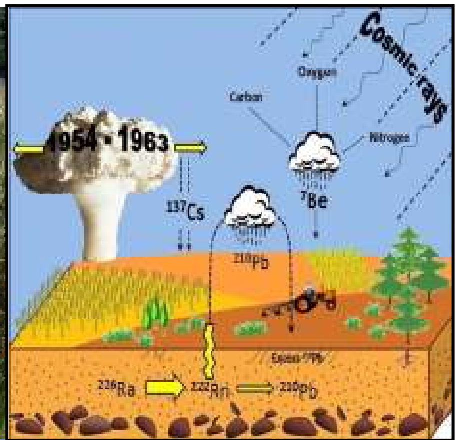
Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

Soil Science Unit

Activities Report

2009



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The Soil Science Unit (SSU) of the FAO/IAEA Agriculture and Biotechnology Laboratory develops and tests nuclear techniques in the field of crop nutrition, soil erosion and sedimentation as well as agricultural water management. During the past year, the research and development work of the Unit continued to have major impact through the transfer of nuclear technology to developing Member States.

Major progress has been achieved during 2009 on the use of fallout radionuclides (FRN) in quantifying soil erosion and sedimentation. Our experimentation in collaboration with the CNESTEN in Rabat, Morocco; the University of Ljubljana, Slovenia; the Chinese Academy of Sciences and Ministry of Water Resources, in Chengdu, Sichuan, China and the MAPAQ in Québec, Canada, has contributed to fine tune FRN techniques in different agroenvironmental conditions and produced valuable data on soil redistribution rates, sedimentation modelling, spatial distribution and content of soil organic matter linked with soil degradation, radionuclides vertical distribution. All these studies have added to the recognised expertise of the Soil and Water Management & Crop Nutrition (SWMCN) Subprogramme in using fallout radionuclides for the quantification of soil degradation. Also, the preparation of a practical IAEA training manual on the use of FRNs (^{137}Cs, ^{7}Be, ^{210}Pb) to investigate erosion and sedimentation processes has been initiated and is expected to be ready for publication by the end of 2010. This IAEA training manual involves a major effort not only from IAEA staff but also from selected members of previous participants of the coordinated research project entitled "Conservation measures for sustainable watershed management using fallout radionuclides (CRP D1.50.08) and some other well known experts in this field. The aim of this manual is to transfer to IAEA Member States basic training and advanced materials to deal with FRN.

Drought, salinity and declining soil fertility underscore the need for expanding the availability of plant varieties that can be productively grown in harsh environments due to the emerging climate change. Capitalizing on the successful results of methodologies developed to use of isotopes of carbon, nitrogen, phosphorus and oxygen to evaluate crop varieties adapted to these harsh environments, the Soil Science Unit collaborated with our Member States in Poland, Slovenia, Bangladesh and the Plant Breeding Unit to evaluate mutant varieties of banana, wheat, maize, and rice for their tolerance to harsh environments. In collaboration with the University of Wyoming, USA, ^{18}O isotopic tracers in dry samples was successfully used to evaluate wheat varieties tolerant to pre- and post-anthesis water stress. A mechanism of adaptation of maize to high temperatures based on the photosynthate partitioning and sugar metabolism using ^{13}C was verified in collaboration with Hiroshima University, Japan. The ^{13}C methodology was successfully tested in Bangladesh through a TC project to help farmers in coastal areas cope with drought and soil salinity.

The SSU also made improvements to reduce the time used for extracting water from plant and soil through cryodistillation from 16 to 4 hrs without affecting the efficiency of extraction. This has helped to provide the needed support to the CRP on "Managing irrigation water to enhance crop productivity under water-limited conditions" through analysis of samples. A manual on "The Use of Phosphorus Isotopes for Improving Phosphorus Management in Agricultural Systems" as a training and reference manual for soil scientists, agronomists, plant physiologists, crop scientists and other end-users *in developing Member States was drafted in 2009. The purpose of reference manual is to provide a comprehensive coverage and up-to-date information on several topics related to P in soil-plant systems.*

Seven fellows from developing Member States received individual fellowship trainings at the SSU during 2009 a total of 21 man-months of training. The fellows were trained in a range of isotope and nuclear techniques related to integrated land, water, and crop management for high crop-water productivity and environmental sustainability. The collaboration between the Plant Breeding Unit and the SSU were further strengthened through joint fellowship training in the use of stable isotopes to identify crops with increased resilience to abiotic stress. Eight scientific visitors received further training on the use of nuclear and isotopic techniques in integrated soil-water-plant- management research by the SSU during the year in the field of crop nutrition, water management and soil erosion and sedimentation for a total of 40 days.

A total of 7749 stable isotope measurements were performed during 2009. Most analyses were for supportive research as well as for training with some 3000 for CRPs and TCPs. Furthermore the SSU performed 360 radioisopes (^{137}Cs) measurements for supportive research in 2009.

The External Quality Assurance of isotope analyses was again outsourced during 2009 with Wageningen Evaluating Programs for Analytical Laboratories (WEPAL) looking after the proficiency test for the FAO/IAEA. Fifteen IAEA-funded stable isotope laboratories participated in 2009 proficiency test (PT)-round, three more than in 2008.

The SSU coordinates a CRP on Selection and Evaluation of Food (Cereal and Legume) Crop Genotypes Tolerant to Low Nitrogen and Phosphorus Soils through the Use of Isotopic and Nuclear-Related Techniques. In addition the SSU coordinated 12 TC projects (Angola, Chile, Bangladesh, Benin, Eritrea, Madagascar, Mali, Ivory Coast, Sierra Leone, Slovenia, Sri Lanka, and Sudan).

A total of 16 publications were produced by the SSU and co-authors during 2009.

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1. PROGRAMMATIC AND UNIT OBJECTIVES

Management practices and technological packages which conserve natural resources, minimize environmental degradation and mitigate climate changes are becoming increasingly vital to improving or even maintaining food security and environmental sustainability. Understanding transformation processes that influence soil health, including the efficient use of water and nutrients, and developing and delivering technological packages through various networks will be essential to enhance the sustainability of agricultural systems. Through the development and improvement of stable and radioactive isotopic techniques, the Soils subprogramme assists Member States (MS) to monitor and predict the impacts of climate change and agricultural land use aimed at addressing the land-water-nutrient issues in the individual countries.

The Soil and Water Management and Crop Nutrition (SWMCN) Section of the Joint FAO/IAEA Division and the Soil Science Unit (SSU) of the FAO/IAEA Agriculture & Biotechnology Laboratory assist in developing and delivering a range of isotopic and nuclear technological packages to MS, which will help conserve natural resources, minimize environmental degradation and mitigate climate change aimed at improving food security and soil health.

Nuclear techniques used in the field of land-water-nutrient management complement conventional techniques and provide unique information which other techniques often cannot provide. This includes:

- Quantitative information on the flow and fate of fertilisers in soils and uptake of nutrients by plants. Such information is essential in identifying efficient fertiliser management practices that minimizes movement of soil nutrients into groundwaters where they become potential pollutants.
- Identification of sources of soil water and its availability to plants, essential in identifying crop plants tolerant to environmental stresses (drought, salinity, nutrients) brought about by climate or other changes to the agri-ecological system.
- Measurement of soil water storage in cropping systems, indispensable in developing novel irrigation and soil management strategies aimed at assessing and mitigating the impact of water scarcity.
- Measurement and quantifying land degradation and soil erosion by the use of fallout radionuclides.
- Identification of sources of soil carbon vital in and estimating the contribution of organic carbon sources to global warming
- Quantification of biological nitrogen fixation in cropping systems, enabling also discrimination between soil and atmospheric nitrogen usage by agricultural crops.

The main roles of the SSU are to:

- To develop and validate the use of stable- and radio isotope applications in the plant-soil-water-atmosphere continuum,
- To train technical staff and scientists from Member States in the analyses of stable isotopes and the use of nuclear and related techniques to address land-water and nutrient issues,
- To provide isotope analyses to projects where analytical facilities are not currently available,
- To supply reference materials and quality assurance services to Member States.

The Soils Newsletter published two times annually by the IAEA provides details on current and future programmes.

