocol with those obtained by more intensive sampling.

<table>
<thead>
<tr>
<th>Location</th>
<th>Land use</th>
<th>Gross soil loss (t ha$^{-1}$ yr$^{-1}$)</th>
<th>Gross soil loss (t ha$^{-1}$ yr$^{-1}$)</th>
<th>net soil loss (t ha$^{-1}$ yr$^{-1}$)</th>
<th>net soil loss (t ha$^{-1}$ yr$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crediton</td>
<td>Arable</td>
<td>7.1 <em>(A)</em></td>
<td>6.2 <em>(B)</em></td>
<td>0.57 *(A)</td>
<td>0.68 *(B)</td>
</tr>
<tr>
<td>Yeovil</td>
<td>Arable</td>
<td>8.7 <em>(A)</em></td>
<td>9.7 <em>(B)</em></td>
<td>6.3 *(A)</td>
<td>5.7 *(B)</td>
</tr>
<tr>
<td>Yeovil</td>
<td>Grass</td>
<td>1.7 <em>(A)</em></td>
<td>2.1 <em>(B)</em></td>
<td>0.2 *(A)</td>
<td>0.2 *(B)</td>
</tr>
<tr>
<td>Cadeleigh</td>
<td>Grass</td>
<td>0.44 <em>(A)</em></td>
<td>0.58 <em>(B)</em></td>
<td>0 *(A)</td>
<td>0 *(B)</td>
</tr>
<tr>
<td>Crediton</td>
<td>Arable</td>
<td>9.1 <em>(A)</em></td>
<td>8.3 <em>(B)</em></td>
<td>4.4 *(A)</td>
<td>3.6 *(B)</td>
</tr>
<tr>
<td>Cadeleigh</td>
<td>Arable</td>
<td>5.4 <em>(A)</em></td>
<td>6.2 <em>(B)</em></td>
<td>0.8 *(A)</td>
<td>0.5 *(B)</td>
</tr>
</tbody>
</table>

Column A is from intensive sampling and B is from the application of the protocol
Exploring other applications of $^{137}$Cs measurements in soil erosion investigations.

The novel approach for using $^{137}$Cs profiles to derive information on average rates of surface lowering within the upstream catchment, developed in collaboration with Professor Xinbao Zhang, is described in detail in a paper published in *Journal of Environmental Quality*, (Zhang and Walling, 2005). Initial work on validating the approach made use of data from lakes and reservoirs in both the UK and China. The catchments of these lakes and reservoirs were characterized by a wide range of sediment yields and the estimates of erosion rates obtained from the $^{137}$Cs profiles measured in cores collected from the water bodies were highly consistent with the sediment yield information and existing understanding of both the sediment delivery ratios of the catchments and the likely spatial distribution of significant erosion rates. Estimates of the relative contribution of the catchment surface and gully and channel erosion to the sediment output from the catchment were also obtained.

References

Soil quality evaluation of agricultural soils under conventional, conservation and no tillage systems using the concept of a Soil Quality Index (SQI)

Andreas Klik and Johanna Hofmann  
Institute of Hydraulics and Rural Water Management;  
Department of Water, Atmosphere and Environment  
University of Natural Resources and Applied Life Sciences Vienna, Austria  
Muthgasse 18, A-1190 Vienna, Austria

Abstract  
Changes in land use and higher environmental standard also demand changes in agricultural management practices. Modern agriculture needs to combine increasing crop yields with decreasing equipment and labour input and to reduce negative environmental impact. Soil management practices with reduced tillage practices are often named as a possible solution. Agriculture and its sustainability have become a major topic in recent years. The investigation and evaluation of different tillage practices and the assessment of soil quality as an indicator for sustainability are nowadays an issue of wide public concern and international debate. The objective of this study was to develop and adopt a model to assess changes of soil quality due to agricultural practices. This is achieved by computing a soil quality index for three different sites of agriculturally used soils in Lower Austria (Hofmann, 2005). Since 1994 the impact of conventional, conservation tillage and direct seeding is investigated at three sites in Lower Austria. The field studies included continuous measurement of surface runoff, erosion and determination of crop yield. Main physical, chemical and biological parameters were determined: aggregate stability (agg. stab.), porosity (POR), total organic carbon (Corg), bulk density (BD), rooting depth (root), total nitrogen (Ntot), pH, total phosphorus (Ptot) and plant available water capacity (PAWC) were determined using standard methods. A scoring system was applied and controlled by sensitivity analyses. Soil quality was evaluated using a framework including three soil functions: (1) sustaining biological activity (provide a favourable environment for plants, provide water and nutrients) (2) regulating and partitioning water (3) filtering and buffering. Each function was defined by indicators. The indicators were then normalized using linear as well as nonlinear scoring functions. Three types of scoring functions were applied depending on the character of the soil indicator (a) more is better, (b) optimum or (c) worse. The individual scores were multiplied by weighting factors and combined by addition into an overall Soil Quality Index. Three different sets of weights were developed from a basic framework and applied for calculation. An improvement of soil quality under reduced tillage was assessed by the applied soil quality model. The results of the field survey (lower soil erosion, higher water retention capacity), laboratory tests (higher amount of organic carbon, higher aggregate stability) and crop yield measurements confirmed the calculation of the Soil Quality Index (SQI). Computing soil quality indices helped to combine different soil properties and processes into a simple tool that explained changes due to different tillage practices. The results support previous studies suggesting that calculation of soil quality indices can be useful for selecting management practices to maintain or improve soil quality. It was demonstrated that adjusting the system for local conditions can make the function ratings more or less sensitive to the management practices being evaluated.

Introduction  
Soil quality has been defined as "the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation" (Karlen et al., 1997). Evaluating the
impact of agricultural practices on soil functions is essential to determine the sustainability of management systems. Various concepts have been developed to assess soil quality, including those that focus on indices assessing soil productivity (Neil, 1979; Pierce et al., 1983) and tilth (Singh et al., 1992). Prior efforts often quantified only the physical state of soil and did not consider environmental aspects. Acton and Gregorich (1995) stressed the importance of selecting appropriate indicators which could be measured and which influenced the capacity of a soil to perform various crop production or environmental functions. For Doran et al. (1996) soil quality indicators should be sensitive enough to detect effects, however they quantified only the physical state of soil and did not consider environmental aspects.

The physical quality of agricultural soils refers primarily to the soils strength and fluid transmission and storage characteristics in the crop root zone (Topp et al., 1997). An agricultural soil with "good physical quality" is "strong" enough to maintain good structure, holds crops upright and resists erosion and compaction but also "weak" enough to allow unrestricted root growth and proliferation of soil flora and fauna. Soil with good physical quality also has fluid transmission and storage characteristics that permit the correct proportions of water, dissolved nutrients and air for both maximum crop performance and minimum degradation (Topp et al., 1997).

Larson and Pierce (1994) discussed the need to assess how soils were functioning with regard to environmental issues. They proposed three different functions associated with good soil quality: (1) function as a medium for plant growth, (2) regulating and partitioning water flow through the environment and (3) serving as an environmental filter and buffer for agrochemicals. To perform these functions, they stated that high quality soil accepts, holds and releases nutrients and water, promotes and sustains root growth, maintains suitable soil biotic habitat, responds to management and resists degradation.

A common approach to assess soil quality is through single indicator-single response studies. These studies are useful for understanding the impact of singular components but they do not provide a comprehensive appraisal of agro-ecosystem performance. One approach that perhaps comes closer to assessing the impact of management on multiple soil functions involves the use of performance-based indices (Karlen and Stott, 1994) based on the general method of multi-attribute ranking. Numerical values for each soil quality indicator were converted into unitless scores ranging from 0 to 1. The score of each indicator was calculated from established lower, baseline and upper threshold limits. Indicators are categorized into elements within specific soil functions and then they are weighted based on their relative importance within the soil system. This approach has been demonstrated to be particularly useful in comparing management systems (Harris et al., 1996, Hussain et al. 1999). To assess soil quality Larson and Pierce (1994) suggested measuring various soil attributes or indicators that controlled or are influenced by the various soil functions.

Arshad and Coen (1992) used soil depth to a root restricting layer, available water holding capacity, bulk density or penetration resistance, hydraulic conductivity, aggregate stability, soil organic matter content, nutrient availability, pH and electrical conductivity, as soil quality indicators because those measurements are generally responsive to management practices. Similarly, Larson and Pierce (1994) suggested a minimum data set for assessing soil quality, however, they substituted particle size distribution for aggregate stability.

Doran and Parkin (1994) mentioned that soil quality could be quantified by using regression equations that describe relationships between the various soil quality indicators and the soil quality functions identified by Larson and Pierce (1994). Mausbach and Seybold (1998) used linear regressions as scoring functions. Due to the lack of regression equations Karlen et al. (1994a,b) adapted standardized scoring functions (SSFs) using a systems engineering approach (Wymore, 1993) to assess changes in soil quality. To quantify relationships between soil quality indicators and soil functions Karlen et al. (1994a, b) selected three Standard Scoring Functions (SSF) to normalize the indicators (Fig. 1). The scoring functions were (a) more is better, (b) optimum and (c) more is worse. Numerical values for each soil quality indicator were converted into unitless scores ranging from 0 to 1. The score for each indicator was calculated after establishing lower threshold limits,
baseline values and upper threshold limits with published values (Karlen and Stott, 1994) or expert opinion.

Fig. 1 Standard scoring function (SSF) used for normalization of soil quality indicators

Karlen et al. (1994a, b) calculated individual ratings for four soil functions: (1) accommodating water entry into the soil, (2) facilitating water transfer, adsorption and delivery, (3) resisting degradation and (4) supporting plant growth. Hussain et al (1999) used the SSF soil quality index approach to interpret an unvaried data set produced by Hussain (1997) and to relate soil properties measured in that field study to soil functions. The SSF technique was used to demonstrate how a soil quality index based on water and nutrient relations and rooting relations could be used to evaluate alternative soil management practices (Harris et al., 1996).

For this study a similar approach is made, as used by Mausbach and Seybold (1998), focusing on only three soil functions:

1. sustaining biological activity (BIO),
2. regulating and partitioning water (WATER),
3. filtering and buffering (FILTER)

Linear and non-linear scoring functions with different weights were used and compared.

Materials and Methods

Site characteristics and management practices

The field experiments started in 1994 in Mistelbach and Pyhra and in 1997 in Pixendorf. All three sites are located in Lower Austria close to Vienna. A crop rotation of corn – small grains was applied. Soil textures ranged from silt loam to loam. Table 1 gives an overview of the key data of the experimental fields. The following treatments were investigated: (1) conventional tillage system (CT), (2) conservational tillage (CS) with cover crops during winter and (3) direct seeding (DS) with cover crops during winter.

Table 1. Key data of the experimental sites Mistelbach, Pixendorf and Pyhra

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mistelbach</th>
<th>Pixendorf</th>
<th>Pyhra</th>
</tr>
</thead>
<tbody>
<tr>
<td>latitude</td>
<td>16° 34' E</td>
<td>15° 58' E</td>
<td>15° 41' E</td>
</tr>
<tr>
<td>longitude</td>
<td>48° 34' N</td>
<td>48° 17' N</td>
<td>48° 09' N</td>
</tr>
<tr>
<td>soil texture</td>
<td>silt loam</td>
<td>silt loam</td>
<td>loam</td>
</tr>
<tr>
<td>sand (%)</td>
<td>9</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>silt (%)</td>
<td>71</td>
<td>64</td>
<td>53</td>
</tr>
<tr>
<td>clay (%)</td>
<td>20</td>
<td>25</td>
<td>38</td>
</tr>
<tr>
<td>slope (%)</td>
<td>12 - 13</td>
<td>5 - 6</td>
<td>15 - 16</td>
</tr>
<tr>
<td>total mean ann. precip. (mm)</td>
<td>645</td>
<td>687</td>
<td>947</td>
</tr>
<tr>
<td>mean ann. temp. (°C)</td>
<td>9,6 °C</td>
<td>10,4</td>
<td>9,4C</td>
</tr>
<tr>
<td>pH</td>
<td>8.1</td>
<td>7.3</td>
<td>6.5</td>
</tr>
</tbody>
</table>
Laboratory and field methods

At Mistelbach and Pyhra site the different tillage systems were in place eight years prior to the investigation, at Pixendorf site the change of the treatment systems was done six years prior to the investigation. Runoff and soil loss were measured from 15 m long and 3 - 4 m wide erosion plots throughout the whole period. Crop yield of 10 m² plots was determined. Soil loss and crop yield were used to evaluate the calculated soil index.

In 2002 (Mistelbach and Pyhra) and in 2003 (Pixendorf) soil samples were taken in fall after harvest of corn for chemical and physical analyses from 0 - 5 cm, 10 - 15 cm, 25 - 30 cm, 50 - 55 cm and 70 - 75 cm soil depth. To avoid potential slope induced differences in soil texture the samples were all taken at the same slope position at the upper third of the slope avoiding the tracks of the machinery. The rooting depth was also determined at that occasion.

Porosity and bulk density were determined from undisturbed soil samples of 200 cm³ volume. Soil pore size distribution was determined from soil water retention curves. The plant available water content (PAWC) was defined as the difference of soil water content at permanent wilting point (15 bar) and field capacity (0.3 bar).

In October 2004 samples for aggregate stability determination were taken from top 2.5 cm. Soil aggregate stability was determined by wet sieving method (Kemper and Koch, 1966).

Samples for chemical analyses were air-dried, crushed, mixed and passed through a 2 mm sieve. Total nitrogen and total carbon were determined by a C/N-element analyser, type varioMAX CN by Elementar. The organic carbon content was calculated as the difference of the total carbon content (C/N- analyser) and the inorganic carbon content (ÖNORM L 1084 (1988); Scheibler- Apparatus). Total phosphorus was determined following ÖNORM L 1085 (1989) using a UV/VIS spectral photometer (DU-640, Beckmann). The results of the chemical analyses were converted into tons per hectare by multiplying with the bulk density. Soil pH was determined in a 1:2.5 soil to water solution, following ÖNORM L 1083 (1989), using a glass electrode by Mentrohm.

Soil quality assessment

A soil quality framework was adopted to assess changes in soil quality due to agricultural practices. Soil quality was assessed using a scoring function system to evaluate soil indicators. Scoring functions and threshold values needed to normalize the indicator data and to assign values between 0 and 1 were taken from the following sources.

In 1983 Jones developed an empirical regression relationship to distinguish a "lower" and an "upper" critical bulk density for various soil textures. The lower boundary was defined by the value below which an effectively root growth is impeded. It was found to range from about 1.2 to 1.6 g/cm³ for soil with silt and clay contents ranging from 90 % to 10 %. The upper critical bulk density is also defined by root growth as the limiting factor and defined by 20 % of the root growth at the lower critical bulk density. Values for the upper critical bulk density were found at 1.4 to 1.8 g cm⁻³. Comparable upper critical limits were proposed by Veihmeyer and Hendrickson (1948) who found that root extension in clayey soils could stop completely at bulk densities of 1.5-1.6 g cm⁻³ and in loamy and sandy soils at densities of 1.6 - 1.8 g cm⁻³.

Good crop and root growth, health and function require additionally an adequate and well balanced soil air and soil water storage capacity. Substantial work over the last 30 years suggests that near-surface air-filled soil pore space (i.e. air capacity) should be at least 10 - 15 % (Grable and Simmer, 1968; Cockcroft and Olsson, 1997). It has also be proposed that plant-available water capacity should be > 20 % (Cockcroft and Olsson, 1997) or within the range of 15-20 % (Craul, 1999).

The carbon content of agricultural soil ranges at 0 % to 2.5 % (Scheffer/ Schachtschabel, 1998). Aggregate stability is a very dynamic parameter, therefore it is important to know the time of sampling for data interpretation. More stable aggregates reduce potential for erosion, soil crusting and surface runoff; therefore a higher amount of stable aggregates is desirable.

To quantify the effects of the three tillage systems on soil quality and to test the sensitivity of various indexing procedures the soil quality frameworks developed by Harris et al. (1996), Hussain et al. (1999) and Mausbach and Seybold (1998) were analysed and different variations were
obtained by modifying them. Variation of the framework included changing and adding additional indicator measurements and changing weighting factors for the indicators and soil functions. The general description for the three functions and their indices was as follows:

1) \( \text{BIO} = f (a_1 \text{root} + a_2 \text{BD} + a_3 \text{POR} + a_4 \text{PWC} + a_5 \text{pH} + a_6 \text{Ptot} + a_7 \text{Corg} + a_8 \text{Ntot}) \);
2) \( \text{WATER} = (b_1 \text{agg. stab.} + b_2 \text{POR} + b_3 \text{BD}) \);
3) \( \text{FILTER} = f (c_1 \text{agg. stab} + c_2 \text{POR} + c_3 \text{Corg} + c_4 \text{Ntot}) \),
where \( a_n, b_n, c_n \) = weighting factor for indices (Table 2).

The overall soil quality index was computed using the equation:

\[ \text{INDEX} = f (x_1 \text{BIO} + x_2 \text{WATER} + x_3 \text{FILTER}) \]

where \( x_n \) = weighting factor for each function.

Six soil quality indices were computed as a result of the combination of two different types of scoring functions (linear and nonlinear) and three different weighting systems with focuses on sustaining biological activity (BIO), regulation and partitioning water (WATER) and filtering and buffering (FILTER). To complete the evaluation the six overall soil quality indices and the individual function ratings were compared.

Table 2  Weighting factors for soil quality functions and indicators

<table>
<thead>
<tr>
<th>Soil Function</th>
<th>function weight</th>
<th>indicator weight</th>
<th>total indicator weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sustaining biological activity</td>
<td>0.6 0.2 0.4</td>
<td>bio water filter</td>
<td>bio water filter</td>
</tr>
<tr>
<td>Rooting medium</td>
<td>0.33 0.30 0.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>root depth</td>
<td>0.60</td>
<td>0.2 0.18 0.15</td>
<td></td>
</tr>
<tr>
<td>bulk density</td>
<td>0.40</td>
<td>0.13 0.12 0.1</td>
<td></td>
</tr>
<tr>
<td>Water relation</td>
<td>0.33 0.40 0.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>porosity</td>
<td>0.60</td>
<td>0.2 0.24 0.15</td>
<td></td>
</tr>
<tr>
<td>PAWC</td>
<td>0.40</td>
<td>0.13 0.16 0.1</td>
<td></td>
</tr>
<tr>
<td>Nutrient relations</td>
<td>0.33 0.30 0.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>0.30</td>
<td>0.1 0.09 0.15</td>
<td></td>
</tr>
<tr>
<td>total P</td>
<td>0.15</td>
<td>0.05 0.045 0.075</td>
<td></td>
</tr>
<tr>
<td>organic carbon</td>
<td>0.40</td>
<td>0.13 0.12 0.2</td>
<td></td>
</tr>
<tr>
<td>total nitrogen</td>
<td>0.15</td>
<td>0.05 0.045 0.075</td>
<td></td>
</tr>
<tr>
<td>Regulating and partitioning water</td>
<td>0.2 0.5 0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>aggregate stability</td>
<td>0.60 0.40 0.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>porosity</td>
<td>0.20 0.30 0.40</td>
<td>0.20 0.30 0.40</td>
<td></td>
</tr>
<tr>
<td>bulk density</td>
<td>0.20 0.30 0.30</td>
<td>0.20 0.30 0.30</td>
<td></td>
</tr>
<tr>
<td>Filtering and buffering</td>
<td>0.2 0.3 0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>aggregate stability</td>
<td>0.60 0.40 0.20</td>
<td>0.60 0.40 0.20</td>
<td></td>
</tr>
<tr>
<td>porosity</td>
<td>0.10 0.30 0.40</td>
<td>0.10 0.30 0.40</td>
<td></td>
</tr>
<tr>
<td>Microbial processes</td>
<td>0.30 0.30 0.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>organic carbon</td>
<td>0.50</td>
<td>0.15 0.15 0.2</td>
<td></td>
</tr>
<tr>
<td>total nitrogen</td>
<td>0.50</td>
<td>0.15 0.15 0.2</td>
<td></td>
</tr>
</tbody>
</table>

Results
Soil and crop properties
Reduced tilled soils (CS and DS) had significant lower long term average (1994 - 2004) soil loss rates than the conventionally tilled field whereas no significant differences could be found for long
term runoff. In addition, no significant differences in crop yield were observed between the investigated treatments (Table 3).

Table 3. Long-term average runoff, soil loss and sediment yield (1994-2004) from the investigated treatments

<table>
<thead>
<tr>
<th>Site</th>
<th>Mistelbach</th>
<th>Pixendorf</th>
<th>Pyhra</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CT</td>
<td>CS</td>
<td>DS</td>
</tr>
<tr>
<td>runoff in mm</td>
<td>8,04 a</td>
<td>2,72 b</td>
<td>4,54 a</td>
</tr>
<tr>
<td>soil loss in t/ha</td>
<td>3,52 a</td>
<td>0,68 b</td>
<td>0,63 b</td>
</tr>
<tr>
<td>relative crop yield to CT</td>
<td>100</td>
<td>94</td>
<td>92</td>
</tr>
</tbody>
</table>

1 Means within the same site followed by same letter are not significantly different at the P=0.5 probability level.

Generally soils under reduced tillage systems had higher plant available water capacity (PAWC) in the upper 70 cm, higher bulk density and higher aggregate stability. At all investigated sites aggregate stability increased significantly under CS and DS (Table 4). Soil pH did not differ among tillage systems, except in Pyhra where it was lower under direct seeding than under CS and CT. Differences in the amount of total nitrogen and phosphorus in the 0 - 20 cm depth were not uniform for all three sites. In Mistelbach (silt loam) the reduced tillage practices resulted in higher amount of stored nitrogen and had no effect on total phosphorus. In Pixendorf (silt loam) no effects due to tillage could be found for nitrogen but phosphorus varied for more than 5 % among the treatments (CS > CT > DS). In Pyhra (loam) total amount of phosphor and nitrogen increased under reduced tillage. The organic carbon content in the top 20 cm increased at all three sites under reduced tillage significantly (Table 4).

Tillage effects could not be classified as entirely negative or positive with regard to soil biological activity, water balance or filtering and buffering if every indicator was analysed separately. Therefore the soil quality framework was applied. Table 4 gives an overview of the obtained results from the laboratory measurements for the chosen parameters that are used to calculate the soil water index and the calculated unitless scores.

Table 4. Effect of tillage treatments on main physical and chemical properties

<table>
<thead>
<tr>
<th>Site</th>
<th>Mistelbach</th>
<th>Pixendorf</th>
<th>Pyhra</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CT</td>
<td>CS</td>
<td>DS</td>
</tr>
<tr>
<td>Aggregate stability % (0-2,5 cm)</td>
<td>8,0 b</td>
<td>10,4 a</td>
<td>11,6 a</td>
</tr>
<tr>
<td>Porosity % (0-70 cm)</td>
<td>48,1 a</td>
<td>46,4 a</td>
<td>44,6 b</td>
</tr>
<tr>
<td>organic carbon t/ha (0-20 cm)</td>
<td>13,8 b</td>
<td>17,6 a</td>
<td>19,0 a</td>
</tr>
<tr>
<td>Bulk density g/cm³ (0-50 cm)</td>
<td>1,4 b</td>
<td>1,4 b</td>
<td>1,5 a</td>
</tr>
<tr>
<td>Rooting depth cm</td>
<td>75,0 b</td>
<td>80,0 a</td>
<td>77,5 b</td>
</tr>
<tr>
<td>Total nitrogen t/ha (0-20 cm)</td>
<td>2,3 b</td>
<td>2,3 b</td>
<td>2,6 a</td>
</tr>
<tr>
<td>pH (0- 30 cm)</td>
<td>8,3 a</td>
<td>8,2 a</td>
<td>8,2 a</td>
</tr>
<tr>
<td>Total P t/ha (0-20 cm)</td>
<td>1,8 a</td>
<td>1,8 a</td>
<td>1,8 a</td>
</tr>
<tr>
<td>PAWC mm (0-70 cm)</td>
<td>118,3 a</td>
<td>109,7 b</td>
<td>123,1 a</td>
</tr>
</tbody>
</table>

1 For each row, values within the same site followed by same letter are not different for more than 5% in comparison to conventional tillage (CT).

Soil function indices

Table 5 to 7 show the calculated function indices with respect to sustaining biological activity (Table 5), regulation and partitioning water (Table 6) and filtering and buffering (Table 7), using linear (l) and nonlinear (nl) scoring functions and three types of weights. From these six results mean values were computed and compared.

For the indicators for sustaining biological activity (Table 5) none of the sites showed significant differences although at two sites (Pixendorf and Pyhra) the direct seeding (DS) had higher numerical values for the index representing biological activity. This indicates an improvement. The
non linear scoring functions show higher values than the linear functions but total indices range for Mistelbach from 0.41 to 0.68, for Pixendorf from 0.45 to 0.69 and for Pyhra from 0.39 to 0.44. Overall the spectrum of the results was narrow, because eight different parameters are influencing the function of sustaining biological activity and therefore a single indicator has not such a big impact on the final result.

Table 5. Function index for sustaining biological activity considering non linear (nl) and linear (l) scoring functions and different indicator weights (bio, water, filter)

<table>
<thead>
<tr>
<th>weights with focus</th>
<th>MISTELBACH</th>
<th>PIXENDORF</th>
<th>PYHRA</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT</td>
<td>CS</td>
<td>DS</td>
<td>CT</td>
</tr>
<tr>
<td>bio</td>
<td>0.66</td>
<td>0.51</td>
<td>0.61</td>
</tr>
<tr>
<td>water</td>
<td>0.68</td>
<td>0.54</td>
<td>0.63</td>
</tr>
<tr>
<td>filter</td>
<td>0.54</td>
<td>0.42</td>
<td>0.50</td>
</tr>
<tr>
<td>Mean</td>
<td>0.56</td>
<td>0.53</td>
<td>0.52</td>
</tr>
</tbody>
</table>

1 Type of scoring function: nl: non linear; l: linear
2 mean calculated index from the combination of type of scoring function and score, bold numbers indicate the maximum; cursive the minimum within a site
3 For each row, means within the same site followed by same letter are not significantly different at the P=0.5 probability level.

Table 6. Function index for regulation and partitioning water considering non linear (nl) and linear (l) scoring functions and different indicator weights (bio, water, filter)

<table>
<thead>
<tr>
<th>weights with focus</th>
<th>MISTELBACH</th>
<th>PIXENDORF</th>
<th>PYHRA</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT</td>
<td>CS</td>
<td>DS</td>
<td>CT</td>
</tr>
<tr>
<td>bio</td>
<td>0.40</td>
<td>0.49</td>
<td>0.39</td>
</tr>
<tr>
<td>water</td>
<td>0.59</td>
<td>0.60</td>
<td>0.55</td>
</tr>
<tr>
<td>filter</td>
<td>0.68</td>
<td>0.67</td>
<td>0.64</td>
</tr>
<tr>
<td>Mean</td>
<td>0.57</td>
<td>0.55</td>
<td>0.50</td>
</tr>
</tbody>
</table>

1 Type of scoring function: nl: non linear; l: linear
2 mean calculated index from the combination of type of scoring function and score, bold numbers indicate the maximum; cursive the minimum within a site
3 For each row, means within the same site followed by same letter are not significantly different at the P=0.5 probability level.

The results focusing on regulation and partitioning water are given in Table 6. They show the same pattern as those of the biological activity. For two sites an improvement in regulation and partitioning of water under reduced tillage (Pixendorf and Pyhra) was calculated. Nevertheless these differences are not significant. Overall the spectrum of the results was wider than for the biological indicator. Mistelbach ranged from 0.35 to 0.67, for Pixendorf from 0.37 to 0.70 and Pyhra 0.16 to 0.50. As this index is calculated only from three parameters the influence of each parameter is higher and therefore the spectrum of the results is broader.

At all three sites an improvement of the filtering and buffering function under reduced tillage practices could be calculated (Table 7). Direct seeding shows always the highest SQI whereas conventional tillage always the minimum. This difference is significant for the loamy soil in Pyhra. Results for Mistelbach ranged from 0.18 to 0.53, for Pixendorf from 0.19 to 0.58 and Pyhra 0.20 to 0.43.

The absolute values of the indices vary depending on the used combination of scoring function and weighting but the relative ranking of the treatments stays always the same. Differences between the index calculations are higher when less parameters were used for calculation.
Tillage had higher soil quality indices than under conventional tillage. This can be interpreted as an improvement of soil quality. The differences in the soil quality index were significant in Pixendorf (silt loam) with DS (0.58) > CS (0.54) > CT (0.51). The differences for Pyhra (loam) were not significant but numerically still high with DS (0.42) > CS (0.40) > CT (0.36). The fields in Mistelbach (silt loam) showed the opposite ranking of SQI but these differences are not significant with: CT (0.51) > CS (0.50) > DS (0.49). Overall it could also be observed, that the silt loam sites (Mistelbach and Pixendorf) had higher soil quality indices than the loam site (Pyhra).

The calculated SQI and function indices showed a big variation depending on the chosen scoring function or weighing system but the ranking of the sites was not influenced by that. This indicates that a change in the function weight would only change the absolute value but not the relative ranking. Therefore the model can be seen as stable regarding the output and depends only on the soil indicators and not on their scoring functions or weights of the indicators.

In terms of overall soil quality assessment, both field observations and the SQI indicated that reduced tillage practices resulted in the best overall soil quality. This reflects a better sustainability for biological activity, better regulation of water and improvement of the filtering and buffering function.

### Table 7. Function index for filtering and buffering considering non linear (nl) and linear (l) scoring functions and different indicator weights (bio, water, filter)

<table>
<thead>
<tr>
<th>weights with focus</th>
<th>MISTELBACH</th>
<th>PIXENDORF</th>
<th>PYHRA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CT</td>
<td>CS</td>
<td>DS</td>
</tr>
<tr>
<td>bio</td>
<td>nl</td>
<td>l</td>
<td>nl</td>
</tr>
<tr>
<td></td>
<td>0.18</td>
<td>0.27</td>
<td>0.22</td>
</tr>
<tr>
<td>water</td>
<td>nl</td>
<td>l</td>
<td>nl</td>
</tr>
<tr>
<td></td>
<td>0.38</td>
<td>0.41</td>
<td>0.40</td>
</tr>
<tr>
<td>filter</td>
<td>nl</td>
<td>l</td>
<td>nl</td>
</tr>
<tr>
<td></td>
<td>0.50</td>
<td>0.45</td>
<td>0.51</td>
</tr>
<tr>
<td>Mean</td>
<td>a</td>
<td>a</td>
<td>a</td>
</tr>
</tbody>
</table>

1 Type of scoring function: nl: non linear; l: linear
2 Mean calculated index from the combination of type of scoring function and score, bold numbers indicate the maximum; cursive the minimum within a site
3 For each row, means within the same site followed by same letter are not significantly different at the P=0.5 probability level.

### Soil quality index

The soil quality index values, calculated using different weighting factors (Table 2), focusing on sustaining biological activity, regulation and partitioning water and filtering and buffering respectively are presented in Table 8. The highest overall ratings for all indices in this study were associated with the direct seeding treatment. Similar differences among tillage systems were obtained by Karlen et al. (1994b). With the exception of Mistelbach (silt loam) soils under reduced tillage had higher soil quality indices than under conventional tillage. This can be interpreted as an improvement of soil quality.

Table 8. Soil Quality Indicators (SQI) considering non linear (nl) and linear (l) scoring functions and different indicator weights (bio, water, filter)

<table>
<thead>
<tr>
<th>weights with focus</th>
<th>MISTELBACH</th>
<th>PIXENDORF</th>
<th>PYHRA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CT</td>
<td>CS</td>
<td>DS</td>
</tr>
<tr>
<td>bio</td>
<td>nl</td>
<td>l</td>
<td>nl</td>
</tr>
<tr>
<td></td>
<td>0.51</td>
<td>0.46</td>
<td>0.49</td>
</tr>
<tr>
<td>water</td>
<td>nl</td>
<td>l</td>
<td>nl</td>
</tr>
<tr>
<td></td>
<td>0.54</td>
<td>0.53</td>
<td>0.52</td>
</tr>
<tr>
<td>filter</td>
<td>nl</td>
<td>l</td>
<td>nl</td>
</tr>
<tr>
<td></td>
<td>0.55</td>
<td>0.48</td>
<td>0.53</td>
</tr>
<tr>
<td>Mean</td>
<td>a</td>
<td>a</td>
<td>a</td>
</tr>
</tbody>
</table>

1 Type of scoring function: nl: non linear; l: linear
2 Mean calculated index from the combination of type of scoring function and score, bold numbers indicate the maximum; cursive the minimum within a site
3 For each row, means within the same site followed by same letter are not significantly different at the P=0.5 probability level.
Summary
Soil quality can not be expressed by a single parameter but it depends on the complex system of various physical, chemical and biological processes. When applying a soil quality model these interactions have to be considered in the development.

The SQI indicates an improvement of soil quality regarding sustaining biological activity, regulation and partitioning water and filtering and buffering functions under reduced tillage practices (CS and DS) for two of the investigated sites, whereas no trend is visible for Mistelbach. Field measurements (soil loss, runoff and crop yield) confirm the calculations; therefore the chosen soil parameters and the approach of calculation of the SQI are useful tools to determine changes in the soil quality.

The calculated SQI, using a framework considering sustaining biological activity (BIO), regulating and partitioning water (WATER), and filtering and buffering (FILTER) is a good indication of changes in soil quality due to different tillage systems. Further work is required to improve the sensitivity analysis and select useful and sensitive indicators for other soil functions to develop a framework for an overall soil quality assessment. In conclusion, this study demonstrated that computing functional components of an overall soil quality index can provide a comprehensive assessment of soil quality and can be used to identify soil management problems that need to be considered to sustain or improve our soil resources.

References


The use of $^{137}\text{Cs}$, $^{210}\text{Pb}$ and $^7\text{Be}$ measurements for assessing soil erosion and sedimentation in the Riva Basin (İstanbul, NW Turkey)

Sevilay Haciyakupoglu

Research Team:
Assist.Prof.Dr.T.Ahmet Ertek, Prof.Des E.Walling³, Prof.Dr.Hasan Saygin¹, Dr.A.Evren Erginal⁴*, Dr.Gursel Karahan⁵, Assoc.Prof.Dr.Ferhat Gokbulak⁶, Assoc.Prof.Dr.Doganay Tolunay⁶, Prof.Dr.Ahmet Hizal⁶, M.Sahip Kiziltas¹, Irfan Oguz⁷.
¹Istanbul Technical University-Institute of Energy, Turkey.
²Istanbul University - Department of Geography, Turkey.
³University of Exeter - Department of Geography, United Kingdom.
⁴Canakkale Onsekiz Mart University- Department of Geography, Turkey.
⁵Turkish Atomic Energy Authority, Cekmece Nuclear Research Center, Turkey.
⁶Istanbul University – Faculty of Forestry, Turkey.
⁷Ministry of Agriculture and Rural Affairs, Tokat Research Institute, Turkey.

Contract Number TUR/12330

Description of research carried out
This study was implemented to explore the use of fallout radionuclides to investigate soil redistribution due to soil erosion in the environs of Omerli Reservoir in the Riva Basin, which is located on the eastern side of Istanbul. The main purpose of this Coordination Research Project is to define specific soil conservation technologies for the Riva basin by obtaining soil redistribution rates for different geological formations and different land use types in four different villages within the watershed of the Omerli Reservoir, which is the largest drinking and daily use water source for the Istanbul mega city. Assessing the effectiveness of soil conservation techniques for sustainable land management in the watershed, which includes improvement of forest, pasture and agricultural activities in catchments by decreasing soil erosion, increasing soil productivity and rural income, will provide a means of protecting this very important reservoir from siltation. During the 3-year project the soil samples were analysed in the laboratories of Cekmece Nuclear Research Centre of the Turkish Atomic Energy Agency. Because of recent reorganization within Cekmece, the last samples collected from Pasakoy (woodland-brush) were sent to IAEA laboratories for measurement.

A key aim of the study is to demonstrate the potential of the FRN methodology to scientists and researchers in Turkey. To establish cooperation with the Ministry of Agriculture and Rural Affairs, a soil scientist from Tokat Research Institute has also participated in the work team. Additionally, another aim of the study is to implement the FRN methodology in the Celikli watershed (Tokat), where the USLE has been used to estimate soil erosion and it will therefore be possible to compare the FRM results with those obtained by USLE. In this context, with the collaboration of Balkan countries a GEF/UNEP Project Development Facility Block-A (PDF-A) proposal was submitted to UNU for implementation of the same methodology in the Tokat area. The WASWC also supported this study.