2. STAFF

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3. STAFF NEWS

Dr. Patcharin Jankong joined the Soil Science Unit, FAO/IAEA Agriculture and Biotechnology Laboratory, Seibersdorf on 22 June 2009 as an intern from Thailand under the supervision of Mr Lionel Mabit. Patcharin will be associated with field research investigations, laboratory work, research data analysis and publications related to the use of Fallout Radionuclides (FRNs) for soil erosion and sedimentation investigation in support of the SWMCN Subprogramme activities. Patcharin's previous work and study include environmental research issues focusing on pollutants analysis in the environment (e.g. soil, water, plants and fish) and soil remediation (especially the effect of rhizosphere factors such as fertilizer, bacteria, and mycorrhiza on soil phytoremediation) which she conducted during her PhD studies at Mahidol University, Bangkok (Thailand) in collaboration with Karl-Franzen University, Graz (Austria).

Dr. Moncef Benmansour, from the Centre National de l'Energie des Sciences et des Technique Nucleaires (CNESTEN), Rabat, Morocco, joined the Soil Science Unit as a consultant for 2 months from 06 July to 11 September 2009. During this period at the IAEA, Moncef worked with Mr. Lionel Mabit in Seibersdorf producing a training manual on the use of Fallout Radionuclides to assess erosion and sedimentation processes. He has extensive expertise in radiometric techniques, in the use of nuclear techniques in the environment and agriculture fields and has participated in many IAEA projects (e.g. Regional TC projects and CRPs).

Mr Sasa Linic joined the Soil Science Unit on 8 June 2009 as a Consultant. Sasa has a Master Degree in Environmental Science (Natural Resource Management and Ecological Engineering) from University of Natural and Applied Life Sciences (BOKU), Austria and Lincoln University, New Zealand. Sasa will work with Joseph Adu-Gyamfi in the area of soil-water-plant relationship with a major focus on mechanisms of tolerance of crops to abiotic stress and crop-water productivity using isotopic tracers (^{13}C, ^{18}O and ^{2}H) and also provide support to the CRP on 'Managing irrigation water to enhance crop productivity under water limited conditions using nuclear techniques'.

4. RESEARCH AND DEVELOPMENT ACTIVITIES

4.1. A first investigation using radioactive tracers (^{137}Cs & ^{210}Pb$_{ex}$) and classical spatialisation/interpolation concept to document soil redistribution rates in Morocco [1]

M Benmansour (CNESTEN), L Mabit (SSU), A Nouira (CNESTEN)

Collaborative work beetween the Centre National de l'Energie des Sciences et des Technique Nucléaires (CNESTEN) in Rabat, Morocco and the Soil Science Unit

4.1.1. The challenge

Due to the intensification of agricultural practices and specific bio-climatic conditions, more than 15 millions hectares of the Moroccan agricultural land are under serious threat and each year around 100 million tons of soil are lost. Despite the severity of land degradation in Morocco, only limited data are available on the actual magnitude of soil erosion rates. Most of the previous research focused on conventional measurements of erosion (e.g. experimental plots, empirical erosion modelling etc.). Since the mid 1990's, few studies have reported the use of ^{137}Cs approach but the use of excess lead-210 (^{210}Pb$_{ex}$) as a soil tracer has never been tested in Morocco before the present study. The objectives of this investigation were:

(i) to test the combined use of ^{137}Cs and ^{210}Pb$_{ex}$ to assess long-term soil redistribution rates for a Moroccan agricultural field;

(ii) to establish a sediment budget for this field using classical assessment of soil redistribution rates and spatialisation approaches.

4.1.2. Experimental design

The experimental site under investigation is a one hectare agricultural field of the "Institut National de Recherche Agronomique" (INRA) located in Marchouch 68 km south east from Rabat, Morocco (Figure 1 and Figure 2). The climate is semiarid, the mean annual precipitation is 405 mm of which 50% falls from December to March. The mean monthly temperature ranges from 10 to 23°C and the altitude above sea level is between 350 to 400 meters.

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[1] *Project 2.1.1.1. Soil Management and conservation for sustainable agriculture and environment – Task 2: Improve FRN methodologies to measure soil redistribution rates at a range of scales in agricultural landscapes with the use of geostatistic approach.*

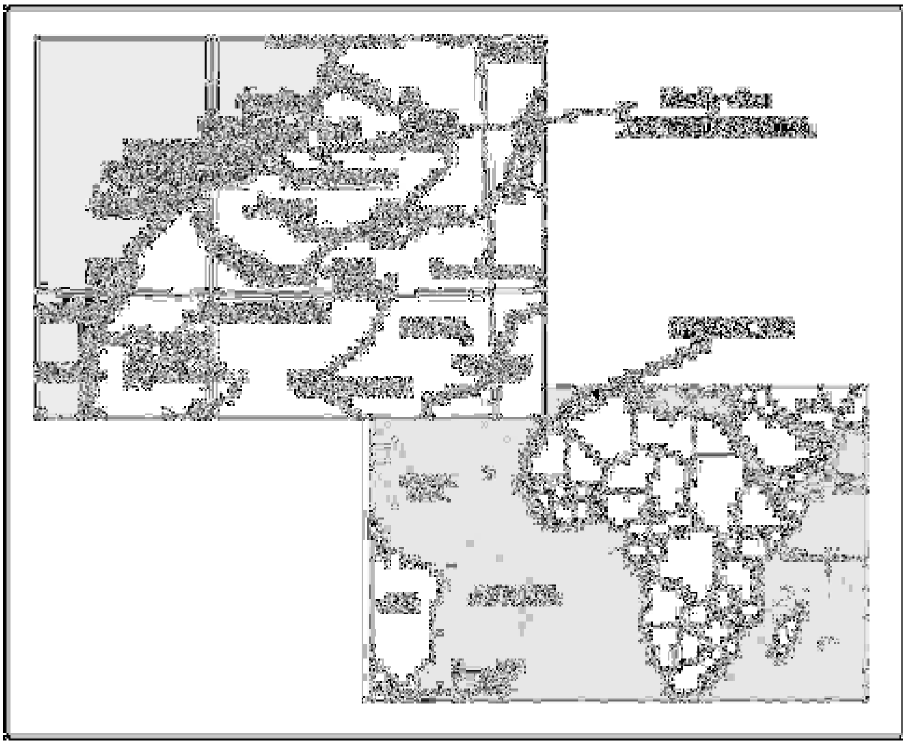

Figure 1. Location of the Marchouch Station (6°42'W, 33°47'N).

Figure 2. Study site at the Marchouch Station

Soil in the field is a clay soil with a mean slope gradient of 17%. The land use is dominated by cereals under conventional tillage (plough depth ~ 16 cm). 50 soil core samples were collected along 5 parallel transects (Figure 3 and Figure 4). The initial ^{137}Cs and ^{210}Pb fallout were assessed through 12 core samples collected in an undisturbed pasture located 3 km from the studied field.

Figure 3. CNESTEN team performing soil samples collection

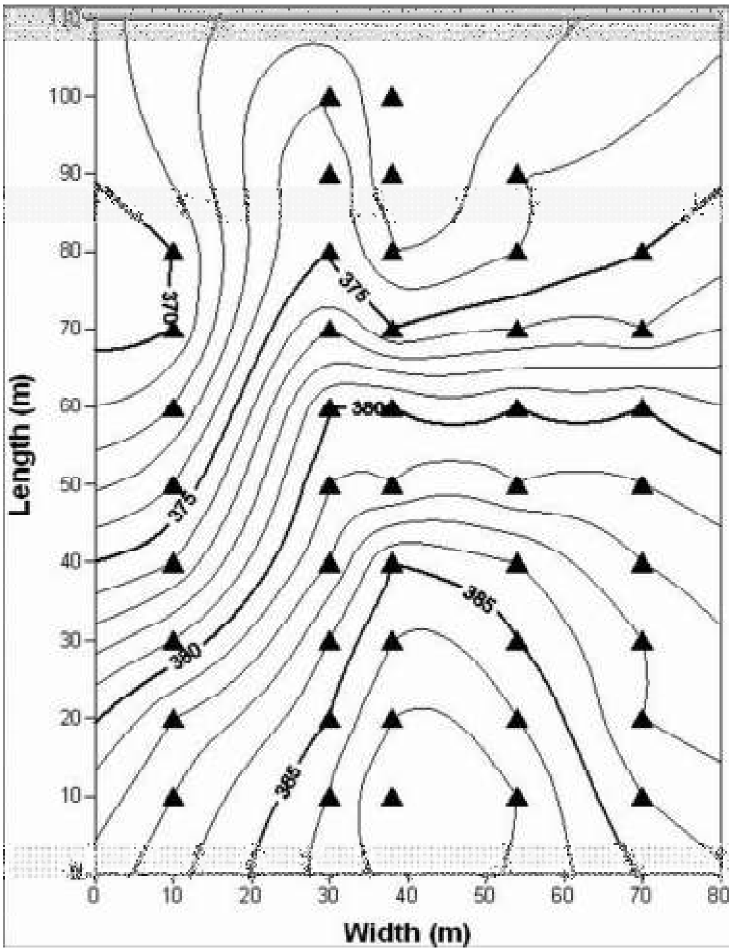

Figure 4. Topography of the experimental field and location of sampled points

Soil samples were dried, sieved and homogenised prior to measure ^{137}Cs, ^{210}Pb and ^{226}Ra by γ-spectrometry using a HPGe "N Type" detector (45 % efficiency). Areal activities of ^{137}Cs and $^{210}Pb_{ex}$ were converted into soil redistribution rates using the conversion model, Mass Balance Model 2 (MBM2). The parameters used for ^{137}Cs were: $\gamma = 0.6$, $H = 4.0$ kg m^{-2}, $d = 217$ kg m^{-2}, $A_{ref} = 1445$ Bq

m^{-2}, p = p'=1; and the parameters used for ^{210}Pb were: γ = 0.6, H = 4.0 kg m^{-2}, d = 217 kg m^{-2}, A_{ref} = 3305 Bq m^{-2}, I = 99 Bq m^{-2} yr^{-1}, p = p'=1.