A workshop was organized by the Istanbul Technical University, Institute of Energy, and supported by the International Atomic Energy Agency (IAEA) Coordinated Research Project to enable the participants of the project group to use the WOCAT tools for documentation, evaluation, monitoring and dissemination of soil and water conservation technologies and approaches and to exchange experiences and knowledge in the field of sustainable land management. The 3-day WOCAT training workshop was accomplished with around 10 participants from various universities and government institutions. One day was spent in the field, looking at degradation

* A. Evren Erginal from the research team finished his PhD at the Istanbul University Department of Geography and now works at the Canakkale Onsekiz Mart University, Department of Geography in Canakkale, Turkey.
problems in the area and at conservation measures, trying to document them with the WOCAT questionnaires. Two village meetings (Pasakoy and Ballica) were held, discussing degradation and conservation issues around Omerli dam, where protection areas cause misunderstanding between villagers and State Forest Service. The serious degradation problems in the area result from cultivation of land with limited vegetation cover and up and down slope tillage, over-grazing and wood cutting in brush and forest land, conflicting protection zones around Omerli reservoir, and urbanization with illegal construction of whole city parts.

Results obtained since October 2004
Geological and topographic maps and forest management maps were obtained for selecting sampling sites with different vegetation cover and the same geological formation in the previously chosen four villages (Ballica, Pasakoy Kurtdogmus, and Esenceli) in the Omerli watershed in the Riva Basin. The land use types represented consist of cultivation (close to Ballica), woodland-brush (Pasakoy), forest land (Kurtdogmus) and pasture (Esenceli). Figure 1 shows the location of the study areas.

For determining the $^{137}$Cs and $^7$Be activity inventory, soil samples were collected from the Pasakoy sampling site. The dominant vegetation of the site is shrubs and the parent material is arkose. In order to compare the $^{137}$Cs activity inventories for soils derived from different parent materials, sectioned cores of soils derived from arkose and Pliocene sedimentary material were also collected from reference areas representing the two different parent materials at Pasakoy. In addition, further samples were collected in order to determine some selected characteristics of the soils (texture, pH, EC (electrical conductivity), CaCO$_3$, hydraulic conductivity, saturation capacity, bulk density, and organic matter), which are likely to have an effect on the vertical movement of radionuclides in the soil profile. Tables 1 to 3 show some soil properties according to soil depth at the Pasakoy reference site (Arkose).

Using a high resolution gamma spectroscopy system, the soil samples collected before from the selected reference areas at Pasakoy, Esenceli, Ballica and Kurtdogmus, were analyzed for $^{137}$Cs activity inventories while only those samples from the Ballica site were analyzed for $^{210}$Pb activity inventories. Results of $^{210}$Pb measurements were found to be unacceptable due to poor gamma spectroscopic system performance. Soil redistribution rates were estimated using the proportional and mass balance model-1 conversion models (Walling and He, 2001; Zhang and Walling, 2005; Zapata, 2002). Soil samples were also analyzed for permeability (Ozyuvacı, 1976), bulk density (Wilde, 1958) saturation capacity (Wilde, 1958), organic carbon Walkley-Black wet digestion method (Gulcur, 1974), CaCO$_3$ Scheibler calcimeter (Gulcur, 1974) and for pH values with glass
electrode Hanna Microprocessor pH Meter. Laboratory work including measurements of activities and some soil properties from Pasakoy study area, are in progress.

Depth and mass depth profiles for Pasakoy (2sites), Ballica, Kurtdogmus (2sites) and Esenceli reference areas at the study sites were obtained. To show the impact of different reference inventories on the derived erosion rates and also to show the difference of erosion rates obtained if different conversion models are used, soil redistribution rates were estimated for the cultivated Ballica site, using the proportional model and mass balance model 1 with different reference inventories.

Table 1a. The properties of soil samples collected taken from the reference site at Pasakoy for 0-26 cm depth *.

<table>
<thead>
<tr>
<th>Sampling depth (cm)</th>
<th>Saturation capacity (%)</th>
<th>Bulk density (g/cm³)</th>
<th>Permeability (cm/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-6.5</td>
<td>22.23</td>
<td>1.4</td>
<td>2.06</td>
</tr>
<tr>
<td>6.5-13</td>
<td>18.14</td>
<td>1.58</td>
<td>7.9</td>
</tr>
<tr>
<td>13-19.5</td>
<td>17.24</td>
<td>1.52</td>
<td>5.84</td>
</tr>
<tr>
<td>19.5-26</td>
<td>16.48</td>
<td>1.35</td>
<td>20.95</td>
</tr>
</tbody>
</table>

Table 1b. Soil properties taken from reference site in Pasakoy for 0-40 cm depth*.

<table>
<thead>
<tr>
<th>Sampling depth (cm)</th>
<th>pH (1/2.5 H₂O)</th>
<th>CaCO₃ %</th>
<th>Organic carbon %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>5.66</td>
<td>-</td>
<td>2.24</td>
</tr>
<tr>
<td>10-20</td>
<td>5.33</td>
<td>-</td>
<td>1.25</td>
</tr>
<tr>
<td>20-30</td>
<td>5.62</td>
<td>-</td>
<td>0.58</td>
</tr>
<tr>
<td>30-40</td>
<td>5.64</td>
<td>-</td>
<td>0.22</td>
</tr>
</tbody>
</table>

Table 2. The properties of soil samples collected from the sloping site at Pasakoy for 0-19.5 cm depth of 1st pit *.

<table>
<thead>
<tr>
<th>Sampling depth (cm)</th>
<th>pH (1/2.5 H₂O)</th>
<th>Organic carbon %</th>
<th>CaCO₃ %</th>
<th>Saturation capacity (%)</th>
<th>Bulk density (g/cm³)</th>
<th>Permeability (cm/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-6.5</td>
<td>5.58</td>
<td>2.28</td>
<td>-</td>
<td>23.16</td>
<td>1.24</td>
<td>18.21</td>
</tr>
<tr>
<td>6.5-13</td>
<td>5.22</td>
<td>1.94</td>
<td>-</td>
<td>20.22</td>
<td>1.49</td>
<td>7.06</td>
</tr>
<tr>
<td>13-19.5</td>
<td>5.20</td>
<td>0.96</td>
<td>-</td>
<td>19.45</td>
<td>1.36</td>
<td>12.57</td>
</tr>
</tbody>
</table>

Table 3. Some properties of soil samples collected from a sloping site at Paşaköy for 0-39 cm depth of 2nd pit *.

<table>
<thead>
<tr>
<th>Sampling depth (cm)</th>
<th>pH (1/2.5H₂O)</th>
<th>Organic carbon %</th>
<th>CaCO₃ %</th>
<th>Saturation capacity (%)</th>
<th>Bulk density (g/cm³)</th>
<th>Permeability (cm/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-6.5</td>
<td>5.37</td>
<td>3.33</td>
<td>-</td>
<td>31.07</td>
<td>1.14</td>
<td>7.37</td>
</tr>
<tr>
<td>6.5-13</td>
<td>5.46</td>
<td>3.07</td>
<td>-</td>
<td>30.37</td>
<td>1.03</td>
<td>55.54</td>
</tr>
<tr>
<td>13-19.5</td>
<td>5.57</td>
<td>2.96</td>
<td>-</td>
<td>28.78</td>
<td>1.12</td>
<td>13.43</td>
</tr>
<tr>
<td>19.5-26</td>
<td>5.52</td>
<td>3.38</td>
<td>-</td>
<td>29.09</td>
<td>1.10</td>
<td>16.02</td>
</tr>
<tr>
<td>26-32.5</td>
<td>5.67</td>
<td>3.68</td>
<td>-</td>
<td>26.60</td>
<td>1.21</td>
<td>22.31</td>
</tr>
<tr>
<td>32.5-39</td>
<td>5.50</td>
<td>2.68</td>
<td>-</td>
<td>29.86</td>
<td>1.19</td>
<td>62.46</td>
</tr>
</tbody>
</table>

* Average of two samples

Discussion of results

Depth and mass depth profiles for the Pasakoy (2sites), Ballica, Kurtdogmus (2sites) and Esenceli reference areas at the study sites showed a large variation which caused variation in the soil redistribution rate results when using different reference inventories for the basin. Using mass
balance model 1 and the proportional model for different reference sites, the results showed that soil erosion rates for the Ballica study area varied between 0.2435 - 30.6425 t ha⁻¹ y⁻¹ and 0.2849 – 66.8079 t ha⁻¹ y⁻¹ for the proportional model and mass balance model 1, respectively. Since the soil loss tolerance value is considered to be 10 t ha⁻¹ y⁻¹ for deep brown forest soils in Turkey (Dogan ve Gucer) soil erosion rates smaller than 10 t ha⁻¹ y⁻¹ will be acceptable within tolerance limits. Those values greater than 10 t/ha/year mean that soil erosion is a serious problem at the site and necessary measures must be taken to prevent soil loss due to erosion. Estimates of soil redistribution rates obtained using mass balance model 1 for the two transects are presented in Table 4.

Table 4. Estimates of soil loss/deposition for the study area in Ballica based on the mass balance model 1 using the reference site in Ballica.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Estimated using the mass balance model 1 results*</th>
</tr>
</thead>
<tbody>
<tr>
<td>First transect</td>
<td></td>
</tr>
<tr>
<td>Mean erosion rate for eroding area</td>
<td>-2.58 kg m⁻² y⁻¹</td>
</tr>
<tr>
<td>Gross erosion rate</td>
<td>-0.92 kg m⁻² y⁻¹</td>
</tr>
<tr>
<td>Mean aggradation rate for aggrading area</td>
<td>+3.87 kg m⁻² y⁻¹</td>
</tr>
<tr>
<td>Gross aggradation rate</td>
<td>+2.49 kg m⁻² y⁻¹</td>
</tr>
<tr>
<td>Net soil redistribution rate</td>
<td>+1.57 kg m⁻² y⁻¹</td>
</tr>
<tr>
<td>Second transect</td>
<td></td>
</tr>
<tr>
<td>Mean erosion rate for eroding area</td>
<td>-3.42 kg m⁻² y⁻¹</td>
</tr>
<tr>
<td>Gross erosion rate</td>
<td>-1.71 kg m⁻² y⁻¹</td>
</tr>
<tr>
<td>Mean aggradation rate for aggrading area</td>
<td>+7.22 kg m⁻² y⁻¹</td>
</tr>
<tr>
<td>Gross aggradation rate</td>
<td>+4.5 kg m⁻² y⁻¹</td>
</tr>
<tr>
<td>Net soil redistribution rate</td>
<td>+1.78 kg m⁻² y⁻¹</td>
</tr>
</tbody>
</table>

*Results were computed using the values of Ballica reference area.

Training on WOCAT tools including database and assessment criteria and developing work plans to use WOCAT in the local programmes showed that the necessary definitive soil and water conservation (SWC) technology and approach should be selected and planned together with land users and then implementation and monitoring should be undertaken. In our case, no systematic monitoring of SWC has been undertaken for agricultural and rangelands in the basin until now. On the other hand, the Forest Service has planted forests in some areas to protect watershed from erosion, but the effectiveness of these works has not been measured. Additionally no data are available for the base map (polygons) for questionnaire methodologies (QM) of WOCAT tools for the Riva basin. This makes it impossible to share the knowledge in the global maps of the WOCAT database. The SWC technology in one of the research areas in Riva basin in the environs of Pasakoy is revegetation with woody species (afforestation) through Forest Service implementation; and in the other research area in the environs of Ballica, it is fencing around water pipelines (wooden structural measure), contour ploughing and rotational cropping.

Conclusions
The results in Table 4 indicate that there is soil redistribution and more deposition than erosion in the study area. The mean erosion rate is equal to the total erosion per unit width divided by the eroding length. The gross erosion rate is equal to the total erosion per unit width divided by total length. The mean aggradation rate is equal to the total aggradation per unit width divided by the aggrading length. The gross aggradation rate is equal to the total aggradation per unit width divided by total length. The net erosion rate is the rate of soil movement (loss) from the sampled area and is equal to the difference between gross erosion and the gross aggradation rates. The excess of
deposition over erosion in the study field could be because the field is not in a closed environment, and that there are sediment contributions from other sources, such as upslope fields. The TURCAT team for Turkey was created for documentation of local SWC Technologies and Approaches; the translation of WOCAT questionnaires into Turkish and the expansion of the current team beyond University level (http://www.wocat.org/MATERIALS/WOCATEER11.PDF). After the WOCAT training workshop first information from Turkey will be put in the world map of WOCAT. If it could be possible to obtain necessary data for Omerli watershed basin, it will be possible to put a database for Omerli watershed basin in the world map of WOCAT.

Cooperation with World Association of Soil and Water Conservation (WASWC) provided collaboration with researchers in Balkan countries and the potential for creating a joint project. This could be another opportunity to strengthening the capacity of using FRN’s methodology in the world.

References


Hizal, A., Erosion Problems and Rehabilitation Works in Turkey, Proceedings International / Regional Workshop, Community Based Rehabilitation of Degraded Lands of Central Balkan Mountains and Northern Turkey, Faculty of Forestry Belgrade University, Belgrade, 52-59, 2004.


Ozyuvacı, N. 1976. Hydrological Characteristics Of The Arnavutkoy Creek Watershed As Influenced By Some Plant-Soil-Water Relations. Istanbul University publication no: 2082, Faculty of forestry publication number: 221, Istanbul.


Use of radionuclides to investigate soil erosion in agricultural fields and to evaluate soil conservation measures in Morocco

Moncef Benmansour
Head of Unit “Radioécologie, Erosion & Datation”
Division « Applications aux Sciences de la Terre et de l’Environnement » (DASTE) - Centre National de l’Energie, des Sciences et des Techniques Nucléaires (CNESTEN)
Rabat, Morocco

Contract number MOR/12325

Introduction
Agriculture plays a major economic and social role in Morocco. The sector employs about half of the active population and contributes to 17% of the GDP. However, accelerate erosion and soil degradation cause an important damage for this sector, due to natural conditions and intensive exploitation of agriculture. More than 20 Millions hectares of agricultural lands are under serious threat. It has been estimated that 100 millions tons of soil are lost each year. But in Morocco, there is limited information about water and wind erosion and other problems such as stoniness, desertification, salinity and soil compaction. Reliable information about soil erosion is essential in order to evaluate the severity of the problem and to optimize strategies for soil conservation and sustainable crop production. The aim of this work under the IAEA/CRP project is to use and develop the environmental radionuclides ($^{137}$Cs, $^{210}$Pb, $^7$Be) to investigate soil erosion in agricultural fields and to evaluate soil conservation measures in Morocco. One pilot site “Merchouch” (experimental station of INRA) located in the “Bouregrag” watershed, near Rabat, had been selected to undertaken the research. The first results of this study obtained in previous years provided preliminary investigation of long and short - terms rates of soil erosion in the site. The $^{137}$Cs technique gave data on long-term soil erosion with good precision compared to the use of $^{210}$Pb$_{ex}$ radionuclide. $^7$Be radionuclide allowed to estimated soil erosion relatively to short rainfall events and was used to compare between the “no till” and conventional tillage practices. The results presented in this report, integrate principally:
- refining of the preliminary data obtained from radionuclide measurements,
- application of “mass balance 3” model, incorporating the tillage effect, when using the $^{137}$Cs technique
- use of modelling (RUSLE 2) to estimate soil erosion,
- comparison between the two tillage practices during the year 2004 and 2005.

Study area
The study area is an agricultural land (~ 1 ha) located in the Merchouch site at 60 km south east from Rabat. Experimental plots (22 x 4 m) had been installed in the study field and the “No-till” practice with cereals has been used as soil conservation technique and compared to conventional cultivation. The studied zone soil presents a great percentage of clay about 46% and less percentage of sand and silt about 33% and 26 % respectively. The “zero tillage” technique appears to be a good method for soil and water conservation and may be of greater benefit relatively to conventional cultivation. It minimizes erosion because crop seeds are planted directly trough the plant residue left from the previous crop without ploughing the field. In addition the active fraction of organic matter greatly increases and the soil structure is improved. The mean annual precipitation is about 405 mm, with high rainfall from December to March period. The mean temperature is ranged between 10 and 23°C. The mean slope and the length of the field are about 17 % and 100 m.

Material and methods
Sampling
Transact approach was adopted for the sampling, which consists of the selection of sequence of samples along the axis of greatest slope from the top to the bottom of the field. The soil samples devoted to $^7\text{Be}$ measurements were taken particularly on the experimental plots. Both bulk soil and sectioned cores were collected in order to determine inventories of radionuclides and their concentration profiles. For $^{137}\text{Cs}$ and $^{210}\text{Pb}_{ex}$, a motorized tube was inserted up to 30 cm depth to retain total radionuclides, while for $^7\text{Be}$, superficial (~2 cm) soil cores were collected because it’s only found in the immediate surface layer, due to its short half-life. Undisturbed sites (two sites for $^{137}\text{Cs}$ and $^{210}\text{Pb}_{ex}$, and two for $^7\text{Be}$) were identified and taken as references sites. The main sampling campaigns for $^7\text{Be}$ were carried out in March period (2004 and 2005). Precipitation in this month is about 40 mm.