Soil redistribution rates obtained from both isotopes were analyzed using geostatistic approach and a classical interpolation concept, Inverse Distance Weighting (IDW). IDW is a deterministic estimation method where unknown values are determined by a linear weighted moving average of values at known sampled points.

Geostatistical and spatial correlation analyses as well as variogram models were performed using the GS^+ software version 7. Applying the protocol of Mabit and Bernard (2007), maps of soil redistribution were established and a sediment budget for the whole field was calculated using the GIS Surfer 8.00 package.

4.1.3. Main results

4.1.3.1. Vertical distribution and inventories of ^{137}Cs and $^{210}Pb_{ex}$

(i) For the reference site, the vertical distribution associated with both radionuclides were similar and concentrated in the top 10 cm with a clear exponential decrease with depth. The ^{137}Cs concentration was highest at the surface (0-3 cm) with a value of 13 Bq kg^{-1}, while the $^{210}Pb_{ex}$ concentration was 25 Bq kg^{-1} at the soil surface. The reference inventory values were estimated at 3305 Bq m^{-2} (n = 12; CV of 30%) and 1445 Bq m^{-2} (n = 12; CV of 18%) for $^{210}Pb_{ex}$ and ^{137}Cs, respectively. This variability of ^{137}Cs reference inventory is well comparable with that reported in the existing literature reviews which indicated the range of CV for pasture and grassland sites chosen as a reference site from 5 to 41%. Our CV of 18% provides accurate information for the assessment of the basis level of ^{137}Cs with a small spatial variability of fallout inputs. In addition, the reference inventory value is within the expected range based on the previous Moroccan studies using ^{137}Cs technique and the correlation between mean annual precipitation and ^{137}Cs initial fallout.

(ii) For the cultivated site, as a result of tillage, the concentrations of both radionuclides were almost uniform throughout the plough layer (~ 16 cm) ranging from 1.9 to 5.9 Bq kg^{-1} and from 2.2 to 16.7 Bq kg^{-1} for ^{137}Cs and $^{210}Pb_{ex}$, respectively. Along the transects, the ^{137}Cs areal activities ranged from 600 to 1900 Bq m^{-2} and the $^{210}Pb_{ex}$ areal activities ranged from 1700 to 5000 Bq m^{-2}. The uncertainties associated with $^{210}Pb_{ex}$ are generally higher than those corresponding to ^{137}Cs due to the low intensity of ^{210}Pb gamma ray and the background contribution in this energy range.

4.1.3.2. Classical assessment of soil redistribution rates as derived from ^{137}Cs and $^{210}Pb_{ex}$

From the results of ^{137}Cs measurement and the conversion model MBM2 application, the erosion rates (over ~ 50 yrs) in the studied field ranged from 4 to 30 t ha^{-1} yr^{-1}. Eroded zones in the upslope part of the field represented 82% of the total area, while soil deposition occurred in the lower slope position on the remaining 18% of the area. From $^{210}Pb_{ex}$ data, the erosion rates (over ~ 100 yrs) ranged from 8 to 27 t ha^{-1} yr^{-1}. The eroded and depositional areas represent 84% and 16%, respectively. Using the average values of the transects, the results provided by ^{137}Cs and $^{210}Pb_{ex}$ isotopic approaches were comparable (Table 1).

Soil redistribution magnitude	**^{137}Cs**	**$^{210}Pb_{ex}$**
Mean erosion (t ha^{-1} yr^{-1})	17.9	15.0
Mean deposition (t ha^{-1} yr^{-1})	6.3	4.1
Gross erosion (t ha^{-1} yr^{-1})	15.4	12.9
Gross deposition (t ha^{-1} yr^{-1})	1.2	0.8
Net erosion (t ha^{-1} yr^{-1})	14.3	12.1
Sediment delivery ratio (%)	92	93

Table 1. Sediment budget and soil redistribution assessment from ^{137}Cs and $^{210}Pb_{ex}$ using simplified approach (Benmansour *et al.,* 2010).

4.1.3.3. Additional soil redistribution evaluation using spatialisation approaches

Experimental variograms for soil redistribution rate calculated from the data provided by the ^{137}Cs and $^{210}Pb_{ex}$ results were fitted. Following the optimization of variographic parameters and cross-validation analysis, the geostatistical study of the data set reported a very weak autocorrelation with a high nugget effect, a non significant coefficient of correlation (r^2) < 0.4 and a low ratio scale to sill close to 0.4. As suggested by Mabit and Bernard (2007) in the case of weak or absent spatial structure, the use of classical methods of interpolation is recommended. Therefore, a simple spatialisation of the data set using IDW2 was used to spatialise soil redistribution based on ^{137}Cs and $^{210}Pb_{ex}$ results. Contour maps and soil redistribution budgets were then established using the IDW2 (Figure 5 and Table 2).

Soil redistribution magnitude	^{137}Cs	$^{210}Pb_{ex}$
Mean erosion (t ha^{-1} yr^{-1})	13.1	11
Mean deposition (t ha^{-1} yr^{-1})	3.5	3
Gross erosion (t ha^{-1} yr^{-1})	11	10.5
Gross deposition (t ha^{-1} yr^{-1})	0.3	0.1
Net erosion (t ha^{-1} yr^{-1})	11.7	10
Sediment delivery ratio (%)	94	95

Table 2. Sediment budget and soil redistribution assessment from ^{137}Cs and $^{210}Pb_{ex}$ using IDW2 interpolation.

Similar results regarding soil redistribution magnitude were obtained for ^{137}Cs and $^{210}Pb_{ex}$. The high Sediment Delivery Ratio (SDR), corresponding to the ratio of net/gross erosion rate which was obtained from using ^{137}Cs and $^{210}Pb_{ex}$ approaches, showed that most of the mobilized sediment was moved out of the field. This is a logical result based on the fact that soil cultivation is conducted along the main slope direction where the slope reaches 17%. This high SDR also reflects that by using ^{137}Cs and $^{210}Pb_{ex}$ techniques, the eroded area represents 93 to 96% of the field surface and the deposition area covers only 7 to 4%.

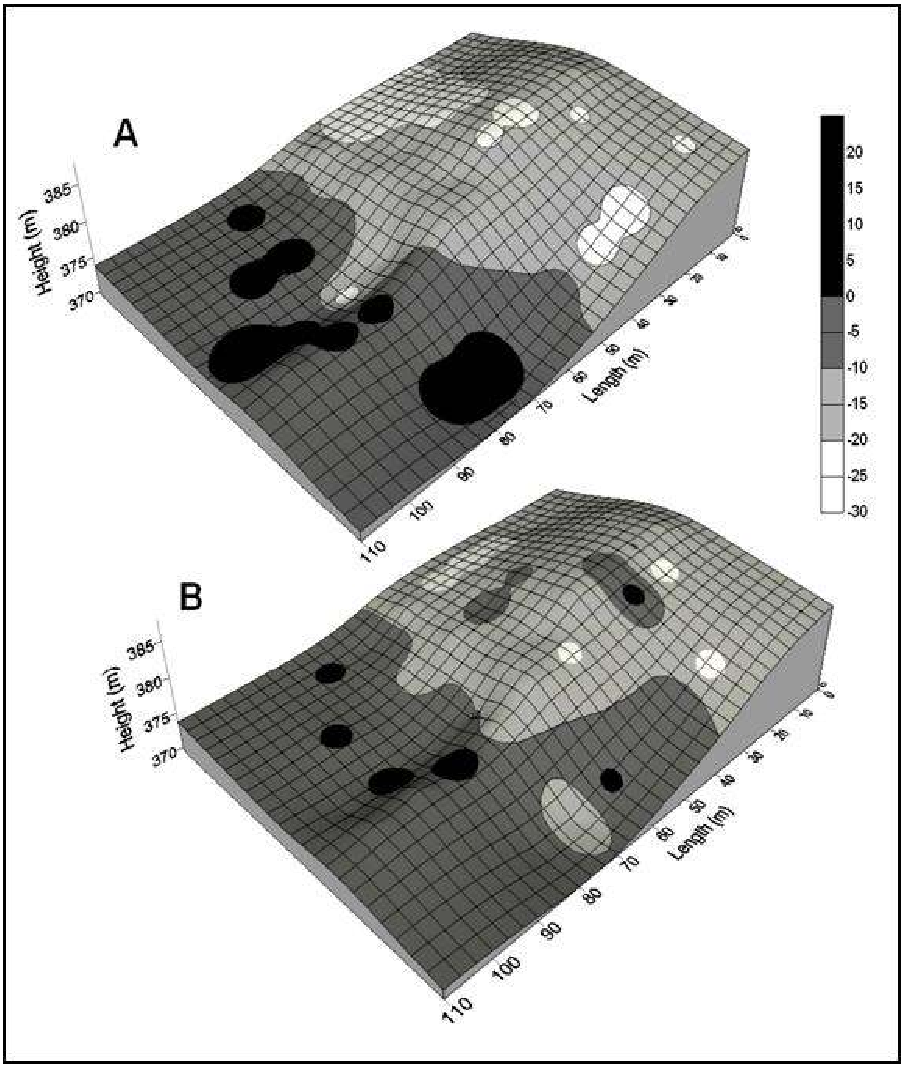

Figure 5. Maps of soil redistribution assessment from ^{137}Cs (A) and $^{210}Pb_{ex}$ (B) using IDW2 (t ha^{-1} yr^{-1}).

4.1.4. Conclusion

This study illustrates a potential benefit of the combined use of fallout ^{137}Cs and $^{210}Pb_{ex}$ and classical spatialisation/interpolation concept to estimate long-term soil redistribution rates and to establish sediment budget of agricultural fields in Mediterranean semiarid area (e.g. Morocco). Under the experimental condition, the soil redistribution rates generated by the ^{137}Cs and $^{210}Pbex$ techniques using the simplified approach (MBM2 without interpolation of the data set) and the spatialisation of the data were in the same order of magnitude. The relatively high erosion rates obtained can be attributed to the steep slope that reaches 17% and to the soil cultivation (tillage) in the direction of the slope.

4.1.5. References

Benmansour, M., Nouira, A., Bouksirat, H., Duchemin, M., El Oumri, M., Mossadek, R., Benkdad, A., Ibn Majah, M. (2010). Estimates of long and short-term rates of soil erosion using ^{137}Cs, $^{210}Pb_{ex}$ and ^{7}Be measurements: case study of one agricultural field in semi-arid west Morocco. IAEA Publication, IAEA-TECDOC (In press).

Mabit, L., Bernard, C. (2007). Assessment of spatial distribution of Fallout RadioNuclides through geostatistics concept. Journal of Environmental Radioactivity, 97(2-3), 206–219.

4.2.Anthropogenic and geogenic radionuclides content in an undisturbed Slovenian forest soil [2]

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Collaborative work between the Department of Agronomy, Biotechnical Faculty, University of Ljubljana, the Soil Science Unit and the Physics, Chemistry and Instrumentation Laboratory, IAEA Laboratories Seibersdorf

4.2.1. The Challenge

The measurement of natural background radiation and anthropogenic radionuclides in terrestrial environment, especially in soil, have been carried out in many countries for several decades to establish base line data of radiation level. So far, the knowledge of radionuclides concentration levels in Slovenia is limited to a few investigations and the use of anthropogenic ^{137}Cs radionuclide has not been used before as soil tracer in Slovenia. Therefore, the purposes of this study were:

(i) to collect the inventory information of naturally occurring radionuclides (^{40}K, ^{226}Ra, ^{232}Th, ^{235}U and ^{238}U) and man-made radionuclides (^{137}Cs) as well as their depth/vertical distribution in soil;

(ii) to complete the radio-ecological surveys in Slovenia and provide information regarding the external dose-rate based on the depth distributions of the gamma emitters in the soil of the study area;

(iii) to establish a reference inventory value of fallout ^{137}Cs in order to prepare a future soil redistribution investigations using ^{137}Cs as a soil tracer under the Slovenian agro-environment;

(iv) to make a complementary characterisation of the chemical composition of the soil, as well as to revealing the major differences in the abundance of some elements through soil depth profile.

4.2.2. Experimental Design

4.2.2.1.Sampling strategy and soil sample analysis

The study site is located in Šalamenci (46°44'N, 16°7'E) close to the Hungarian and Austrian borders. A few meters from a future agricultural study area, an undisturbed forest was selected for establishing the natural radioactivity level as well as assessing the initial fallout ^{137}Cs (reference inventory) for a future investigation on soil erosion and sedimentation assessed by comparing this reference inventory with other values from agricultural areas. In this forest, a total of 20 sampling points were collected at 4 different depth increments (0-10 cm, 10-20 cm, 20-30 and 30-40 cm) using a systematic grid sampling on the basis of a rectangular grid (40x30 m) as shown in Figure 6. 80 dried, sieved and homogenised samples were subsequently analysed:

(i) by x-ray using an Energy Dispersive X-Ray Fluorescence (EDXRF) spectrometer. The list of determined elements includes major and minor constituents (Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, Mn and Fe) as well as trace elements (Cr, Ni, Cu, Zn. Ga, As, Br, Rb, Sr, Y, Zr, I, Cs, Ba, La, Ce, Pb, Th and U). Only the results obtained from some of those elements were considered reliable to reveal differences in the soil depth profile;

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[2] *Project 2.1.1.1 Soil Management and conservation for sustainable agriculture and environment - Task 2: Improve FRN methodologies to measure soil redistribution rates at a range of scales in agricultural landscapes with the use of geostatistic approach*

(ii) by γ-spectrometry using the gamma detector of the Soil Science Unit for determination of gamma-emitting radionuclides (^{137}Cs, ^{40}K, ^{226}Ra, ^{232}Th, ^{235}U and ^{238}U). The total inventory at each sampling point was calculated as the sum of the depth interval areal activity. The distribution of areal activities (Bq m^{-2}) was also tested for normality by using Kolmogorov-Smirnov test at a confidence level of 95 %.

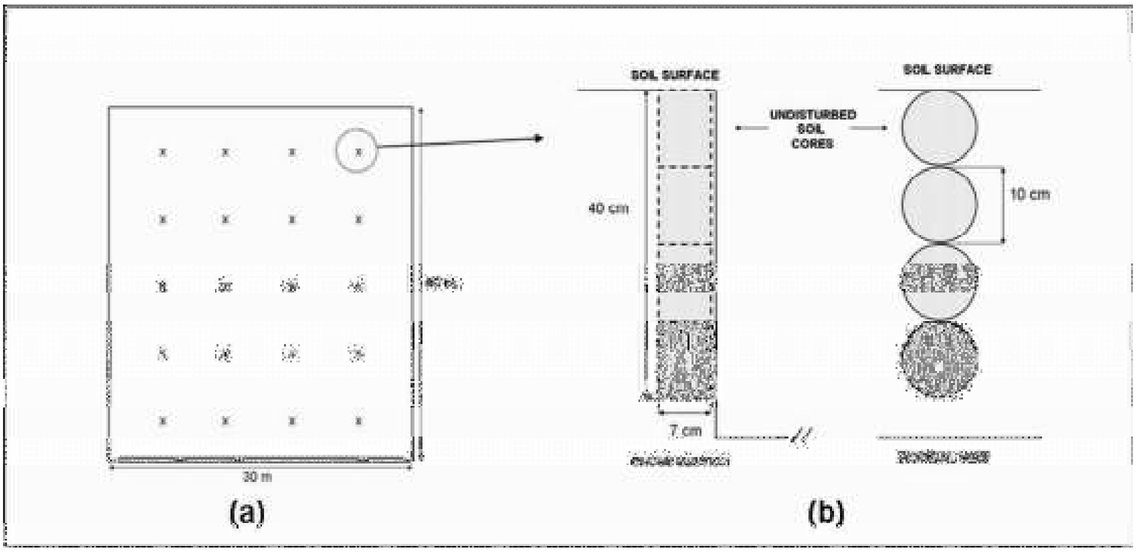

Figure 6. Rectangular grid (40x30 m) sampling points (a) and profile of soil sample at 4 different depth increments (b) in the forest site.