Radioactivity measurements

All the samples were dried, lightly ground, sieved (< 2 mm) and homogenised prior to measure $^{137}\text{Cs}$, $^{210}\text{Pb}$, $^{226}\text{Ra}$ (from $^{214}\text{Bi}$) and $^7\text{Be}$ by gamma spectrometry using HPGe detectors. Two high resolution coaxial detectors (Canberra p-type 50% and Oxford n-type) were used for the measurements. The calibration of the detection systems was done by preparing standards from a certified multi-gamma source (Amersham) and IAEA reference materials (IAEA 327, IAEA 375). Generally, samples were placed in Marinelli bakers (0.5 l) or cylindrical containers (200 ml). $^{137}\text{Cs}$, $^7\text{Be}$, $^{210}\text{Pb}$ and $^{214}\text{Bi}$ activities were determined from the net peak areas of gamma rays at 662, 478 and 46.5 keV respectively. The counting rates varied from 12 to 24 hours providing a precision of about 5 to 20% at 95% level of confidence. However indirect determination of excess $^{210}\text{Pb}$ activity from total $^{210}\text{Pb}$ and $^{226}\text{Ra}$ gave a low precision on the activity value (can reach 50%). Furthermore, measurement by alpha spectrometry through $^{210}\text{Po}$, daughter of $^{210}\text{Pb}$, was performed for some soil samples. The method requires a total digestion of soil sample containing $^{210}\text{Po}$, $^{210}\text{Po}$ and tracer $^{209}\text{Po}$, using acids (HNO$_3$, HCl, and HF) and spontaneous deposition of polonium isotopes in silver discs. The counting is insured by silicon detectors (EG&G Ortec). The alpha spectrometry provides a good precision for measuring $^{210}\text{Pb}$ but needs more time compared to gamma spectrometry. Quality control procedures were applied using control charts (efficiency, resolution and background), certified reference materials and regular participation in Inter-laboratory tests.

Results and discussion

Long-term erosion rates using $^{137}\text{Cs}$ and $^{210}\text{Pb}_{ex}$

Vertical distributions of $^{137}\text{Cs}$ and $^{210}\text{Pb}_{ex}$ associated with reference sites show sharp declines of concentrations with depth. Most of $^{137}\text{Cs}$ and $^{210}\text{Pb}_{ex}$ are being contained in the top 10 cm. Whereas for the cultivated site, radionuclides are almost uniform through the plough layer as a result of mixing caused by cultivation. $^{137}\text{Cs}$ inventory at the reference site was found about 1444 Bq.m$^{-2}$ while the reference inventory of $^{210}\text{Pb}_{ex}$ was estimated to be 3010 Bq.m$^{-2}$ after refining of the results and using alpha spectrometry. The radionuclides inventories of the soil cores collected in the cultivated field are generally lower than the reference inventory, particularly those of the upslope area, indicating the loss of soil.

The refined mass balance model 2 (Walling and Quine, 1990; Walling and He, 1999a) has been used for converting $^{137}\text{Cs}$ or $^{210}\text{Pb}_{ex}$ measurements into estimates of long-term rates of soil redistribution (45 and 100 yr for $^{137}\text{Cs}$ and $^{210}\text{Pb}_{ex}$ respectively). From $^{137}\text{Cs}$ measurements, the global results (all transects) indicate that the erosion rates in the study field are ranged between 0.4 and 3.0 kg m$^{-2}$ yr$^{-1}$ (30 t ha$^{-1}$ yr$^{-1}$). The eroding zones in the upslope part represents 70% of the total area and deposition, observed in the down slope zones, is occurred on 30%. The gross erosion rate was estimated to be about 1.5 kg m$^{-2}$ yr$^{-1}$ and the gross deposition rate for depositional areas about 0.12 kg m$^{-2}$ yr$^{-1}$. The net erosion rate for the entire field is 1.4 kg m$^{-2}$ yr$^{-1}$. The sediment delivery ratio for this field is estimated to be 92%. In spite of the low precision in the measurements provided by $^{210}\text{Pb}$, the results of erosion rates are comparable to those obtained by $^{137}\text{Cs}$ technique. Gross erosion and deposition rates are about 1.1 kg m$^{-2}$ yr$^{-1}$ and 0.2 kg m$^{-2}$ yr$^{-1}$ respectively and the
net erosion was estimated to be 0.8 kg m\(^{-2}\) yr\(^{-1}\). The application of the mass balance 3 model (Govers et al., 1994; Walling and He, 1999b) permitted to estimate the tillage effect. This model is based on \(^{137}\)Cs measurements undertaken along slope transect parallel to the down-slope direction of the flow. The erosion rates include both water and tillage erosion. The total gross erosion and deposition rates are about 2.2 kg m\(^{-2}\) yr\(^{-1}\) and 0.65 kg m\(^{-3}\) yr\(^{-1}\) respectively and indicate that the contribution of the tillage on the site during the last 45 years is not negligible. However, the net erosion rate is found about 1.5 kg, m\(^{-2}\) yr\(^{-1}\) practically the same value than that determined by the mass balance model 2. This result confirms that the water erosion is the main origin of the soil exported from the field. Integrated data using different models together with results obtained by RUSLE2 model are included in table 1.

**Short-term erosion rates using \(^{7}\)Be**

Due to its short half-life, \(^{7}\)Be concentration is found in the upper layers of the soil surface (<5 mm) and declines exponentially with depth. By performing a very thin \(^{7}\)Be profile, a new value of the parameter H (describing the profile shape) was determined. It was found about 5 kg.m\(^{-2}\). The soil erosion and deposition rates were related to short rainfall events corresponding to March in 2004 and 2005, with precipitations of 48 and 34 mm respectively. The local \(^{7}\)Be reference inventories associated with the two years in March were estimated to be 120 Bq.m\(^{-2}\) and 101 Bq.m\(^{-2}\) respectively. These values are in close agreement with the value obtained from the fallout-derived \(^{7}\)Be inventories resulting from precipitation of 110 Bq.m\(^{-2}\) in March 2004 and 90 Bq.m\(^{-2}\) in the cultivated field. \(^{7}\)Be inventories are ranged between 50 and 180 Bq.m\(^{-2}\). The average activities obtained from results of all plots (6 for each type of plots) were determined about 117 and 108 Bq.m\(^{-2}\) for the “No-till” and “Conventional Cultivation” plots in March 2004 and about 94 and 92 Bq.m\(^{-2}\) in March 2005. Therefore, \(^{7}\)Be inventories, for soil where the “No-till” technique is practiced, were found slightly higher than those of soil under conventional cultivation (cover crop). It means that the soil erosion is reduced when the no-till practice is used. The conversion model used to determine erosion rates from \(^{7}\)Be measurements is based on the exploitation of the concentration profile of \(^{7}\)Be (Blake and Walling, 1999). Preliminary data indicate that the average of mean erosion rates, corresponding to the rainfall event of March 2004, were found to be 1.0 and 1.6 kg m\(^{-2}\) in the plots under “No-till” (NT) and conventional cultivation tillage (CT) respectively, and about 0.6 and 0.8 kg m\(^{-2}\) in March 2005 for NT et CT plots respectively (table 2). These results suggest that the soil loss is reduced when the No-till management is practiced compared to the conventional tillage. Gross erosion and particularly net erosion rates were observed significantly lower in the NT plots than those of the CT plots.

**Estimation of long-term soil erosion using RUSLE2 model and comparison with radionuclides results**

The RUSLE2 model (software) was used to predict soil erosion in the study site taking account of on the available parameters. Like RUSLE1, this model is based on the RUSLE equation (Renard et al., 1997). A major advancement was the use of sub-factor relationships to compute C factor values from basis features of cover-management systems, which allowed RUSLE2 to be applied to far more conditions than the RUSLE1. It’s expressed using the following equation: 

\[
A = R*K*LS*C*P
\]

Where:

- \(A\): represents the potential, long term average annual soil loss in tonnes per hectare per year. This is the amount which is compared to the “tolerable soil loss” limits;
- \(R\): is the rainfall factor;
- \(K\): is the soil erodibility factor;
- \(L\) and \(S\): are the slope length and steepness factors, respectively;
- \(C\): is the cropping-management factor;
- \(P\): is the support practice factor.
Soil erosion rates were predicted using RUSLE 2 software based on available parameters. They include monthly precipitation, soil texture, soil management, topographic factors, etc...

The data obtained shown that erosion rates from the top to the bottom along the transects of the field (the same as those exploited for $^{137}$Cs and $^{210}$Pb) are ranged between 0.5 and 8 kg.m$^{-2}$ yr$^{-1}$. The gross erosion and deposition rates are found about 2.5 kg.m$^{-2}$ yr$^{-1}$ and 0.8 kg.m$^{-2}$ yr$^{-1}$. The net erosion is estimated to be 1.6 kg.m$^{-2}$ yr$^{-1}$. Taking account of the errors on the RUSLE2, the radionuclides methodologies, and also the error on the values of altitudes of sampling points determined by a GPS, data on erosion rates obtained by RUSLE2 (modelling of water erosion) and radionuclides (Mass balance 2) are comparable. However, the sedimentation was found higher by the RUSLE2 model than that estimated by $^{137}$Cs or $^{210}$Pb. On the other hand, the results obtained by $^{137}$Cs (Mass balance 3) and RUSLE 2 are practically the same. All comparisons are given in Table 1.

Table 1. A comparison of the rates of soil redistribution within the studied field estimated from $^{137}$Cs, excess $^{210}$Pb and RUSLE2 model

<table>
<thead>
<tr>
<th>Erosion Rates (kg.m$^{-2}$ yr$^{-1}$)</th>
<th>From $^{210}$Pb$_{ex}$</th>
<th>From $^{137}$Cs</th>
<th>From RUSLE2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mass balance 2</td>
<td>Mass balance 3</td>
<td></td>
</tr>
<tr>
<td>Erosion range</td>
<td>0.8-2.6</td>
<td>0.4-3.0</td>
<td>0.8-7.0</td>
</tr>
<tr>
<td>Mean erosion</td>
<td>1.6</td>
<td>1.8</td>
<td>2.6</td>
</tr>
<tr>
<td>Mean deposition</td>
<td>0.7</td>
<td>0.6</td>
<td>1.3</td>
</tr>
<tr>
<td>Gross erosion</td>
<td>1.1</td>
<td>1.5</td>
<td>2.2</td>
</tr>
<tr>
<td>Gross deposition</td>
<td>0.2</td>
<td>0.1</td>
<td>0.6</td>
</tr>
<tr>
<td>Net erosion</td>
<td><strong>0.8</strong></td>
<td><strong>1.4</strong></td>
<td><strong>1.6</strong></td>
</tr>
<tr>
<td>Sediment delivery</td>
<td>77%</td>
<td>92%</td>
<td>70%</td>
</tr>
</tbody>
</table>

Table 2. Rates of soil redistribution within 2 types of plots (NT, CT) using 7Be measurements during March 2004 and March 2005 (average value calculated from data of 3 plots for each type)

<table>
<thead>
<tr>
<th>Erosion Rates (kg.m$^{-2}$)</th>
<th>No-till plots - NT -</th>
<th>Conventional tillage - CT-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean erosion</td>
<td>1.0</td>
<td>0.6</td>
</tr>
<tr>
<td>Mean deposition</td>
<td>1.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Gross erosion</td>
<td>0.6</td>
<td>0.5</td>
</tr>
<tr>
<td>Gross deposition</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>Net erosion</td>
<td>0.2</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Conclusion

Investigation of soil erosion in the “Merchouch” site using environmental radionuclides has allowed to identify performances and constraints of these methodologies when applying in agricultural fields of Morocco. The $^{137}$Cs technique has permitted to quantify the erosion rates with a good precision compared to the $^{210}$Pb$_{ex}$ technique. Refining of the results for $^{210}$Pb$_{ex}$ was done by combining gamma and alpha spectrometry which gives more precise values of $^{210}$Pb$_{ex}$. The application of the “mass balance 3” model allowed to estimate the tillage effect during the last 45 years and to indicate that the contribution of the tillage in soil loss inside the field is not negligible compared to the water erosion. The net erosion in the field was found important and contribute to more than 80% of sediment delivery ratio when using $^{137}$Cs technique. Comparison between radionuclide methodologies and RUSLE2 model was performed. Taking account of the errors, the data on soil erosion estimated by the two approaches were found in the same magnitude. Nevertheless, the deposition was found higher by using RUSLE2 model. The $^7$Be results have shown that the mean
erosion rates in the plots under the “no-till” practice are lower than those under conventional tillage. The result was observed during 2 short rainfall events of two years (2004 and 2005). These results suggest that the soil loss is reduced when the no-till management is practiced compared to the conventional tillage.

References
Walling, D.E., Quine, T.A. 1990. Calibration of $^{137}$Cs measurements to provide quantitative erosion rate data. Land degradation and Rehabilitation 2 161-175.
Measuring redistribution of soils and soil organic carbon on small research watersheds with Cesium-137

Jerry C. Ritchie¹, Erik Veneteris², Gregory W. McCarty¹, and Lloyd B. Owens³
¹USDA ARS Hydrology and Remote Sensing Laboratory, Beltsville, MD 20705, USA
²Ohio Division of Geological Survey, Columbus, Ohio 43224, USA
³USDA ARS North Appalachian Experimental Watershed, Coshocton, Ohio 43812, USA
owens@coshocton.ars.usda.gov

Contract number USA/12394

Abstract
Patterns of soil erosion and soil organic carbon (SOC) vary across the landscape especially for agricultural areas where water, wind, and tillage erosion redistribute soils and SOC. This study used fallout $^{137}$Cs to determine rates and patterns of soil and SOC redistribution on small catchments at the USDA ARS North Appalachian Experimental Watershed (NAEW) at Coshocton, Ohio. The NAEW has 27 first order catchments that have been managed since 1935. Management practices include conventional tillage, no-till, pasture, and natural meadows. Soil erosion rates and SOC differed significantly between management practices with no-till having the lowest soil erosion rates and highest levels of SOC. These studies show the impact of soil redistribution patterns between management practices and aid in understanding soil erosion and SOC patterns.

Introduction
Sequestration of soil organic carbon (SOC) by agricultural ecosystems has been proposed as a way of reducing CO$_2$ in the atmosphere (Schlesinger, 2000; Follett, 2001; Lal, 2004a, b). Patterns of SOC distribution on the landscape are a function of soil redistribution, vegetative productivity, mineralization of SOC, landscape position, and management (Follett, 2001). Understanding the patterns and processes involved in SOC distribution across agricultural landscapes is key to understanding the potential for SOC sequestration in agricultural ecosystems. The amount of SOC varies with land use and management (Schlesinger, 2000; Lal, 2004b). Changing agricultural management has been suggested as a key way to increase the sequestration of SOC. The purpose of this study was to measure soil redistribution and SOC distribution on small first-order watersheds that are under long-term single management regimes.

Methods
The study was conducted on the USDA ARS North Appalachian Experimental Watershed (NAEW) near Coshocton, Ohio USA. The NAEW was established in the late 1930’s and is an ideal location for studying the effects of management practices on SOC since records of soil management, rate of fertilizer and manure (animal waste) additions, cropping practices, and water and sediment runoff have been maintained long-term on the different first-order watersheds (Owens et al., 2002). Our study involved 20 of the 27 research watersheds located within the 625 ha NAEW research area. Seventeen of the 20 watersheds sampled were less than 1.1 ha and the other 3 watersheds were less than 3.1 ha.

A stratified random sampling technique based on prior grid sampling results, topography, soils, and watershed size were used to determine the number and location of sampling sites within each watershed. At least 10 sites were sampled in each watershed. All soil sample sites were located using a differential Geographic Positioning System (GPS) (Trimble Geosurveyor XT¹) and are accurate to less than 1 meter. All surface macro-organic material was removed before sample collection and analyses. Three soil samples were collected for the 0-30 cm layer using a 3.2 cm

¹ Trade names are included for the benefit of the reader and do not imply an endorsement of or a preference for the product listed by the U. S. Department of Agriculture
diameter push probe at each predetermined sampling site and composited into a single sample for analyses. The composited soil samples were dried and screened through a 2-mm sieve. The dried soil samples were placed in Marinelli beakers and sealed for $^{137}$Cs analyses. Analyses for $^{137}$Cs were made by gamma-ray analysis using a Canberra Genie-2000 Spectroscopy System that receives input from three Canberra high purity coaxial germanium crystals (HpC >30 % efficiency) into 8192-channel analyzers. The system is calibrated and efficiency determined using an Analytic mixed radionuclide standard (10 nuclides) whose calibration can be traced to U.S. National Institute of Standards and Technology. Measurement precision for $^{137}$Cs is ± 4 to 6 % and is expressed in Becquerels per kilogram (Bq kg$^{-1}$) or Becquerels per square meter (Bq m$^{-2}$) (Ritchie et al., 2005). Total carbon (%) was measured by dry combustion using a Leco CNS 2000 elemental analyzer on a sub-sample of the dried composited soil sample that had been ground to a very fine powder with a roller grinder. Calcium carbonate (CaCO$_3$) was measured byashing the soil samples in a furnace (420°C for 16 hours) and reanalyzing the ashed sample for the remaining C in CaCO$_3$. SOC was calculated from the difference between total carbon and CaCO$_3$ carbon (Nelson and Sommers, 1996).

Reference soil samples were collected from a native grass watershed (#130 Meadow – good) where records showed that soil disturbance had not occurred since the 1930s when the watershed was established and used to determine baseline $^{137}$Cs input for the area. Forty-nine sites were collected in this watershed. Average $^{137}$Cs concentration in the reference samples was 4092 ± 1025 Bq m$^{-2}$. Soil redistribution (erosion or deposition) rates and patterns were calculated for each soil sample site by comparing the $^{137}$Cs concentrations in the samples with the $^{137}$Cs at the reference site using models that convert $^{137}$Cs measurements to estimates of soil redistribution rates (Zapata, 2002). The Mass Balance Model 2 (Walling et al., 2002) that uses time-variant $^{137}$Cs fallout input and consideration of the fate of freshly deposited fallout was used to calculate soil redistribution rates. Sample sites with less $^{137}$Cs than the $^{137}$Cs at the reference site are assumed to be eroding while sites with more $^{137}$Cs than the $^{137}$Cs at the reference site are assumed to be deposition sites (Walling et al., 2002). A plough depth of 30 cm was used to convert $^{137}$Cs activity to erosion/deposition rates.

Results
Watershed area ranged from 0.49 to 3.06 ha with 17 of the 20 sampled watersheds being less than 1.1 ha. Watershed 109 was sampled on a 25 m grid and 4 other watersheds (#111, 129, 130, 191) were sampled more extensively to help develop criteria for the stratified random sampling that was used on the other 15 watersheds. Soil redistribution rates ranged from +0.3 (deposition) in the reference watershed to −27.3 t ha$^{-1}$ yr$^{-1}$ (soil loss) with an average of −13.5 ± 13.5 t ha$^{-1}$ yr$^{-1}$ for the 551 samples collected. SOC ranged from 0.95 to 2.14 % with an average of 1.41 ± 0.44 % for the 551 samples.

Table 1. Average values of soil organic carbon and soil redistribution by management practice. Averages with different letters are significantly different at 0.05 level of probability by the LSD test.