4.2.2.2. External gamma dose rate

The kerma rate in the air at 1 m above ground level from external exposure of naturally occurring radionuclides – K in nGy h^{-1} – was calculated using conversion factors proposed by ICRU:

$$K\ (\text{nGy h}^{-1}) = 0.462C_U + 0.604C_{Th} + 0.042C_K \quad (1)$$

where C_U and C_{Th} are the specific soil activities (in Bq kg^{-1}dry weight) of uranium series and thorium series radionuclides, respectively, and C_K is the specific soil activity of ^{40}K.

This equation assumes secular equilibrium in both the uranium and thorium series, and that these natural radionuclides are distributed homogeneously in the ground. For the uranium series, the specific soil activity of ^{226}Ra was used in the calculations for two reasons: about 99% of the uranium series kerma rate conversion factor is due to gamma rays from ^{226}Ra and its progeny, and the analytical uncertainty for determination of ^{226}Ra by gamma spectrometry is lower than that for ^{238}U.

4.2.3. Main results

4.2.3.1. Activity level of natural radionuclides in the forest

The bulk density of soil increased with depth as expected in forest soil with fibric and organic matter enriched top soil. However under 20 cm the variability of soil density is low and reached a value of 1.4 - 1.5 t m^{-3}. The variability of top soil increment will influence directly all the radionuclide contents when the results are presented in terms of areal activity. The average activity concentrations of natural radionuclides in each soil layer ranged from 535 ± 16 to 703 ± 20 Bq kg^{-1} for ^{40}K, from 49 ± 2 to 52 ± 2 Bq kg^{-1} for ^{226}Ra, from 54 ± 6 to 62 ± 4 Bq kg^{-1} for ^{232}Th, from 7.8 ± 0.8 to 8.1 ± 0.3 Bq kg^{-1} for ^{235}U and from 58 ± 22 to 68 ± 27 Bq kg^{-1} for ^{238}U (Figure 7). The variability of the coefficient of variation of the different layer is less than 10 % for ^{40}K, ^{226}Ra, ^{232}Th ^{235}U. The variability of ^{238}U mass activity in soil (Bq kg^{-1}), that shows a high standard deviation (SD), is related to a relatively high measurement error which ranged from 30 to 38 %.

The vertical profiles of the investigated environmental radionuclides reveal different depth distributions. The mass activities of ^{226}Ra, ^{235}U, ^{232}Th and ^{238}U are relatively constant within the different soil layers and horizons (Figure 7c-f). On the other hand, the mass activity of ^{40}K slightly increased with depth (Figure 7b). The maximum mass activity of ^{40}K, 724 Bq kg^{-1}, was measured in the 30-40 cm soil increment. The increment with depth of ^{40}K mass activity will have a significant influence for the calculation of the gamma dose rate which will be presented and discussed in the following section. Generally, the vertical distribution of ^{40}K in soil is uniform. However, our mass activity results suggest that potassium distribution in natural soils is not always homogenously distributed. Similar results were found in other investigations. Moreover, the variations of ^{40}K mass activity with depth may relate to biological activities in subsoil, such as root uptake of the nutrients, as soluble and exchangeable K is plant available.

The world average concentration levels of ^{40}K, in soil are 400 Bq kg^{-1} with a range from 140 to 850, 35 Bq kg^{-1} for ^{226}Ra with a range from 17 to 60, and 30 Bq kg^{-1} for ^{232}Th with a range from 11 to 64 (UNSCEAR, 2000). Comparing our results with these data, the mass activity of all naturally occurring radionuclides (^{40}K, ^{226}Ra and ^{232}Th) in forest soil from Slovenia are clearly above the world average value even though they are still within the world range. The results of areal activity of natural radionuclides in soil are presented in Table 3.

Table 3. Inventory and depth distribution of radionuclides in the forest soil.

Soil depth interval (cm)	Areal activity of radionuclide (Bq/m^2)					
	^{137}Cs	^{40}K	^{226}Ra	^{232}Th	^{235}U	^{238}U
0-10	6127 ± 2514* (41%)**	49457 ± 11227 (23%)	4842 ± 1040 (21%)	5216 ±1137 (22%)	751 ± 161 (21%)	6487 ± 2999 (46%)
10-20	972 ± 719 (74%)	75686 ± 12383 (16%)	6884 ± 880 (13%)	7362 ± 977 (13%)	1060 ± 125 (12%)	8744 ±3761 (43%)
20-30	145 ± 110 (75%)	96038 ± 5032 (5%)	7401 ± 317 (4%)	8436 ± 512 (6%)	1162 ± 60 (5%)	9580 ± 2565 (27%)
30-40	70 ± 40 (56%)	105530 ± 23833 (4%)	7387 ± 346 (5%)	9264 ± 519 (6%)	1216 ± 30 (2%)	8692 ± 3320 (38%)
Total (0-40)	7316 ± 2525 (34%)	326745 ± 24572 (7%)	26517 ± 1720 (6%)	30280 ± 2172 (7%)	4190 ± 290 (7%)	33504 ± 6412 (19%)

* *m ± SD, n = 20*
** *% CV*

The total areal activity calculated from each soil layer (0-40 cm depth) showed the base-line level of, 326745 ± 24572 Bq m^{-2} for ^{40}K with 7 % of a coefficient of variation (CV), 26517 ± 1720 Bq m^{-2} for ^{226}Ra with 6 % of CV, 30280 ± 2172 Bq m^{-2} for ^{232}Th with 7 % of CV, 4190 ± 290 Bq m^{-2} for ^{235}U with 7 % of CV and 33504 ± 6412 Bq m^{-2} for ^{238}U with 19 % of CV (Table 3). As a result of ^{40}K mass activity, the increment with depth of ^{40}K activity is even much more sensitive using the areal activity which increased 85 % from 0-10 cm to 30-40 cm of soil layers (Table 3). The parametric test of Kolmogorov-Smirnov at a confidence level of 95 % showed that the distributions of these data for all natural radionuclides (summary of soil increments, 0-40 cm) are normal.

4.2.3.2. Activity level of man made radionuclides (137Cs)

For the results of ^{137}Cs level, a maximum mass activity of 147 Bq kg^{-1} with an average of 70 ± 33 Bq kg^{-1} was found in the first 10 cm of the forest soil (Figure 7a). The activity of the ^{137}Cs measured in the 20-30 and especially 30-40 cm increment were close to or under the detection limit of the detector. Consequently, the vertical distribution of ^{137}Cs in this forested soil follows an typical exponential decrease as expected in a stable undisturbed and uneroded site. Based on the 20 collected soil profiles (0-40 cm), the initial fallout ^{137}Cs or the total inventory in this forest was evaluated at 7316 ± 2525 Bq m^{-2} with a CV of 34% (Table 3). The result from parametric test of Kolmogorov-Smirnov showed a normal distribution of ^{137}Cs areal activity at a confidence level of 95%.

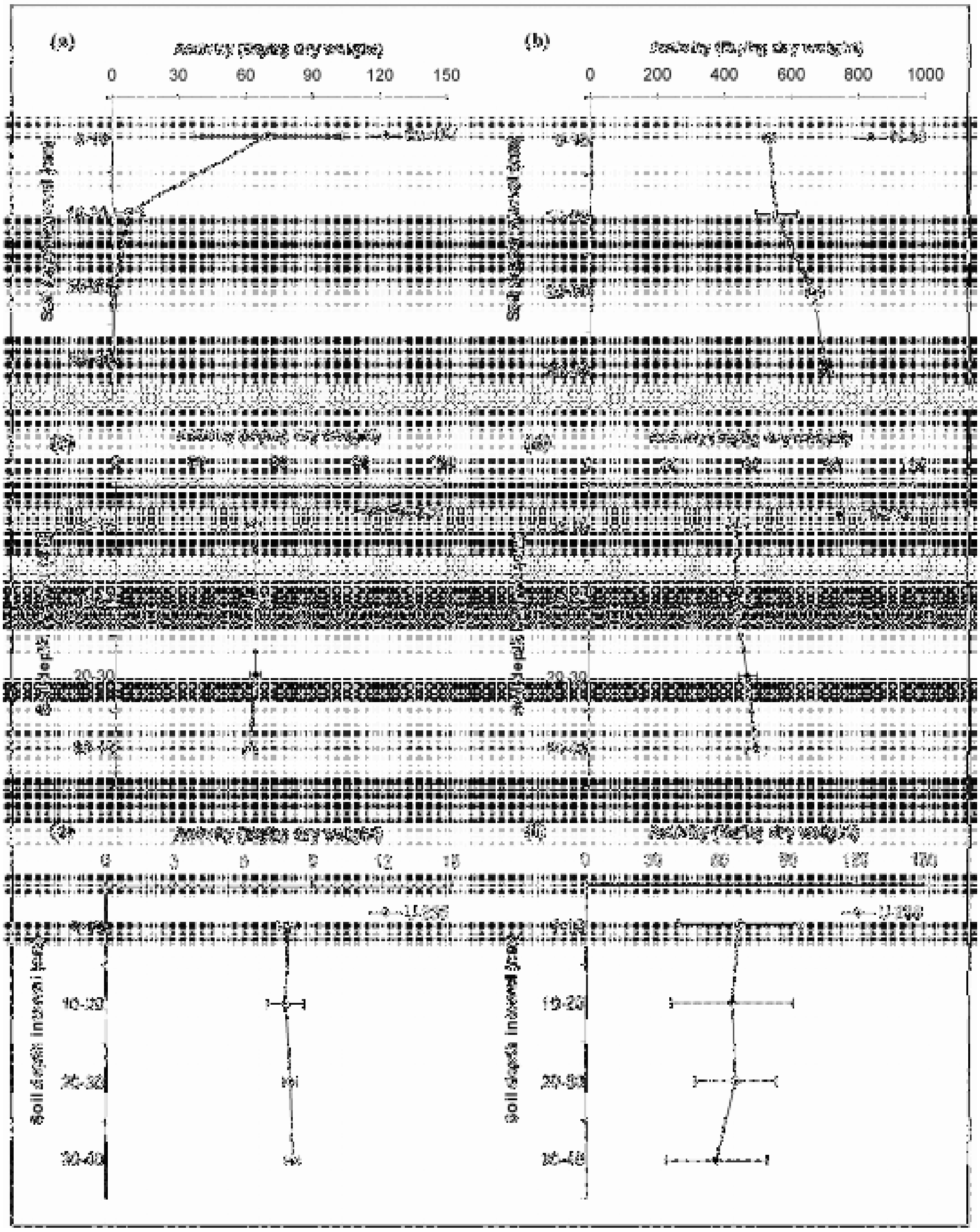

Figure 7. Vertical distribution of mass activity of ^{137}Cs (a), ^{40}K (b), ^{226}Ra (c), ^{232}Th (d), ^{235}U (e), and ^{238}U (f). Data presented as mean ± SD (n = 20).

4.2.3.3. External gamma dose rate estimates

As discussed in the previous section, the kerma rate (*K*) can be calculated from the mass activities of ^{226}Ra, ^{232}Th and ^{40}K in the soil, for this the mass activities in the 0-10 cm layer were used, giving a value of 79 ± 3 nGy h^{-1}. This estimate is approximate, because of the assumptions of secular equilibrium in the decay chains, and homogeneity in the soil. The ^{40}K mass activities increase slightly with depth, however due to the significant attenuation of gamma rays from the lower levels, this change with depth would result in only a small influence on the actual kerma rate at the surface. The *K* value at the surface is about 30% higher than the global average external exposure rate from terrestrial gamma radiation established at 57 nGy h^{-1} by UNSCEAR (2000). Comparing with the Slovenian data obtained from UNSCEAR Survey of Natural Radiation Exposures, our results for each soil layer are higher than 56 nGy h^{-1}, the average value for outdoors. The contribution to the external dose rate of the naturally occurring radionuclides due to ^{232}Th is the most important in this forest soil with 41%, while ^{226}Ra and ^{40}K contribute 28% and 31% to the external dose rate of the naturally occurring radionuclides, respectively. On the other hand, the assessment of external gamma dose rate for ^{137}Cs varies with depth decrement from 0.06 ± 0.03 to 8.2 ± 3.9 nGy h^{-1}.

4.2.3.4. Compositional differentiation of soil layers

From all analysed elements using XRF, the average value of some elements with a relative uncertainty better than 10% were selected and reported in Table 4. The XRF results show a similar profile shape for the total concentration of K, Th and U to their radioactive component (^{40}K, ^{232}Th, ^{235}U and ^{238}U). The higher top surface content of Pb can perhaps be linked with an anthropogenic contamination. The soil layer 30-40 cm is enriched in Al and Fe (Table 4). It can also be noticed that the content of total K and Mg behave in the same way increasing significantly with depth. The specific migration of these elements can be associated with a podzolisation processes that could take place under the acidic condition in this forest. This hypothesis is also supported by the fact that Si content is maximum in the top layer of the soil (Table 4).

Table 4. Concentration of major interested elements in the forest soil obtained by XRF technique.

Soil interval (cm)	Concentration (µg/g)*							
	Si	**Al**	**Fe**	**K**	**Mg**	**Pb**	**Th**	**U**
0-10	(280 ± 8) x10^3	(72.3 ± 2.1) x10^3	(30.9 ± 1.2) x10^3	(16.6 ± 0.4) x10^3	(9.54 ± 0.78) x10^3	34.0 ± 7.3	14.1 ± 0.7	4.99 ± 0.77
10-20	(284 ± 4) x10^3	(81.7 ± 2.6) x10^3	(35.4 ± 1.6) x10^3	(18.4 ± 0.4) x10^3	(12.0 ± 0.7) x10^3	27.3 ± 2.5	14.5 ± 0.8	4.27 ± 1.20
20-30	(273 ± 4) x10^3	(90.5 ± 1.5) x10^3	(39.9 ± 1.7) x10^3	(20.4 ± 0.2) x10^3	(14.6 ± 0.6) x10^3	24.6 ± 2.8	14.6 ± 0.8	3.83 ± 0.70
30-40	(262 ± 7) x10^3	(94.2 ± 1.6) x10^3	(46.4 ± 2.1) x10^3	(20.9 ± 0.2) x10^3	(15.8 ± 0.7) x10^3	25.7 ± 1.7	16.6 ± 0.5	5.53 ± 0.83

** Data are presented as m ± SD, n = 20*

4.2.4. Conclusion

The results showed that of the profile activities of the naturally occurring radionuclides only ^{40}K exhibits variation in distribution with depth. For ^{137}Cs, a typical exponential distribution was found as expected in classical undisturbed soils. The top soil mass activity of ^{137}Cs is 7 to 8 times less than the ^{40}K content. For this local radio-ecological survey, depending on the depth increment, the value of external dose rate is 30 to 40 % more than the world average. The base-line level of ^{137}Cs in this Slovenian forest soil was established at 7316 ± 2525 Bq m^{-2} with a coefficient of variation of 34 % and this value will be used as an initial inventory for future ^{137}Cs investigation to assess soil erosion and sedimentation processes. Our study demonstrates that before future erosion and sedimentation investigations in neighbouring agricultural fields using this soil tracer, additional soil samples should be collected in this undisturbed area to reduce the CV to a reliable value for the initial ^{137}Cs fallout. Comparison of data from this study with the ROKO Database of the Environmental Radioactivity Measurements in Slovenia (SNSA) (Official Gazette of RS, 2007) indicates that approximately 45% of the mean present-day ^{137}Cs inventory is due to the Chernobyl contribution.

4.2.5. References

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4.3. Could low sedimentation rates be overestimated by ^{137}Cs and ^{210}Pb$_{ex}$ classical sedimentation models?

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4.3.1. The Challenge

Based on the results of a previous study conducted in Qinghai Lake (Figures 8 and 9), China for dating sediments using ^{210}Pb$_{ex}$ and ^{137}Cs, this study proposes a new interpretation of the data on the magnitude of sediment deposit. Depth distribution of both radioisotopes, which is usually used to quantify sedimentation rate, should also take an isotopic migration factor into consideration especially in case of low sedimentation process, otherwise it could create far too high deposition rate. To estimate sedimentation rate in Qinghai Lake, this study included the local reference inventory of ^{137}Cs and ^{210}Pb$_{ex}$ in an undisturbed terrestrial area, which is close to the investigated lake, in the Mass Balance Model as proposed by Zhang *et al.* (2009). The compared result with this proposed model suggested that sedimentation rate derived from the profile shape models could be overestimated considering the process of post-depositional mobilization.