<table>
<thead>
<tr>
<th>Watershed Management</th>
<th>N</th>
<th>Carbon %</th>
<th>Soil Redistribution T ha$^{-1}$ yr$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meadow (Reference site)</td>
<td>1</td>
<td>1.58 bc</td>
<td>+0.3 a</td>
</tr>
<tr>
<td>No Tilled with Manure</td>
<td>1</td>
<td>2.14 a</td>
<td>- 6.9 b</td>
</tr>
<tr>
<td>Conventional Tilled with Manure</td>
<td>2</td>
<td>1.44 d</td>
<td>- 9.3 b</td>
</tr>
<tr>
<td>Pasture – Medium Fertility</td>
<td>4</td>
<td>1.54 cd</td>
<td>- 9.5 b</td>
</tr>
<tr>
<td>Conventional Tilled without Manure</td>
<td>5</td>
<td>1.03 f</td>
<td>-17.2 c</td>
</tr>
<tr>
<td>Pasture – High Fertility</td>
<td>5</td>
<td>1.68 b</td>
<td>-19.5 cd</td>
</tr>
<tr>
<td>Meadow – Poor Condition</td>
<td>2</td>
<td>1.27 e</td>
<td>-22.0 d</td>
</tr>
</tbody>
</table>

Average values for soil redistribution and carbon content for the differently managed watersheds are given in table 1. The no tilled with manure added, conventional tilled with manure added, and
medium fertility pastures managed watersheds had similar (not statistically different at the 0.05 level of probability) soil redistribution rate with the no tilled with manure added having the lowest rates. The meadow in poor condition had the highest soil redistribution rates.

The no tilled watershed with manure added had the greatest carbon content. The conventional tilled watershed without manure added had the lowest carbon content. The differently managed watersheds had different contents of carbon indicating that different management strategies affected carbon content (Follett, 2001). The addition of manure significantly affected the carbon content of the conventional tilled watershed and no tilled watershed with manure added watersheds having high carbon content. A plot of soil redistribution rates versus soil organic carbon content showed a decrease in carbon with an increase in soil erosion rates. The different management systems had different carbon content.

Conclusions
Soil redistribution and SOC differed significantly between management practices with natural meadows having the lowest soil erosion rates followed by no-tillage, pastures, and conventional tillage. SOC generally decreases as soil erosion increases. These studies show the relationship between soil redistribution and SOC patterns within small watersheds between management practices, and will aid in understanding soil erosion patterns and identifying sources of sediment related to management practices.

References
Update on Canadian Research on Soil Erosion and Soil Conservation Using Radioisotopes

David Lobb
University of Manitoba
Dept of Soil Science
Canada

Contract number CAN/12426

Facilities and Operations

The Landscape Dynamics Laboratory at the University of Manitoba was established in 2000 with two Canberra BEGe gamma detectors. The persistent problem with one of these systems has been resolved and these systems are operating at full capacity. The lab has been expanded with the addition of five well-type gamma detectors from Fisheries and Oceans Canada. Expanded operations permitted and required the employment of a full-time technician. A strategic plan has been developed for the maintenance and replacement of equipment, including a new fee structure for analyses which better reflects the laboratory’s ability to recover true, full costs. All procedures have been reviewed. A review of Quality Assurance and Quality Control procedures has been carried out; it included the analysis of IAEA standard samples as well as standards from other sources. Written Standard Operating Procedures for sample collection, preparation and handling have been established. New Health and Safety standards have been employed. A training program is being established for users (i.e. graduate students).

Research Activities

Assessment of Soil Erosion Processes and Models Using Fallout Radionuclides

a) Cesium-137 is being used to estimate gross soil redistribution by wind, water and tillage erosion, and this information is being used to estimate the individual contributions of wind, water and tillage erosion using optimization procedures (spatial signatures of each process). This research builds on that carried out in the province of Ontario by Lobb and Kachanoski as part of the National Soil Conservation Program (NSCP). It includes ongoing research in the province of Manitoba and the state of Minnesota, supported by the Natural Science and Engineering Research Council (NSERC), and in the provinces of Manitoba, Saskatchewan and New Brunswick and in the state of South Dakota, supported by the National Agri-environmental Health Analysis and Reporting Program (NAHARP). In this research, of particular interest is the interaction between tillage translocation and tillage erosion, and the interaction between tillage erosion and water erosion.

Assessment of Soil Conservation Practices Using Fallout Radionuclides

b) Cesium-137 is being used in the validation of models of soil erosion under a variety of cropping and tillage conditions. These validated models are used to predict the impacts of changes in cropping and tillage systems on soil erosion/conservation. This model validation and predictive modelling is being carried out as part of the Agricultural Policy Framework (APF) at the federal level under NAHARP (ecoregion- to ecozone-scale, provincial- to national-scale) and is also being considered by the province of Manitoba under the APF (landscape- to ecodistrict scale, farm- to municipality-scale).

c) Cesium-137 is being used in the comparison of soil conservation practices.
Research was carried out by R.G. Kachanoski in the late 1980’s and early 1990’s across the province of Ontario comparing conventional tillage systems to conservation tillage systems (including no-till). This work was funded by the Soil and Water Environmental Enhancement Program (SWEEP). This work is the best comparison of tillage systems carried out in Canada. Although reported, this research has not been published; consequently, it may be revisited (resampling a couple of sites) this year and may be published.

Under the National Soil Conservation Program, two field sites in the province of New Brunswick were established by T.L. Chow and H.W. Rees to compare up-downslope cropping and tillage H systems to cross-slope cropping and tillage systems under potato production. Sites were sampled and analyzed for 137Cs in 1989 and again in 1993. Both sites have been resampled a third time in 2005 as part of the NAHARP Tillage Erosion Risk Indicator (TillERI) project.

Assessment of the State of Soil Erosion

d) Cesium-137 is being used to assess the state of soil erosion in a variety of research landscape-based projects. These projects include: the impact of soil erosion on pesticide fate, the impact of soil erosion on greenhouse gas production and emission, and the need for the practice of landscape restoration.

Research Issues

In the assessment of soil conservation practices (SCPs) using fallout radionuclides (FRNs), several issues have arisen and been given consideration:

The research is focused on in-field assessments of land management practices to conserve soil, rather than catchment assessments of land use practices to control runoff and sediment.

The research has been focused on 137Cs. Lead-210 is valuable in assessing long-term (50-100 years BP) impacts of land use. It is the most appropriate FRN for assessing change in soil organic carbon in the northern Great Plains region of North America. However, 210Pb is not being used due to concerns with: (i) the reliability of analysis using the methods employed for 137Cs on soil samples, and the costs associated with separate analyses specific to 210Pb; and (ii) the reliability of information on land management practices greater than 50 years BP.

The research is focused on time scales of 5 to 10 to 25 years. SCPs relevant to decision making today have a fairly short history, less than 25 years. The most intensively studied and promoted, and the most widely adopted SCP in North America is conservation tillage (including no-till and zero-till). These technologies and practices were largely developed between 1975 and 1985, and were adopted on a wide scale between 1985 and 1995. The development of other land management practices for soil and water conservation, such as cover crops, have a similar history. Consequently, there are serious concerns with the standard approach to using 137Cs to estimate soil erosion whereby estimates are based on a reference site (bulk of fallout between 1958 and 1962). With this approach it is not possible to reliably isolate the impact of SCPs that have a short, recent history. As well, there are concerns regarding the reliability of reference sites – the lack adequate precision (highly variable fallout). The approach being used as an alternative to the use of a reference site employs multiple sampling, whereby a baseline sampling is used rather than a reference site. This approach is being used on sites in the provinces of Ontario and New Brunswick and will be used on sites in the province of Manitoba and the state of Minnesota.

Land managers practice landscape restoration, which is very problematic for the use of 137Cs and 210Pb.

Recent Presentations


Related Publications


Fingerprinting the sources of fluvial sediment using fallout radionuclides in forested watershed in Japan

Yuichi Onda
Laboratory of Integrative Environmental Sciences, School of Life and Environmental Sciences University of Tsukuba, Tsukuba 305-8572, Japan

Contract number JPN/12391

Summary
To study the fluvial sediment sources in forested watershed in Shikoku Island, Japan, the concentration of $^{137}\text{Cs}$ and $^{210}\text{Pb}_{ex}$ and U decay series radionuclides were analyzed. The soil sampling was conducted in hillslopes in various locations such as landslide scar, soil surface in unmanaged Hinoki ($Chamaecyparis obtusa$) plantation and unsealed forest road, and detailed sampling in the stream bed and bank was also conducted in several tributaries. The activities of $^{137}\text{Cs}$, $^{210}\text{Pb}$, $^{214}\text{Pb}$ and $^{214}\text{Bi}$ of soils and fluvial sediments were determined by gamma-ray spectrometry. The study area is in the upstream of Shimanto river basin, located 700 km southwest of Tokyo. The 18.8 km$^2$ area watershed ranges in elevation from 170 m to 780 m above sea level. Low concentrations of $^{137}\text{Cs}$ and ex in fine sediments and surface soil at stream bank and dirt forest road suggest that fluvial sediments are derived from surface soil of the stream bank or forest road. The concentrations of $^{137}\text{Cs}$ and $^{210}\text{Pb}_{ex}$ of fluvial sediment are found to be varied between each sampling term. Therefore, there is temporal variation of suspended sediment sources in the watershed. In unmanaged Hinoki plantations watershed, contribution of forest floor as suspended sediment source could be estimated as high as ~36 %. The results suggest that forest floor should be recognized as important source of fluvial sediment in this watershed.

Introduction
In most forested hillslopes, virtually all runoff travels underground, but overland flow in forest floors in unmanaged Hinoki ($Chamaecyparis obtusa$) plantation becomes a serious problem in
Japan. This is due to the dense coverage of the tree canopies in Hinoki, causing the forest floor being too dark for understory vegetation, and the litter from the Hinoki is easy to dissipate and susceptible to move downward. Forest floors in unmanaged Hinoki plantations are therefore like bare land without any understory vegetation, causing crusting at the surface with surface soil erosion. The surface materials thought to be the significant problem for downstream effects; flooding during storm and environmental impact to downstream. However, no data set of the source of fine sediment in river is available. Therefore, fingerprinting of fine sediment is required for appropriate watershed management in Japan. To study the fluvial sediment sources in forested watershed in Shikoku Island, Japan, the activity of $^{137}$Cs and U decay series radionuclides of surface soil in potential sources and suspended sediment were analyzed.

**Integrated suspended sediment sampler and portable suspended sediment sampler**

There are many studies on fingerprinting of fluvial suspended sediment using $^{137}$Cs, $^{210}$Pb$_{ex}$ and mineral composition (c.f., Wallbrink et al., 1998; Onda et al., 1997; Motha et al., 2003). For fingerprinting study using environmental radionuclides, however, it is important problem to obtain enough suspended sediment for analyzing its radionuclide activities. In order to obtain the sample, a large amount of suspended sediment should be collected during the rainfall event, and filtered or centrifuged. Phillips et al. (2000) developed a simple, inexpensive time-integrated suspended sediment sampler that employs the principles of sedimentation. In some cases, it is very difficult in approaching to the riverside, installing the sampler and urgent sampling during unexpected runoff events or short term field survey. Then, we developed the portable type sampler from time-integrated suspended sediment sampler (Photo 2). The instruments is 1) shortening the length to drive more easily, 2) tacking two driving ropes in the front of the body to control the sampler in the stream, 3) installing the weight in both end of the body to stabilize the direction of the body to the flow, and 4) attaching an angled short cylinder below the body and a vinyl string (1 m in length) at the end of the body to submerge the body stably. Koga et al. (2004) and Osanai et al. (2005) conducted the sampling efficiency test of the sampler in flume experiment, and found that the volume of suspended sediment obtained by the sampler linearly increases with flow velocity and sediment concentration.

![Photo 1. Suspended sampler set in the stream at the end of the watershed](image1)

![Photo 2. Portable suspended sediment sampler developed](image2)

**Study area and sampling methods**

The study area is Tsuzura River watershed, midstream a tributary of Shimanto River basin, located 700 km southwest of Tokyo. The 18.8 km2 area watershed ranges in elevation from 170 to 780 m above sea level. The average annual precipitation between 1979 and 2000 was 2735 mm in Taisho town. The possible sources of fine sediment to river will be stream bank, landslide scar, dirt forest road, and forest floor (Photo 3).
The soil sampling was conducted in hillslopes in various locations such as landslide scar and soil surface in unmanaged Hinoki (*Chamaecyparis obtusa*) plantation, and in the stream such as detailed sampling in the stream bed and bank was also conducted in several tributaries. In order to observe overland flow on the floor in unmanaged Hinoki plantation forest, we set a plot sized 50 cm by 200 cm along the slope. Overland flow was gathered and introduced to a tank with hose pipe. The sediment transported by overland flow was trapped at the end of the plot and collected. In order to collect enough volume of the suspended sediment in runoff events for gamma-ray analysis, time-integrated suspended sediment sampler was adopted (Phillips et al., 2000). We set the suspended samplers at the end of watershed and its tributaries, and collected samples from Jun to November in 2004 (Photo 1).

analyses

To measure the $^{137}\text{Cs}$ and $^{210}\text{Pb}_{\text{ex}}$ content, gamma ray spectrometry was performed at our laboratory in the University of Tsukuba, using low-energy HPGe gamma spectrometers (Eurysys EGC-200-R; Eurysys EGC25-195-R) coupled with multi-channel analyzer. In gamma ray spectrometry, $^{210}\text{Pb}_{\text{ex}}$ activities are determined from the difference between total and supported $^{210}\text{Pb}$ activities (Joshi, 1987). Assuming equilibrium between $^{226}\text{Ra}$ and $^{222}\text{Rn}$ in the soil samples, the supported $^{210}\text{Pb}$ activity can be calculated from the activity of its short-lived daughter $^{214}\text{Pb}$ (half-life 27 minutes), which derives from $^{222}\text{Rn}$ in the $^{238}\text{U}$ decay series (Joshi, 1987; Murray et al., 1987).

$$^{210}\text{Pb}_{\text{ex}} = (^{210}\text{Pb}_{\text{total}}) - (^{214}\text{Pb}) \quad (1)$$

The collected sediment samples were dried for 48 hours at 105 °C, sieved using a 2 mm open sieve, packed in a 100 cm³ plastic bin and sealed. These samples were sealed for more than five times the half-life period of $^{222}\text{Rn}$, or 21 days before analysis, to allow equilibrium to occur between $^{226}\text{Ra}$ and $^{222}\text{Rn}$ (cf. Joshi, 1987; Murray et al., 1987). For $^{137}\text{Cs}$ and excess $^{210}\text{Pb}$ analyses, the gamma activity of each sediment sample was measured for 43,200 to 86,400 seconds. Using a low-energy germanium detector, gamma activity was determined at the 661.6 keV photopeak for $^{137}\text{Cs}$, 46.5 keV for total $^{210}\text{Pb}$, and 352.0 keV photopeak for $^{214}\text{Pb}$. All radionuclides detected were quantified as concentration (Bq kg⁻¹) from reference samples including $^{210}\text{Pb}$ and $^{137}\text{Cs}$, and $^{152}\text{Eu}$. The self-adsorption of gamma rays by the sample, and background effects during the measurement of
gamma rays were calibrated by comparison with the reference samples, following Noguchi (1980) and The Science and Technology Agency of Japan (1992).

Following hydrogen peroxide treatment to decompose organic matter in the sediment, the particle size distribution was analyzed by sieving and employing the laser beam diffraction method (Shimadzu SALD-3100). The organic matter content was also analyzed by measuring ignition loss after heating samples at 450 °C for 4 hours. The particle-size correction factor $P$ is calculated for each samples as followings (He and Walling, 1996),

$$ P = (S_{ms} / S_{sl})^v $$

where $S_{ms}$ and $S_{sl}$ are the specific surface area of mobilized sediment and original soil, respectively. $v$ is a constant with a value of 0.65 for $^{137}$Cs and 0.76 for $^{210}$Pb$_{ex}$, respectively. We also extracted the organic matter fraction from the soil of forest floor according to Wallbrink et al. (2002) and measured $^{137}$Cs and $^{210}$Pb$_{ex}$ concentration. Assuming that there is linear relationship between organic matter content and $^{137}$Cs or $^{210}$Pb$_{ex}$ concentration, the organic content effect was calibrated for each sample.

**Results and discussion**

$^{137}$Cs and $^{210}$Pb$_{ex}$ activities of forest floor soil and land slide scar ranged in almost same value area (Fig. 2). In forest road samples $^{137}$Cs and $^{210}$Pb$_{ex}$ ranged lower than forest floor, and they were not detected in the samples of stream bank (Fig. 2). The $^{137}$Cs and $^{210}$Pb$_{ex}$ activities of the runoff sediment from the plot were obviously higher than suspended sediment samples except that collected in 27 June (Fig. 3). It is assumed that the forest road and stream bank were easy to erode, and little $^{137}$Cs accumulated activities were detected on the surface.

![Figure 2. $^{137}$Cs and $^{210}$Pb$_{ex}$ activities of potential sources](image1)

![Figure 3. $^{137}$Cs and $^{210}$Pb$_{ex}$ activities of suspended sediment and potential source](image2)

Relatively higher variation in Pb-210ex concentration of suspended sediment was shown than $^{137}$Cs (Fig. 3). $^{210}$Pb concentration of suspended sediment is the highest in 27 June, and seems to decrease rapidly, suggesting that the $^{210}$Pb$_{ex}$ has been accumulated on the surface during winter and spring with relatively small precipitation, and high concentration $^{210}$Pb$_{ex}$ could be transported with sediment in large rainfall events in early summer. Therefore, it seems to be difficult to use $^{210}$Pb$_{ex}$ as a tracer of fingerprinting of suspended sediment. On the other hand, $^{137}$Cs has no accumulated effect since it has already stopped falling since 1970s.

Assuming that the suspended sediment was composed of the surface soil of forest floor and stream bank, the contributions of forest floor during 7 rainfall events were estimated as 8 to 36 % by the
end-member of $^{137}$Cs (Fig. 4). This result suggests that the forest floor could be an important source of suspended sediment in the unmanaged Hinoki plantation watershed. In field observation, turbid water running through the forest road and collapse of stream bank had been found during the heavy rainfall event. Relatively high contribution of forest floor to the suspended sediment could be found during small and medium rainfall events, and lower contribution of forest floor maybe resulted from the erosion of forest road and stream bank (Fig. 5).