4.3.2. Findings and discussion

Fallout radionuclides ^{137}Cs and ^{210}Pb$_{ex}$ have been widely used all over the world as soil redistribution tracers and also for radiometric chronology and dating sediments of lakes, reservoirs, floodplains, peatland and sea bays. Typical depth distribution profiles of ^{210}Pb$_{ex}$ and ^{137}Cs in the sediments of the central part of the Qinghai Lake in China are shown in Figure 10 (Shen, *et al.,* 2001).

For the ^{210}Pb$_{ex}$ profile, the maximum concentration occurs at the surface and declines exponentially with depth. Assuming that the sedimentation rate in the lake is constant, the relationship between ^{210}Pb$_{ex}$ concentrations and depths can be described following the Constant Sedimentation Rate (CFCS) Model:

$$C(x) = Ce^{-ax} \tag{1}$$

where $C(x) = {}^{210}Pb_{ex}$ concentrations at depth x (mBq g^{-1}), $C = {}^{210}Pb_{ex}$ concentration at the core surface, also termed "initial ${}^{210}Pb_{ex}$ concentration" (mBq g^{-1}), a = coefficient of ${}^{210}Pb_{ex}$ depth profile shape (cm^2 g^{-1}), and x = mass depth ($g\ cm^{-2}$).

The deposition or sedimentation rate can be derived from the following equation:

$$R = -\lambda/a \qquad (2)$$

where R = sedimentation rate ($g\ cm^{-2}\ yr^{-1}$), λ = ${}^{210}Pb$ radioactive decay constant (0.03114 yr^{-1}).

Two other models have also been developed: (i) the Constant Rate of ${}^{210}Pb$ Supply (CRS) that assumes a constant atmospheric flux of ${}^{210}Pb$; and (ii) the Constant Initial ${}^{210}Pb$ Concentration (CIC) that assumes that the variation of the sedimentation magnitude does not affect the ${}^{210}Pb$ concentration. The sedimentation rates derived by these models are slightly different from the results provided by the CFCS model.

Global depositions of ${}^{137}Cs$ fallout in the late 1950 and mid 1960 are mainly related to nuclear testing activity with maximum fallout in 1963. Therefore in the ${}^{137}Cs$ depth profile, the maximum concentration (peak concentration) occurs at a certain depth (H) that is likely to indicate the year 1963 corresponding to moratoriums on testing and the Test Ban Treaty signed also that year. The deposition rate can then be derived by the following equation:

$$R = H/n\text{-}1963 \qquad (3)$$

where H = depth of the ${}^{137}Cs$ peak concentration (cm), n = sampling year.

Figure 8. Sediments collection in the Qinghai Lake.

Figure 9. Soil samples collection in reference grassland in the bench plain of the lake

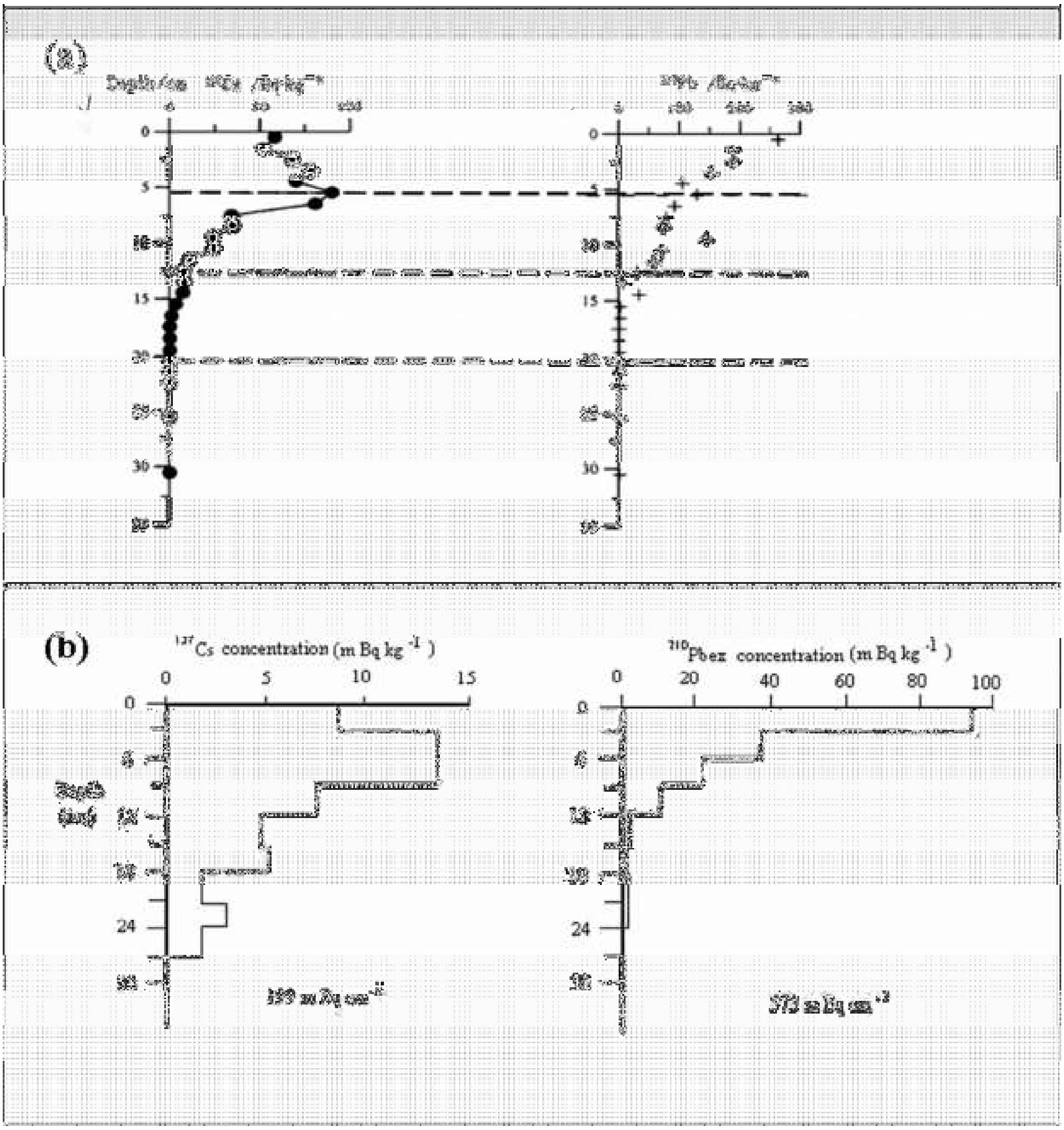

Figure 10. ^{137}Cs and ^{210}Pb depth distribution in the sediments of the central part of Qinghai Lake (Shen *et al.,* 2001) (a) and in undisturbed soils of grass land in the Chinese Loess Plateau (Zhang *et al.,* 2003) (b).

Post-depositional mobilizations by diffusion, migration and bio-disturbances (sediment soil fauna interaction) in the surface layer of lake sediments have been observed but the extents and contribution of these processes can not be easily established and modeled. Post depositions are of course site specific and these parameters were generally not taken into account into the classical sedimentation models. However, the sedimentation rates derived by using the above equations (Eq. 1-3) have been widely used for interpreting recent environmental changes. For example in the Qinghai Lake, sedimentation rates of 0.10-0.12 cm yr^{-1} were derived by using those equations (Shen *et al.,* 2001). The core located 36°36′11″N; 100°30′29″E was taken in 2000 at water depth of 22.3 meters and deposited sediment was grey black silted clay. Depth profiles of $^{210}Pb_{ex}$ and most ^{137}Cs in non-accumulated uncultivated soils, e.g. the loess soil in the Loess Plateau, China (Zhang *et al.,* 2003), are very similar to the lake sediment profiles (Figure 10). The core located 37°22′12″N, 109°16′01″E was collected in 2001. For the $^{210}Pb_{ex}$ depth profiles, most of $^{210}Pb_{ex}$ are contained in the upper several centimeters and only a little amount of $^{210}Pb_{ex}$ is detected in the depth below 15-20 cm. For the ^{137}Cs depth profiles, the maximum concentration occurs at a few centimeters depth and like for the depth profile of $^{210}Pb_{ex}$, only a small amount of ^{137}Cs was detected below the 15-20 cm layer.