![Figure 4. Contribution of forest floor to suspended sediment estimated by $^{137}$Cs. An arrow indicates the typhoon event occurred](image)

![Figure 5. Eroded dirt forest road after typhoon](image)

We quantified the volume of the forest road erosion (Fig. 5) occurred during the typhoon event in 28 August to 1 September, and calculated the average sediment yield on the forest floor using relative contribution (Table 1). Higher $^{137}$Cs concentration in the plot sediment than in the suspended sediment suggests the low contribution of overland flow to the suspended sediment. However, estimated sediment yield was found as same order as fine fraction of plot sediment, indicating that the overland flow could transport the fine sediment on the surface in unmanaged Hinoki plantation forest.

<table>
<thead>
<tr>
<th></th>
<th>$^{137}$Cs (error)</th>
<th>$^{210}$Pb (error)</th>
<th>Measured sediment yield on the plot (g/m$^2$)</th>
<th>Average sediment yield on forest floor (g/m$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Bq/kg)</td>
<td>(Bq/kg)</td>
<td>$\phi &gt; 75 \mu$m</td>
<td>$\phi \leq 75 \mu$m</td>
</tr>
<tr>
<td>K14 (P8) Plot (3 Sep. 2004)</td>
<td>65.4 (10.5)</td>
<td>184.6 (148.7)</td>
<td>36.7</td>
<td>35.2</td>
</tr>
<tr>
<td>Suspended sediment sampler (07) (28 Aug-1 Sep. 2004)</td>
<td>8.0 (10.8)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Ongoing Project**

We are conducting the research project with forest hydrologist, recording the runoff and sediment from plot scale to watershed scale, including the recording of runoff, suspended sediments sampling by time-integrated suspended sediment sampler in Shimanto River basin and small mountain watershed in Mie prefecture, central Japan. Using the end-member of $^{137}$Cs concentration, we conducted the estimation of relative contribution of forest floor to suspended sediment in unmanaged Hinoki plantation forest watershed. To confirm the accuracy, we will investigate the contribution quantitatively using discharge and turbidity data.
References
Using fallout radionuclides to assess effectiveness of soil conservation measures in reducing soil erosion and improving soil quality in China

Yong Li
Institute of Agro-Environment and Sustainable Development
Chinese Academy of Agricultural Sciences
Beijing, China (IAED, CASS)

Contract number CPR/12323

Description of Research Carried Out
The following the research work was conducted according to the objectives of IAEA Research Contract No. 12323/R2:
1) Complement the reference inventories of $^{137}$Cs, and $^{210}$Pb$_{ex}$ in SW-China and seasonally sampling for $^7$Be reference inventory in northern China (in process).
2) Evaluating gully and rill or sheet erosion in Changshanling catchment in SW-China, using $^{137}$Cs and $^{210}$Pb$_{ex}$ tracers and RTK-GPS survey.
3) Assessment the effectiveness of re-vegetation of tree/shrub and grasses in improving surface soil quality parameters using $^{137}$Cs and $^{210}$Pb$_{ex}$ in Majiasongpo catchment, SW-China.
4) Conducting a preliminary *in situ* measurement of FRNs in Xilinhot grassland of Inner Mongolia in northern Beijing using portable gamma spectrometer.
5) Determination of the distribution of fallout radionuclides among different particles sizes, and
6) Measurements of samples collected and data processing and paper preparation under IAEA

During the period October 2004 to February 2006, we sampled about 600 samples for measuring FRNs, made GPS surveys of more than 7000 points. So far we have completed the measurements of 398 soil samples collected, several papers under IAEA Research Contract No. 12323 were published in Soil &Tillage Research, Science in China and Journal of Soil and Water Conservation, and two papers were submitted to related International journals.

Results Obtained Since October 2004
Reference inventories of fallout $^{137}$Cs and $^{210}$Pb$_{ex}$ in SW-China
In order to make an accurate assessment of reference inventories of $^{137}$Cs and $^{210}$Pb$_{ex}$, we sampled 25 sites at un-disturbed, and uncultivated grassland at hilltop in Changshanling and Majiasongpo catchments in 2004 and 2005. Reference values of $^{137}$Cs and $^{210}$Pb$_{ex}$ inventories were calculated to $802\pm49$ Bq m$^{-2}$ and $7823\pm1382$ Bq m$^{-2}$, respectively, for the Majiasongpo catchment, and $916\pm75$ Bq m$^{-2}$ and $6642\pm1303$ Bq m$^{-2}$, respectively, for the Changshanling catchment. The coefficients of variation (CV, %) for 25 sampling sites were in range of 23-33% for $^{137}$Cs and 21-25 for $^{210}$Pb$_{ex}$ in the upper Yangtze River Basin, SW-China. The depth-incremental profiles of both fallout $^{137}$Cs and $^{210}$Pb$_{ex}$ in reference sites shows a typical exponential decrease with soil depth, and majorly of the $^{137}$Cs and $^{210}$Pb$_{ex}$ concentrated within the top layers of 0-10 cm.

Contributions of gully and sheet erosion to total sediment yield in SW-China, using $^{137}$Cs and $^{210}$Pb$_{ex}$ tracers and GPS survey
Gullies are extensively distributed in the Upper Yangtze River Basin, SW-China. But the impact of these gullies in total sediment output is still not clear. Our objectives for this period are: a) to quantify gully erosion rates as affected by land use change over the last 100 years, and b) to assess relative importance of different erosion types including gully and rill or sheet erosion in sediment production in selected gully catchments. Our investigations were carried out in the Anning Warm-Dry Valley of southern Sichuan in the territory of Xichang. We selected two catchments of Changshanling for our objectives. We measured the gully system using RTK-GPS and established...
Digital Elevation Mode (DEM) of the gully catchment, and proposed a method for extract gully system from the established DEM in frame of GIS. Sediment production by gully was estimated from DEMs based on RTK-GPS survey data. By establish a sediment chronology within the gully systems using $^{137}$Cs and $^{210}$Pb dating we intended to develop a relationship between gully development and the history of gully catchment land use. Sediment production by rill or sheet erosion on slope of the catchment was estimated by combinative use of fallout $^{137}$Cs and $^{210}$Pb measurements. Results indicated that the gully density in Changshanling catchments was 46.7 m ha$^{-2}$, and annual sediment production by gully erosion ranged from 6 to 110 t ha$^{-1}$, averaging 61 t ha$^{-1}$ yr$^{-1}$. Average sediment yields by sheet erosion was 26.42 t ha$^{-1}$ yr$^{-1}$, nearly three times lower than gully erosion in the study catchment. Gully erosion with 12% of total area represented 87% of total sediment yield whereas sheet erosion with 87% of total area accounted for 13% of the total soil loss in the study catchments (Tables 1). Our results suggested that gully erosion is the major sediment sources and the dominant water erosion process in the Upper Yangtze River Basin, SW-China.

Table 1: Relative contribution of gully erosion derived from $^{137}$Cs and excess $^{210}$Pb dating and GPS-survey and slope sheet erosion derived from $^{137}$Cs and excess $^{210}$Pb measurements for Changshanling gully catchment.

<table>
<thead>
<tr>
<th>Item</th>
<th>Area Contribution</th>
<th>Erosion/deposition</th>
<th>Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ha</td>
<td>%</td>
<td>t</td>
</tr>
<tr>
<td>Gully erosion</td>
<td>0.6</td>
<td>11.90</td>
<td>15275</td>
</tr>
<tr>
<td>Loss</td>
<td>2.65</td>
<td>52.58</td>
<td>3500</td>
</tr>
<tr>
<td>Sheet erosion</td>
<td>1.79</td>
<td>35.52</td>
<td>1222</td>
</tr>
<tr>
<td>Gain</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total sediment</td>
<td>5.04</td>
<td>100.00</td>
<td>17553</td>
</tr>
</tbody>
</table>

Note: Area of several major gullies in Changshanling catchment, and small gullies were not included in this calculation.

Effects of vegetation restoration on SOM, available P, and BD organic matter and FRNs

We examined the effects of vegetation restoration after 15-30 year on SOM and fallout $^{137}$Cs and excess $^{210}$Pb inventories. This study was conducted in a hillslope with terraces within Majiasongpo catchment in SW-China. The terraced hill slope contained 9 terraced fields, constructed in 1940s. The terraced fields had been cultivated since construction until 1950s. Four treatments were included in this study: a) tree-growth area, trees, b) shrub-growth area, shrubs, c) natural-regrowth area, grasses, and vegetation loss area, bareland. Soil samples for determination of soil quality parameters were taken to a depth of 10 cm in four treatments of three replicates at the top, upper, mid, lower position of the terraced hillslope. To ensure complete profile of $^{137}$Cs and excess $^{210}$Pb inventories included, soil samples were taken to a depth of 40 cm in each terraced field of three replicates.

Figure 1 indicates the spatial pattern in $^{137}$Cs and excess $^{210}$Pb, on terraced hillslope with growth of tree/shrubs and grasses. Top position contained the highest amount of $^{137}$Cs and excess $^{210}$Pb whereas the upper position the lowest for the terrace hillslope. The amounts of $^{137}$Cs decreased in the following order: upper < mid < lower < upper positions in the terraced hillslope. Spatial variation in excess $^{210}$Pb inventories followed a shape of M along the down terraced hillslope. Both $^{137}$Cs and excess $^{210}$Pb inventories were random and showed no association with slope positions in grassed and forested areas of the terraced hillslope. By comparing the study hillslope sites with the reference sites, the upper slope position lost 26% of $^{137}$Cs inventories and 58% of excess $^{210}$Pb whereas no significant differences were found in the mid and lower positions of the terraced hillslope. But we found a significant gain at top position, 36% for $^{137}$Cs and 75% for excess $^{210}$Pb inventories, which suggest some additional soil material delivered from the hilltop areas. The sediment budget calculated using $^{137}$Cs and excess $^{210}$Pb inventories showed no net soil lost from the study hillslope.
Figure 1. Spatial pattern in $^{137}$Cs and excess $^{210}$Pb inventories on terraced hillslope and their residuals of percentage compared to the values from reference sites of Majiasongpo catchment.

Fig. 2 the distribution of SOM, available P, and BD grouped by slope location and vegetation species on terraced hillslope of the Majiasongpo catchment.
Comparison of $^{137}$Cs inventories between in-situ and laboratory measurement

Figure 2 summarized the distribution of SOM, available P, and BD grouped by slope location and vegetation species. The differences between slope positions and vegetation species are apparent: for example, shrub and grasses increased SOM faster than trees as compared with bareland where slope position did not significantly affect SOM. The positive effects of vegetation on available P increase in the following order: grasses > shrub > tree where available P increased along the downslope direction. Table 2 show $^{37}$Cs inventories from in situ and laboratory measurements. A similar change trend of $^{137}$Cs inventories with the study sites was found for in situ and laboratory measurement. But in-situ measurement provided a 21-31% decrease of magnitude for all the sites except MG-6 site with a 3.66% decrease compared with laboratory measurement. The mean of relative error between in situ and laboratory is 23.40%, indicating that in situ measurements are able to provide representative values of $^{137}$Cs inventory comparing the laboratory measurement of $^{137}$Cs.

<table>
<thead>
<tr>
<th>Sites</th>
<th>In-situ (Bq m$^{-2}$) Activity</th>
<th>Uncertainty</th>
<th>laboratory (Bq m$^{-2}$) Activity</th>
<th>Uncertainty</th>
<th>Relative error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MG-1</td>
<td>2166</td>
<td>138</td>
<td>2993</td>
<td>122</td>
<td>-27.63</td>
</tr>
<tr>
<td>MG-4</td>
<td>2114</td>
<td>139</td>
<td>2681</td>
<td>153</td>
<td>-21.14</td>
</tr>
<tr>
<td>MG-5</td>
<td>2019</td>
<td>136</td>
<td>3005</td>
<td>198</td>
<td>-32.81</td>
</tr>
<tr>
<td>MG-6</td>
<td>2451</td>
<td>161</td>
<td>2544</td>
<td>176</td>
<td>-3.66</td>
</tr>
<tr>
<td>MG-lee</td>
<td>2113</td>
<td>136</td>
<td>3043</td>
<td>177</td>
<td>-30.56</td>
</tr>
<tr>
<td>UG99-1</td>
<td>2270</td>
<td>141</td>
<td>3011</td>
<td>128</td>
<td>-24.61</td>
</tr>
<tr>
<td>Mean</td>
<td>2188.8</td>
<td>142</td>
<td>2879.5</td>
<td>159</td>
<td>-23.40</td>
</tr>
</tbody>
</table>

Discussion

Reference inventories of fallout $^{137}$Cs and $^{210}$Pb$_{ex}$ in SW-China. Fallout $^{137}$Cs and $^{210}$Pb$_{ex}$ in SW-China is mainly distributed in top 15 cm soils. Averaged reference values of $^{137}$Cs and $^{210}$Pb$_{ex}$ were 802±49 Bq m$^{-2}$ and 7823±1382 Bq m$^{-2}$, respectively, for the Majiasongpo catchment, and 916±75 Bq m$^{-2}$ and 6642±1303 Bq m$^{-2}$, respectively, for the Changshanling catchment. The coefficients of variation (CV, %) for 25 sampling sites were in range of 23-33% for $^{137}$Cs and 21-25 for $^{210}$Pb$_{ex}$ in the upper Yangtze River Basin, SW-China.

Role of gully erosion in sediment yields in SW-china. $^{137}$Cs and $^{210}$Pb dating is effective tool for developing a relationship between gully development and the history of gully catchment land use. Our results indicated that the gully erosion resulted in sediment yields of 6 to 110 t ha$^{-1}$, averaging 61 t ha$^{-1}$yr$^{-1}$, three times greater than sheet erosion that resulted in net soil loss of 26.42 61 t ha$^{-1}$yr$^{-1}$. Gully erosion represented 87% of total sediment yield whereas sheet erosion accounted for 13% of the total soil loss in the study catchments in SW-China.

Evaluation of the effectiveness of vegetation restoration. The fact of the differences in SOM, BD, and $^{137}$Cs and $^{210}$Pb$_{ex}$ appears to be happening across the terraced hillslope irrespective of slope positions suggests a significant positive role of vegetation species restoration in improving soil quality parameters and reducing soil erosion. Planted shrub and grasses were more effective in increasing SOM than planted trees as compared with bareland. The positive effects of vegetation on available P increase in the following order: grasses > shrub > tree. Planted shrubs were the only species that significantly reduced BD in the upper 0-10 cm soil compared with the bareland area, but planted trees and natural re-growth grasses could not significantly affect BD in the upper 0-10 cm surface soil.

Comparison between in situ and laboratory measurement of $^{137}$Cs. The field-portable detector offers considerable potential for documenting $^{137}$Cs inventory. The use of an in situ detector overcomes a number of the disadvantages and uncertainties associated with standard $^{137}$Cs measurement involving sample collection and laboratory measurement. The major advantages of in situ measurement includes: a) fast and easy to use in the field and point measurement of the total...
CsI inventory, b) without disturbing the soil and possible to check the precision of each measurement immediately in the field. But the in situ measurements are not without their limitations. The major limitations includes: a) affected by lower inventories and high gradients and large obstacle, b) insensitive to $^{137}$Cs contained in the upper 40 cm of the soil profile. The results obtained from this study is only a first comparison of $^{137}$Cs between in situ measurements and laboratory in grassland, more studies are urgently needed in order to test the viability of use of in situ measurement to derive other FRNs ($^{210}$Pb and $^{7}$Be) in China.

**Conclusions**

a) Averaged reference values of $^{137}$Cs ranged from 802±49 to 916±75 Bq m$^{-2}$, and from 6642±1303 to 7823±1382 Bq m$^{-2}$ for $^{210}$Pb, in the upper Yangtze River Basin, SW-China;

b) $^{137}$Cs and $^{210}$Pb dating is effective tool for developing a relationship between gully development and the history of gully catchment land use. Gully erosion represented 87% of total sediment yield whereas sheet erosion accounted for 13% of the total soil loss in the study catchments in SW-China;

c) Planted shrub and grasses were more effective in increasing SOM and available P than planted trees as compared with bareland, but planted trees and natural re-growth grasses could not significantly affect surface soil BD of 0-10 cm;

d) In-situ measurement generally provided a 21-31% decrease of $^{137}$Cs inventory for the study sites compared with the laboratory measurement. More studies are urgently needed in order to test the viability of use of in situ measurement to derive other FRNs ($^{210}$Pb and $^{7}$Be) in China.

**References**


Investigation of soil erosion and sedimentation by using nuclide tracers of $^{137}$Cs, $^{210}$Pb$_{ex}$ and $^7$Be in the upper Yangtze River Basin of China

Xinbao Zhang
Institute of Mountain Hazards and Environment,
Chinese Academy of Sciences
China
Contract Number: CPR/12322

Introduction
This progress report includes three parts: 1. Interpreting of variations of $^{137}$Cs, $^{210}$Pb$_{ex}$ and fine particle contents in a deposit profile of the Jiumondian Reservoir; 2. A study on soil erosion and sediment production by sediment deposits dating with the $^{137}$Cs technique in reservoirs and ponds in small purple soil catchments of the Hilly Sichuan Basin and the Three Gorges Region; 3. A simplified diffusion process model for $^{137}$Cs redistribution in undisturbed soil profile.

Interpreting of variations of $^{137}$Cs, $^{210}$Pb$_{ex}$ and fine particle contents in a deposit profile of the Jiumondian Reservoir, Chuxiong, Yunnan, China
This study was carried out in the Jiumondian Reservoir, located in the upper reaches of Zidianhe River, in the Jinshajiang River Basin (Fig.1). A depth incremental profile spanning a total depth of 393 cm was collected at the central of the drought reservoir bottom when it was drained out in April of 2004.

Fig.1 A sketch map of the Jiumondian Reservoir Catchment and sampling locations
Except for the 1963’s $^{137}$Cs peak of $4.26\pm0.35$Bq·kg$^{-1}$ at the depth of 231~237 cm in depth, the profile has other two unusual $^{137}$Cs and $^{210}$Pb$\text{ex}$ peaks: the upper peak at the depth of 15~21 cm, which has a $^{137}$Cs concentration of $10.90\pm0.49$Bq·kg$^{-1}$ and a $^{210}$Pb$\text{ex}$ concentration of $59.20\pm3.4$Bq·kg$^{-1}$, respectively; and the lower peak at the depth of 231~237 cm, which has only a high $^{210}$Pb$\text{ex}$ concentration of $43.40\pm6.4$ Bq·kg$^{-1}$ (Fig.2).

The upper peak was related to the 1998’s forest and shrub fire while the lower peak to the 1960’s fire of reclaiming land for cultivation. No $^{137}$Cs is detected in the lower peak layer, probably because little $^{137}$Cs fallout had deposited on the earth surface yet. Timber harvesting during the Great Leap Forward period of 1958~1959 and following vegetation rehabilitation has great effects on soil erosion in the catchment and sediment deposition in the reservoir. Due to severe soil erosion caused by timber harvesting in 1958~1959, the sediment deposit rate in the reservoir and the correspondent specific sediment yield for the catchment were very high and $83.86\times10^4$ t·y$^{-1}$ and 255.4 t·km$^{-2}$·y$^{-1}$, respectively. Since then, soil erosion has become lightening because of stopping of timber harvesting and natural vegetation recovery. The sediment deposit rate in the reservoir and the correspondent specific sediment yield for the catchment decreased to $40.88\times10^4$ t·y$^{-1}$ and $1587.0$ t·km$^{-2}$·y$^{-1}$, respectively, in 1960~1962 and to $6.19~7.73\times10^4$ t·y$^{-1}$ and $240.2~291.5$ t·km$^{-2}$·y$^{-1}$, respectively, since 1963.

A study on soil erosion and sediment production by sediment deposits dating with the $^{137}$Cs technique in reservoirs and ponds in small purple soil catchments of the Hilly Sichuan Basin and the Three Gorges Region

Four small catchments with a drainage area of less than 1 km$^2$ in Yanting and Nanchong of Sichuan Province and Kaixian of Chongqing were selected for this study (Fig.1). Incremental samples of sediment deposit profiles for $^{137}$Cs dating were collected in the ponds of those catchments to estimate the deposition volumes since 1963, and to analyses the specific sediment yields and the average erosion rates of those catchments. The highest specific sediment yields for deposition in the ponds is $1869$ t·km$^{-2}$·y$^{-1}$ for the Chunqiu Gully in Kaixian, and $802$ t·km$^{-2}$·y$^{-1}$ and $713$ t·km$^{-2}$·y$^{-1}$ for the Wujia Gully and the Jiliu Gully in Yanting, respectively. The yield in the pond is about 566 t·km$^{-2}$·y$^{-1}$.
t·km⁻²·y⁻¹ for the Tianmawan Gully in Nanchong. By analyses of the topography characteristics and the ¹³⁷Cs depth distribution in rice fields of valleys, no significant sediment accumulation occurs in the valley areas. So it is reasonable to use the specific sediment yields for deposition in pond to represent the specific sediment yield and soil erosion rate of the study catchments excluding the Tianmawan Gully in Nanchong where the current water surface area of the pond used for estimation of the yield is less than the deposition area. The estimated regional erosion rates are 2000 t·km⁻²·y⁻¹ for Kaixian, 1200 t·km⁻²·y⁻¹ for Nanchong and 1000 t·km⁻²·y⁻¹ for Yanting, respectively. The main factors of the erosion severities for the regions are topography, soil erodibility, and bedrock bedding conditions.

Fig.1. a sketch map of the sampling locations and the depth distributions of ¹³⁷Cs and clay content of the deposit profiles in the ponds (a sketch map of the sampling locations (a); <0.002mm fine particle content depth distribution of the Jiliu Gully (b); ¹³⁷Cs concentrations depth distributions of the Jiliu Gully (c) and the Wujia Gully (d) and the Tianmawan Gully (e) and the Chunqiu Gully (f)

A simplified diffusion process model for ¹³⁷Cs redistribution in undisturbed soil profile
Temporal variations of ¹³⁷Cs depth distribution in undisturbed soils after its deposition on the ground due to diffusion and migration processes are not considered in the previous simple profile-shape model (e⁻h·Z·A=A₀ 0). Thus, the soil losses are overestimated by the model. Due to the
diffusion and migration processes, $^{137}\text{Cs}$ depth distribution profile shapes in undisturbed soils are not fixed but changeable after its deposition on the ground (Fig.1).

![Fig.1](image)

(a) Variations of $^{137}\text{Cs}$ depth distribution with time by diffusion process in an uneroded soil profile (a) and in an eroding soil profile (b)

A simplified diffusion process model to describe the post redistribution of $^{137}\text{Cs}$ fallout in undisturbed soil is developed as following:

$$A_{(1963)} - A_{(1963+\tau)} = \sum_{\tau=0}^{z_{(1963+\tau+1)}} \Phi_{\tau} e^{-\lambda \tau} \frac{1}{\sqrt{4\pi \tau}} \int e^{-\frac{z^2}{4\tau}} \, dz$$

The change of $^{137}\text{Cs}$ depth distribution due to diffusion processes in an undisturbed soil profile with time after its deposition on the ground can be generally described as following: $^{137}\text{Cs}$ concentration in the surface horizons decreases with time while $^{137}\text{Cs}$ distribution depth increases with time. However, the $^{137}\text{Cs}$ concentration still always decreases exponentially with depth and the maximum $^{137}\text{Cs}$ concentration occurs in the surface horizon of the profile. Although the $^{137}\text{Cs}$ inventory at an eroded site is less than the reference value, the soil profile has same $^{137}\text{Cs}$ depth distribution shape as the profile at the reference site if the two profiles have same uniform soil textures. The soil losses related to different $^{137}\text{Cs}$ loss proportions of the reference inventory at the Kaixian site of the Three Gorge Region, China, are estimated by the two models. The longer the time gap between the sampling year and 1963 and the greater the $^{137}\text{Cs}$ loss proportion of the reference inventory, the severer the overestimation extents of the soil losses by the previous simple profile-shape model. For 20% -60% of $^{137}\text{Cs}$ loss proportions of the reference inventory, the annual soil loss depths estimated by the new simplified diffusion process model are only 21.9%~28.4% of the values estimated by the previous model.

Acknowledgement
This study was supported by National Natural Sciences Foundation of China (40271015), Chinese Academy of Sciences (Grant Nos. KZCX3-SW 422 and 330), and International Atomic Energy Agency (12322/RO). Geography and Archeology Department, Exeter University, UK is gratefully acknowledged for sample analyses.
References
Field investigations for sediment fingerprinting and assessment of erosion and sedimentation remediation strategies using nuclear techniques

Muhammad Rafiq Sheikh
Pakistan Institute of Nuclear Science and Technology
Radiation and Isotope Application Division (RIAD)
P.O. Nilore, Islamabad, PAKISTAN

Contract Number PAK-12392

Field investigations for assessment of erosion and sedimentation in Rawal catchment and dam reservoir using fallout radionuclides

Description of research carried out

Soil is the most important natural resource, since it provides the basis for crop and livestock production and this component is the most affected by erosion. Natural soil erosion presents no local problem, as long as its rate is balanced by the rate of formation of new soil. Deforestation, overgrazing, urbanization, industrialization, low organic matter, improper tillage practices have accelerated the soil erosion (Ashraf et al. 2002). Both natural and accelerated erosion can lead to irreversible loss of soil and the siltation of the rivers and reservoirs. Therefore, it is imperative to minimize the rate of soil erosion in the watersheds and sedimentation in the structures.

Traditional methods of documenting rates of soil loss and sedimentation redistribution possess many limitations (Loughran, 1989) Through the subject CRP, the Institute would be able to learn and practice application of nuclear techniques especially the fallout radionuclides (\(^{137}\)Cs and \(^{7}\)Be) in characterizing soil erosion problems and their use in the evaluation of erosion and sedimentation remediation solutions (Walling, He and Blake, 1999, Campbell et al, 1986, Loughran and Elliott, 1996). For this purpose, study of sedimentation in Rawal Dam and soil erosion in its catchment is continued. The watershed is very large having diverse nature of its land use, soil and geology. The study site that has been selected consists of dam reservoir, tributaries and a field station in catchment area (being managed by National Agricultural Research Center). The other activities in the area like construction of roads and land leveling for housing and agricultural practices have also been monitored to establish/ find the changes in sediment load accordingly.

Soil sampling

River Kurang and Main Streams: Samples were collected from River Kurang and all major streams that contribute to the dam reservoir. These samples help to determine the actual \(^{137}\)Cs level in different sediments from all tributaries.

Watershed: Soil erosion sampling in the watershed was started at a site called Satra Meel, which is already under investigation of NARC (National Agricultural Research Center) using conventional techniques. Samples have been collected from this area since 2002 for \(^{137}\)Cs and three reference inventories have also been made on the basis of these results. However, this time more emphasis is given to sampling for \(^{7}\)Be to estimate the erosion according to event or seasonal basis. For this purpose, a small plot (1.5m X 1.5m) at flat area of the hill 1 was selected for reference inventories on the basis of rain events. Another site was selected for reference inventory at top of hill 2. Samples were also collected from hill slopes and channel bed to see the redistribution of the sediment.

Dam reservoir: Six sediment cores with section of 10cm each were collected from the dry bed of the reservoir with auger. However, only two cores were deep enough (up to 270cm) whereas others were of around 80-100cm. Since, the dam level is decreasing and more dry bed is appearing, sampling of more cores will be performed during next two months.

Results and discussion
Reference sites: No new sampling is done for new reference inventory for $^{137}$Cs this year. Old reference inventories established in 2002-3 were used to calculate the eroded material. The shapes of $^{137}$Cs profiles in these reference inventories indicate a peak and the position of the maximum concentration is not at the soil surface, but several centimeters below the surface (He and Walling, 1997). The total inventory of 3280 Bq m$^{-2}$ is used.

![Depth profile of $^{137}$Cs inventory first reference site at River Kurang and main streams](image)

<table>
<thead>
<tr>
<th>No.</th>
<th>Site Description</th>
<th>$^{137}$Cs (Bq kg$^{-1}$)</th>
<th>$^{7}$Be (Bq kg$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEDI-1</td>
<td>River Kurang Main</td>
<td>1.169857</td>
<td>2.604882</td>
</tr>
<tr>
<td>SEDI-2</td>
<td>Chatter Tributary</td>
<td>1.655348</td>
<td>3.064051</td>
</tr>
<tr>
<td>SEDI-3</td>
<td>After mixing 1+2</td>
<td>2.431353</td>
<td>2.98606</td>
</tr>
<tr>
<td>SEDI-4</td>
<td>Channel coming from NARC field</td>
<td>4.040881</td>
<td>7.643066</td>
</tr>
<tr>
<td>SEDI-5</td>
<td>Kurang river at dam mouth</td>
<td>40.41856</td>
<td>3.451078</td>
</tr>
<tr>
<td>SEDI-6</td>
<td>NoorPur tributary to dam</td>
<td>1.815228</td>
<td>4.629709</td>
</tr>
</tbody>
</table>

Sediment Cores
Six cores taken from dry bed of the reservoir were divided in sections of 10 cm each. However, more sampling is needed with small intervals of 1 cm for $^{7}$Be measurement because the concentration is diluted with 10 cm core. Two cores have been analyzed so far for $^{137}$Cs and $^{7}$Be. The results indicate that $^{7}$Be is present only at top layer, whereas $^{137}$Cs is distributed along the whole profile.
Depth profile of $^{137}$Cs concentration along Core No. 1 at River Kurang in Rawal Dam Reservoir

Depth profile of $^{137}$Cs concentration along Core No. 2 at River Kurang in Rawal Dam Reservoir

$^7$Be profiles

Samples taken from the watershed were analyzed for $^7$Be content. Measurements of $^7$Be can be used to indicate movement of topsoil (Wallbrink and Murray 1996). Four samplings were carried out to establish a reference inventory. First sampling was performed from a flat area at the top of hill-1 of the catchment, whereas three more samplings were carried out after making a plot to prohibit any water entry/runoff from sides. Two samples were also collected from the adjacent hill to see the difference in inventories. The Be-7 penetration to ground is in upper few centimeters and goes maximum to 4 cm with high rain during that period. The $^7$Be concentration indicates enough input and well distribution along the depth profile. Small inventory is also observed at two locations and the reason might be uneven land and presence of stones. The samples taken along the transects from top of the hill to the bottom flat area and along the channel have $^7$Be inventory lower and higher than the reference inventory indicating erosion/deposition. The $^7$Be and $^{137}$Cs concentrations can be used to describe erosion processes in catchments and in some cases the soil depth in the soil profile from which the sediment was eroded (Wallbrink and Murray, 1993; Wallbrink et al., 1999). The samples along the slopes show zero $^7$Be at most of the locations whereas high $^7$Be content of the samples at different pockets, especially the flat areas and the land under vegetation cover which indicate significant deposition. At bottom of hill, very high $^7$Be (Average 171 Bq m$^{-2}$) shows the maximum deposition before entering to the main channel.
Conclusions

The results drawn from the data so far indicate good potential of $^{137}$Cs and $^7$Be fallout radionuclides in estimating soil redistribution due to natural and human activities. The significant reduction in inventory evident for most of the cores indicates that most of the sampling points have experienced appreciable net erosion over the period since the commencement of $^{137}$Cs fallout in the mid 1950s. $^{137}$Cs inventory is generally very low at the track as compared to bush samples. On the other hand, $^7$Be inventories indicate the soil redistribution for short events and the inventories are also very low on the tracks. However, $^7$Be inventories at the bottom flat areas and the areas under vegetation cover show significant deposition.

The sediment samples collected from different tributaries of the main River Kurang show the effect of human activities on sediment loads. The low $^{137}$Cs content from unmanaged catchments of River Kurang shows deep soil and high $^{137}$Cs concentration from the sediment of managed area indicates the erosion of topsoil only. Deforestation, construction of new roads and bulldozing of land for cultivation seems to be the major cause of increase in sediment loads to the River and ultimately the dam reservoir. However, more sampling and data is needed to draw the conclusion and to indicate the potential sites to be managed for controlling the erosion.

Acknowledgements

The research project (PAK-12392) is being carried out under the framework of IAEA CRP “Sediment tracing (Fingerprinting) by nuclear techniques”. Financial and technical support provided by the agency is gratefully acknowledged. Sincere thanks are due to Dr Claude Bernard (Technical Officer), Ms. Leon and other staff members of the Division for their help in the project execution. Cooperation of end-user departments Small Dams Organization and National Agricultural Research Center is acknowledged with gratitude.

References


Assessment of soil erosion rates and the effectiveness of soil conservation measures using fallout radionuclides and plots

Phan Son Hai
Dalat Nuclear Research Institute
Vietnam Atomic Energy Commission
S. Hai Phan¹, T. Binh Nguyen¹, D. Hien Pham¹, D.Khoa Tran¹
T. Mui Nguyen¹, V. Hoa Tran¹, C. Tu Trinh², C. Lich Le²
¹ Vietnam Atomic Energy Commission
² National Institute for Soil and Fertilizer

Contract Number VIE-12331

Summary
The study was carried out at five experimental plots having following features: cultivation land applying soil conservation measures (plot NT1) and without soil conservation (plot NT5), bare soil with soil conservation technique (plot NT3) and without soil conservation (plot NT4) and pasture land (plot NT2). Eroding soil exported out of plots was measured in three years, from 2003 to 2005. Data showed that soil erosion rate at bare soil plot was the greatest in all, and that by using 3 grass bands along contour lines soil erosion rate decreased 11 times in the year 2005. For cultivated land the rate of soil loss is less than that for bare soil and it decreased respectively 26 times and 46 times in the year 2004 and 2005 owing to 3 strips of grass.

Radionuclide $^{137}$Cs was used for estimation of the average soil erosion rate for plot area. The Proportional Model and an empirical model developed by Dalat team were applied for assessment of soil erosion rates. Two models gave compatible results in the range of uncertainties.

Radionuclide $^{7}$Be was utilized for assessment of soil loss at plots in a short period of time. During three years 10 investigations were carried out at 5 plots over different time scales. The shortest duration of soil erosion investigated is 22 days, and the longest duration is 7 months from the beginning to the end of a rainy season. Soil erosion rates estimated by conversion models were compared with those measured by run-off plot method. Results showed that Be-7 can be utilized for assessment of soil redistribution and the effectiveness of soil conservation measures for a short time scale, even after only a few heavy rain-storms. The conversion model applied overestimated soil erosion rate when the particle size correction factor P is omitted, and gave the result close to net soil loss with taking factor P into account. In the case of high erosion rates the conversion model overestimated the soil loss when P=1 and underestimated erosion rate when P≠1. Based on the pattern of $^{7}$Be and soil redistributions the capability of grass-retaining strips was identified.

Introduction
This study was carried out in the frame of the CRP D1.50.08 on “Assessment of the effectiveness of soil conservation measures for sustainable watershed management using fallout radionuclides”. The study aimed at:

- Assessment of the soil redistribution using Cs-137 and Be-7 radionuclides;
- Estimation of the effectiveness of soil conservation measures using Be-7 and experimental plots;
- Testing conversion models used in soil erosion investigations;
- Estimation of soil erosion rates for different land use and vegetation.

The Study Area
The study has been carried out at five plots which were built in a hill slope near Dalat Nuclear Research Institute and these plots came into operation in 2003 (Fig. 1). The plots have the same area of 128 m² and the slope of about 25%. Plot NT1 has been used for cultivation in the same way as farmers do for most land in this region with the utilization of 1.2m grass bands to reduce soil
loss. Meanwhile, NT5 has been cultivated as NT1 but without soil conservation measures. The vegetation in plot NT2 is grass and this plot has not been cultivated. NT3 and NT4 have been bare soil but for NT3, 30 cm grass bands along contour lines were utilized to retain eroding materials. For retaining eroding soil ditches were built at the end of the plots as farmers do for most land in this region with the utilization of 1.2m grass bands to reduce soil loss. Meanwhile, NT5 has been cultivated as NT1 but without soil conservation measures. The vegetation in plot NT2 is grass and

![Figure 1. Five experimental plots in Dalat](image)

this plot has not been cultivated. NT3 and NT4 have been bare soil but for NT3, 30 cm grass bands along contour lines were utilized to retain eroding materials. For retaining eroding soil ditches were built at the end of the plots.

There are two distinct seasons for the region. The dry season lasts about 5 months, from December of the last year to April and the rainy season lasts from May to November. The average of annual rainfall for this region is 1670 mm for the last 40 years.

**Study Methods**

Eroded materials in sediment traps of plots were collected after a period of time, weighed and processed for estimation of soil loss and analysis of radionuclides. Based on the amount of sediment and $^{137}$Cs concentration in sediments, loss of $^{137}$Cs in comparison with reference inventory value was calculated. Then values of soil loss assessed by conversion models were compared with net soil loss in sediment traps.

In order to assess the distribution pattern of $^{137}$Cs and soil erosion rates for the plot area, soil cores with 10 cm diameter and 30 cm depth were taken in plots NT1, NT2, NT3 and NT4. The location of sampling points in plots with grass bands and plots without grass bands is showed in Figure 2. Soil samples were dried, ground and processed for $^{137}$Cs analysis. Based on the Cs-137 redistribution soil erosion rates were estimated using two conversion models, namely NRI Model (Hai P.S. et al. 2001) and the Proportional Model (He and Walling, 1996).

In studies of soil erosion using $^7$Be, soil samples were collected in the area of 800 cm$^2$ and down to 5 cm. The sampling diagram in plots with grass bands and plots without grass bands is showed in Figure 2. For reference values, soil samples were taken in the pasture land near the study area. For plot NT1 one investigation was carried out at the end of the dry season for estimation of remaining $^7$Be level in soil and two others were made at the end of two rainy seasons in two years for assessment of soil erosion and the effectiveness of soil conservation measures. Sampling in plot NT2 was made at the end of the year, when the rainy season almost finished. For plot NT3 one investigation was carried out at the end of the rainy season for estimation of the impact of grass bands, and the other was performed after a period of 22 days from the beginning of the rainy season for assessment of the impact of the soil conservation measure under the influence of some heavy rain-storms took place in a short time. Similarly, for examination of the capability of $^7$Be technique in assessment of soil erosion for a short time scale sampling in NT5 was undertook when the rainy season had lasted for three months. For plot NT4 two sampling stages at the end of two successive
rainy seasons were implemented for estimation of soil erosion rates. Soil samples were also taken in NT4 after two rainy months for assessment of Be-7 redistribution in a short time.

In Be-7 technique, the soil erosion amount $R_{Be}$ is calculated by following formula (Q. He, D.E. Walling and P.J. Wallbrink, 2002):

$$ R_{Be} = h_0 \ln \frac{PA_{Be,ref}}{PA_{Be,ref} - A_{Be,ref} + A_{Be}} $$

(1)

where, $h_0$ is relaxation mass depth describing the shape of the initial $^7$Be depth distribution (kg m$^{-2}$); $A_{Be,ref}$ is the $^7$Be reference inventory; $A_{Be}$ is the $^7$Be inventory; $P$ is the ratio of the $^7$Be concentration of mobilized sediment to that of the original soil.

The deposition amount $R'_{Be}$ is calculated as:

$$ R'_{Be} = \frac{A_{Be} - A_{Be,ref}}{C_{Be,d}} $$

(2)

where, $C_{Be,d}$ is the $^7$Be concentration of the deposited sediment and is estimated by following formula:

$$ C_{Be,d} = \frac{A_{Be,ref} (1 - e^{-R_{Be}/h_0})}{R_{Be}} $$

(3)

In this study $C_{Be,d}$ is inferred from the $^7$Be concentration of sediment in the sediment trap of the plots. Values obtained by this way are close to those calculated by equation (3). The amount of soil loss/gain was estimated in two cases: the particle size correction factor P was taken into account ($P \neq 1$) and it was neglected ($P = 1$).

When soil samples were taken in the plots for estimation of erosion rates using $^7$Be, eroding soils in the sediment traps were also collected. Therefore, the validation of conversion models can be examined.

Radionuclides $^{137}$Cs and $^7$Be were determined by gamma spectrometry using high purity germanium detectors with a 30% relative efficiency. Gamma counting usually lasts for 24 hours. For this analysis, all samples prepared as a fine homogeneous powder were cast using polyester resin in the desired geometry. Radionuclide $^{137}$Cs was measured by its gamma emission at 662 keV and $^7$Be was measured at 477 keV.

Results and Discussion

Estimation of soil loss using $^{137}$Cs

The distribution of $^{137}$Cs in 4 plots was showed in Figure 3. The amount of soil loss (positive value) or gain (negative value) estimated using $^{137}$Cs data and two conversion models was given in Table 1. The results showed that the $^{137}$Cs distribution patterns for plots are not identical. Except plot NT3, soil erosion rates assessed by two conversion models are well compatible in the range of uncertainties.
Assessment of soil erosion using \( ^{7}\text{Be} \)

**Plot NT1**: The distribution patterns of \( ^{7}\text{Be} \) in NT1 from 3 investigations are showed in Fig. 4. The study carried out at the end of the dry season (NT1-1) gave very low \( ^{7}\text{Be} \) inventories (the mean is 31 Bq m\(^{-2}\)) in comparison with those obtained from studies at the end of the rainy season. This means that after a 5 month dry season the value of \( ^{7}\text{Be} \) inventory in soil can be negligible. Based on \( ^{7}\text{Be} \) data, soil erosion rates were estimated and given in Table 2. In comparison with eroded soil in the sediment trap, the conversion model (1) with \( P = 1 \) overestimated soil erosion rates. Meanwhile, with taking the particle size correction factor \( P \) into account, the conversion model gave the result close to net soil loss.

<table>
<thead>
<tr>
<th>Plot code</th>
<th>Soil loss/ gain NRI model (kg/plot(\cdot)y(^{-1}))</th>
<th>Unc.</th>
<th>Soil loss/ gain Prop. model (kg/plot(\cdot)y(^{-1}))</th>
<th>Unc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>NT1</td>
<td>64.4</td>
<td>15.6</td>
<td>57.8</td>
<td>13.3</td>
</tr>
<tr>
<td>NT2</td>
<td>-48.9</td>
<td>5.8</td>
<td>-57.8</td>
<td>7.1</td>
</tr>
<tr>
<td>NT3</td>
<td>242.2</td>
<td>17.1</td>
<td>355.6</td>
<td>22.2</td>
</tr>
<tr>
<td>NT4</td>
<td>-0.5</td>
<td>12.2</td>
<td>-0.1</td>
<td>11.1</td>
</tr>
</tbody>
</table>

Table 1. Soil loss/ gain calculated from \( ^{137}\text{Cs} \) data

At the beginning of the year 2004 three grass bands (The width of each grass strip is 1.2 m) were created along contour lines in model NT1 as a soil conservation measure. Results from the last investigation (NT1-3) showed that in comparison with plot NT5 grass bands reduce considerably soil loss, and that eroding soil was trapped in 40 – 60 cm wide strips up slope of the grass bands.

**Plot NT2**: The distribution patterns of \( ^{7}\text{Be} \) and soil erosion/ deposition rates at NT2 are showed in Figure 5. Soil loss estimated by the conversion model mentioned above is given in Table 2. In comparison with eroded soil in the sediment trap, the conversion model overestimated soil erosion.
rate in the case of \( P=1 \). With \( P \neq 1 \) the model gave the result consistent with net soil loss of the plot in the range of uncertainties.

**Plot NT3**: Soil and \(^{7}\text{Be} \) redistributions in NT3 after a 6 month rainy season are showed in Figure 6.

![Figure 6](image-url)

Figure 5. The distribution pattern of Be-7 and soil erosion rates at plot NT2

Figure 6. The distribution pattern of Be-7 and soil erosion rates obtained from two investigation at plot NT3

(denoted by NT3-1). Soil and \(^{7}\text{Be} \) redistributions in NT3 after a period of time of 22 days from the beginning of the next rainy season are also showed in Figure 6 (NT3-2). In this stage some heavy rain-storms happened with a total rainfall of 233 mm. The data showed that although under the influence of the surface flow in a short time, the distribution pattern of \(^{7}\text{Be} \) and soil from this investigation (NT3-2) is quite different from previous one. This means that \(^{7}\text{Be} \) can be utilized for assessment of soil redistribution, and therefore for assessment of the effectiveness of soil conservation measures, after only a few heavy storms. Data showed that with the existence of three 0.3m grass bands, eroding soil was trapped in the neighbouring area up slope of the grass bands, and that the grass band near the sediment trap retained eroding soil more effectively than two other grass strips. Pay attention that plot NT3 is bare soil without tillage. Therefore, soil redistribution in this plot is only due to surface flow.

The amount of soil loss estimated by the conversion model is given in Table 2. In comparison with the amount of eroded material in the sediment trap, the conversion model overestimated soil erosion rates with \( P = 1 \) and gave the result consistent with the net soil loss when factor \( P \) was taken into account.

**Plot NT4**: Soil and \(^{7}\text{Be} \) redistributions in NT4 at the end of two years, when the rainy season finished, are showed in Figure 7. Soil erosion rates calculated from Be-7 data are given in Table 2. Results showed that in the first study (NT4-1) the conversion model overestimated soil erosion rates with \( P = 1 \), and gave the result consistent with net soil loss in the case \( P = 1.76 \). For second study (NT4-2) the conversion model overestimated soil erosion rates in the case \( P = 1 \) and underestimated the erosion rate with \( P = 1.7 \). The predicted values have a difference of about 36% with net soil loss.
Figure 7. The distribution pattern of Be-7 and soil erosion rates obtained from two investigations at plot NT4

Figure 8. The distribution pattern of Be-7 and soil erosion rates at plot NT4

Table 2. Soil erosion rates at the plots estimated by the conversion model (1) using $^7$Be data and net soil loss amounts collected at sediment traps

<table>
<thead>
<tr>
<th>Plot code</th>
<th>Survey code</th>
<th>Soil loss kg/plot ($P=1$)</th>
<th>Unc.</th>
<th>Soil loss kg/plot ($P\neq1$)</th>
<th>Unc.</th>
<th>Sediment collected (kg)</th>
<th>Note</th>
<th>Value $P$</th>
<th>Value $C_{Be}$ (Bq kg$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NT1</td>
<td>NT1-1</td>
<td>24</td>
<td>9</td>
<td>-0.2</td>
<td>5.4</td>
<td>4.2</td>
<td>1.76</td>
<td>5.2</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>NT1-2</td>
<td>83</td>
<td>23</td>
<td>3</td>
<td>11</td>
<td>13.9</td>
<td>1.76</td>
<td>16.65</td>
<td>25.0</td>
</tr>
<tr>
<td></td>
<td>NT1-3</td>
<td>45</td>
<td>12</td>
<td>10</td>
<td>7</td>
<td>16.6</td>
<td>1.76</td>
<td>21.0</td>
<td>21.0</td>
</tr>
<tr>
<td>NT2</td>
<td>NT2</td>
<td>52</td>
<td>14</td>
<td>14</td>
<td>9</td>
<td>4.9</td>
<td>1.76</td>
<td>21.0</td>
<td>25.0</td>
</tr>
<tr>
<td>NT3</td>
<td>NT3-1</td>
<td>162</td>
<td>30</td>
<td>66</td>
<td>15</td>
<td>74.7</td>
<td>1.76</td>
<td>23.0</td>
<td>45.0</td>
</tr>
<tr>
<td></td>
<td>NT3-2</td>
<td>252</td>
<td>22</td>
<td>110</td>
<td>11</td>
<td>114</td>
<td>1.76</td>
<td>45.0</td>
<td>21.1</td>
</tr>
<tr>
<td>NT4</td>
<td>NT4-1</td>
<td>203</td>
<td>39</td>
<td>72</td>
<td>18</td>
<td>87.4</td>
<td>1.76</td>
<td>21.1</td>
<td>20.0</td>
</tr>
<tr>
<td></td>
<td>NT4-2</td>
<td>713</td>
<td>90</td>
<td>339</td>
<td>41</td>
<td>520</td>
<td>1.7</td>
<td>20.0</td>
<td>32.0</td>
</tr>
<tr>
<td></td>
<td>NT4-3</td>
<td>476</td>
<td>41</td>
<td>225</td>
<td>20</td>
<td>352</td>
<td>1.7</td>
<td>32.0</td>
<td>25.7</td>
</tr>
<tr>
<td>NT5</td>
<td>NT5</td>
<td>415</td>
<td>68</td>
<td>202</td>
<td>32</td>
<td>310</td>
<td>1.76</td>
<td>25.7</td>
<td></td>
</tr>
</tbody>
</table>
The third investigation was made for study of soil redistribution in NT4 in a short period of time of two rainy months. Soil and Be-7 redistributions at NT4 are showed in Figure 8. The total rainfall at NT4 for this period is 542 mm. Soil erosion rate estimated using $^7\text{Be}$ data is given in Table 2. Data showed that after two rainy months the pattern of $^7\text{Be}$ distribution is quite different from that obtained by last investigation namely NT4-2, and that after some heavy rain-storms a large amount of soil was eroded and exported out of the plot. Soil collected in the sediment trap in this stage is 352 kg. Meanwhile, the conversion model gave predicted value of 476 kg with $P = 1$ and 225 kg with $P = 1.7$. Therefore the conversion model overestimated soil erosion rates with $P = 1$ and underestimated the erosion rate in the case $P \neq 1$

**Plot NT5**: Plot NT5 was cultivated as NT1 but without soil conservation measures. $^7\text{Be}$ and soil redistribution in NT5 was assessed when the rainy season had lasted for three months. Results obtained from the investigation are given in Table 2. The redistribution of $^7\text{Be}$ and soil erosion/deposition rates in the plot are shown in Figure 9. Soil collected in the sediment trap at this time is 310 kg. Meanwhile, the conversion model gave the amount of soil loss of 415 kg with $P = 1$ and 200 kg with $P = 1.76$. Therefore, the conversion model overestimated soil erosion rates when $P = 1$ and underestimated the erosion rate when $P = 1.76$. The predicted values have a difference of about 35% with net soil loss.

**Assessment of soil erosion rates using plot data**

The amount of soil eroded from five plots in the years 2003, 2004 and 2005 is given in Tables 3. $^{137}\text{Cs}$ loss in comparison with the reference value is also given in this table.

| Table 3. Soil loss data from experimental plots and the conversion model NRI |
|---------------------------------|-------|-------|-------|-------|-------|
|                                 | NT1   | NT2   | NT3   | NT4   | NT5   |
| Net soil loss (t ha$^{-1}$),     | 2003  | 0.33  | 0.61  | 5.86  | 6.85  |
|                                 | 2004  | 1.09  | 0.38  | 17.30 | 40.79 | 28.00 |
|                                 | 2005  | 0.20  | 0.24  | 2.72  | 29.03 | 9.11  |
| $^{137}\text{Cs}$ loss (%),     | 2003  | 0.014 | 0.023 | 0.425 | 0.476 |
|                                 | 2004  | 0.068 | 0.022 | 1.207 | 2.615 | 1.139 |
|                                 | 2005  | 0.012 | 0.014 | 0.192 | 1.877 | 0.418 |
| Soil loss estimate, NRI model (t ha$^{-1}$) | 2003  | 0.17  | 0.30  | 7.62  | 8.65  |
|                                 | 2004  | 1.00  | 0.28  | 24.23 | 57.08 | 22.72 |
|                                 | 2005  | 0.15  | 0.18  | 3.16  | 39.52 | 7.48  |

The data obtained from the plots showed that soil erosion rate is greatest for bare soil (NT4), and that by using 3 grass bands (0.3m wide for each band in plot NT3) along contour lines soil erosion rates in the years 2004 and 2005 decrease 2.4 times and 10.7 times, respectively. For cultivated land (NT5) the rate of soil loss is less than that for bare soil. Especially, by utilizing 3 strips of grass (1.2 m wide for each band in plot NT1) soil erosion rates in the years 2004 and 2005 decrease 26 times and 46 times, respectively. The mean rate of soil loss for pasture land is 0.41 t ha$^{-1}$ over three years.
For validation of the NRI conversion model eroded soil in the sediment trap of 5 plots was collected in the years 2003 – 2005. Based on the amount of sediment and $^{137}$Cs concentration in sediments, loss of $^{137}$Cs in comparison with reference inventory was calculated. Then values of soil loss assessed by the model were compared with net soil loss in sediment traps. Results are given in Table 3. Data in Table 3 showed that the difference between values estimated by the conversion model NRI and net soil loss varies from 8% to 50% with the mean value of 29.3% and the standard deviation of 12.5%.

**Conclusions**

In studies of soil erosion using $^{137}$Cs technique, the Proportional Model (He and Walling, 1996) and empirical NRI Model developed by Dalat team (Hai P.S. et al. 2001) gave compatible estimates in the range of uncertainties. In comparison with the net soil loss from experimental plots, NRI Model gave results with the difference of 29% in average. In fact this difference is acceptable and these conversion models can be used for estimation of soil erosion rates in Vietnam.

Radionuclide $^7$Be can be utilized for assessment of soil redistribution and for assessment of the effectiveness of soil conservation measures for a short time scale, even after only a few heavy rainstorms. The conversion model (1) overestimates soil erosion rate when the particle size correction factor P is omitted, and gives the result close to net soil loss when factor P is taken into account. In the case of high erosion rates, the conversion model overestimates soil erosion rates if P=1 and underestimated erosion rate if P≠1.

Strips of grass along contour lines created as a soil conservation measure can retain soil in the neighbouring area up slope of the bands. This method reduced considerably soil loss at plots. The decrease in soil loss due to grass bands ranges between 11 and 46 times depending on the width of the grass band.

**References**


Annex 4 - Publications related to the CRP

Publication in the $^{137}$Cs Bibliography since 2003 of Scientists with projects supported by the IAEA/FAO CRP to Assess the Effectiveness of Soil Conservation Techniques for Sustainable Watershed Management Using Fallout


Owens, P.N. and D.E. Walling. 2003. Temporal changes in the metal and phosphorus content of suspended sediment transported by Yorkshire rivers, U.K. over the last 100 years, as recorded by overbank floodplain deposits. Hydrobiologia 454:185-191.


Schuller, P., Walling, D.E., Sepúlveda, A., Castillo, A. 2006. Use of $^{137}$Cs measurements to evaluate the effectiveness of a change from conventional to reduced tillage practices in controlling soil erosion. (Accepted ISCO Conference, Marrakech, Morocco, 14-19 May 2006).