Depth distribution of these fallout radionuclides in stable uncultivated soils, neither affected by erosion nor sedimentation, is influenced by physico-chemical interaction and mainly caused by post-depositional diffusion, migration and bio-disturbances (soil fauna interaction) processes after their wet and dry fallouts deposited on the ground. Assuming that these profiles are associated with the sedimentation processes, the sedimentation rate can be derived from depth distribution profiles of the existing ^{137}Cs and $^{210}Pb_{ex}$ profile shape models by using CIC, CRS or CFCS models (Figure 10b). In this case, the sedimentation rates measuremented from ^{137}Cs and $^{210}Pb_{ex}$ profile shape models would be 0.10 cm yr^{-1} and 0.15 cm yr^{-1}, respectively. Those rates were similar to the sedimentation rates estimated by Shen et al (2001) in the central part of the Qinghai Lake i.e. 0.10-0.12 cm yr^{-1}.

In 2005, 36 soil cores were collected by the author's team from the pasture land of beach plain in Qinghai Lake and 3 bulk cores of sediments from the center part of the Qinghai Lake, which were nearby the Shen's core drilled in 2000 (Shen *et al.,* 2001). The mean local reference inventory of ^{137}Cs derived from the pasture land was 117.7 mBq cm^{-2}. The mean ^{137}Cs inventory of the three lake cores was of 124.2 mBq cm^{-2}, i.e. 105.5% of the local reference. The sedimentation rates were derived by using the Mass Balance Model (Zhang *et al.,* 2009):

$$A - A_o = C_a H \gamma \qquad (4)$$

where A = ^{137}Cs sediments inventory (mBq cm^{-2}), A_o = local ^{137}Cs reference inventory (mBq cm^{-2}), C_a = average ^{137}Cs concentration of the deposited sediments since 1963, the main period of nuclear bombs testing (mBq g^{-1}), and γ = bulk density of the deposited sediments (g cm^{-3}).

Assuming that the fallout ^{137}Cs was totally deposited on the earth surface in 1963 with measured values of 30 mBq g^{-1} for C_a and 0.55 g cm^{-3} for γ, the average sedimentation rate since 1963 was estimated at 0.01 cm yr^{-1}, which was only 10% of the sedimentation rates obtained by using the ^{137}Cs and $^{210}Pb_{ex}$ profile shape models. This result suggested that, like in undisturbed soils, the ^{137}Cs and $^{210}Pb_{ex}$ depth distribution profiles of the sediments in the central part of the Qinghai Lake were mainly controlled by the post depositional mobilization of those fallout nuclides. Subsequently, the sedimentation rates in the central part of Qinghai Lake can be assumed to have been significantly overestimated by using the existing profile models. Generally movement of ^{137}Cs in soil matrix by chemical and biological processes can occur, but is limited. However, based on the existing literature, ^{137}Cs migration in mineral soil can reach 1.3 cm yr^{-1}. The dynamics and rate parameters of ^{137}Cs vertical migration are variable, depending on soil types and moistening conditions. For example, ^{137}Cs migration rate of soils in redundant moistening conditions can easily reach 1.2-2 cm yr^{-1} and in organic soil, soil with high organic matter content (e.g. peat soil), the migration rate can reach up to 12.3 cm yr^{-1}. Some authors also demonstrate that rate of the post-Chernobyl ^{137}Cs migration is significantly higher and exceed the migration rate of ^{137}Cs coming from the previous nuclear tests.

In lake, after direct deposition or/and indirect deposition (e.g. watershed wash out), ^{137}Cs (sorbed to suspended matter and dissolved forms) is distributed in the water column and settle down to the bottom. Diffusion and bioturbation processes result in ^{137}Cs transfer within the sediment column as well as exchange between the sediment and the overlaying water. ^{137}Cs in water can be adsorbed directly onto the sediment and part of the ^{137}Cs can also be released back into the water column by redissolution from the sediments as well as by resuspension of solid material. Therefore, before to conclude that a rapid rise in accumulation rate is caused for example by recent changes in management practices, it should be distinguished from chemical and biological processes affecting radio-isotopic migration. Site specific processes that influence radionuclides mobility should also be taken into consideration, so we could assume that the sedimentation rates derived by using the profile shape models (R) are the sum of the real sedimentation rate (R_r) and the nuclide sediment transfer linked to the proper infiltration rate of the element (R_i), i.e. $R = R_r + R_i$.

With high accumulation rates (> 1 cm yr^{-1}) of deposited material in lakes, the sedimentation magnitude derived by using existing profile shape models can be assumed to be representative of the real rates because the nuclide infiltration rates can be neglected when compared to the real sedimentation rates. On the other hand, a low sedimentation, e.g. 0.1 cm yr^{-1} in the central part of Qinghai Lake derived by using the existing profile shape models (Shen *et al.,* 2001), may not be representative of the real rates. When using ^{137}Cs to study sediment accumulation in water bodies, it should be considered that ^{137}Cs is difficult to use in the areas where sedimentation rate < 1 cm yr^{-1} because of sampling accuracy problem (e.g. "smearing" of the sediment profile during coring and core extraction).

4.3.3. Conclusion

Therefore, the limitations of sediment tracers, especially $^{210}Pb_{ex}$ and ^{137}Cs, and their applications in different depositional environments should be strongly considered. Some recent publications have tried to improve sedimentation model using ^{137}Cs for example by taking into account fixation and redissolution, compaction of sediments, and the influence of competing ions on the retarded diffusion within the sediments. A new theoretical treatment of compaction and the advective-diffusive processes in sediments has also been proposed to improve the conventional data treatment that overestimates the radioisotopic concentrations in the upper sediment layers due to solids diffusional flow.

4.3.4. References

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4.4. Spatial distribution and content of soil organic matter in an agricultural field in Eastern Canada, as estimated from geostatistical tools3

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Collaborative work between the Soil Science Unit and the Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (MAPAQ), in Québec, Canada

4.4.1. The challenge

Soil degradation through erosion is coupled with changes in soil quality that modifies soil fertility. Soil organic matter (SOM) is a key determinant of soil quality and also represents one of the largest reservoirs of organic C in the global carbon cycle that may influence global warming. Additional research on soil carbon sequestration, storage and redistribution at various scales are therefore needed.

Even though the economical and agronomical impacts of soil erosion on water quality are widely recognized, research information on soil carbon dynamics in relation to soil degradation in general and soil erosion in particular is scarce. In landscape studies, simple statistics are not suitable to document and assess the spatial structure of soil parameters. However, the use of geostatistics and spatialisation tools in combination with global positioning system (GPS), digital elevation model (DEM) and geographic information system (GIS) can provide this information and help to establish improved distribution patterns of soil parameters in the landscape. Increased accuracy in the delimitation of SOM content classes could assist in meaningful soil quality predictions and its relation to soil redistribution.

In previous studies (SSU annual report 2006; Mabit and Bernard, 2007; Mabit *et al.,* 2008), the assessment of radiocesium (^{137}Cs) redistribution in a Canadian field using different interpolation methods, the associated soil redistribution map and sediment budget were presented. The objective of this additional investigation in the same study area was to complement these contributions by analysing the spatial distribution and SOM budget using geostatistical tools.

4.4.2. Experimental design

The study site is a 2.16 ha flat agricultural field (46° 40.800' N, 70° 51.000' W) located in the upstream part of the Boyer River in Eastern Canada. The soil texture is a sandy loam (a well developed Podzol) and crop rotaion was developed within the field with barley and corn. 42 composite soil samples were collected in the field following a sampling strategy and protocol detaily described in previous papers (Mabit *et al.,* 2007; Mabit *et al.,* 2008). Soil surface samples (0-20 cm) were oven dried and sieved at 2 mm and SOM content was determined.

Spatial continuity of SOM was investigated by semivariogram calculation. Using GS$^+$ software version 7, the model with the smallest residual sum of squares (RSS) was further investigated to find the number of neighbours that returned the best cross-validation result. Afterwards, the variographic parameters and fitted models were introduced into the GIS software Surfer 8.00. Following the protocol proposed by Mabit and Bernard (2007), two spatial distributions of SOM were produced using Ordinary Kriging (OK) and Inverse Distance Weighting power two (IDW2).

4.4.3. Results

(i) SOM content was significantly correlated (r^2 = 0.63; $p < 0.001$) to ^{137}Cs soil surface inventories (SSU annual report 2006).

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[3] *Project 2.1.1.1 Soil Management and conservation for sustainable agriculture and environment - Task 2: Improve FRN methodologies to measure soil redistribution rates at a range of scales in agricultural landscapes with the use of geostatistic approach*

(ii) Stable estimates of SOM variogram and good spatial autocorrelation were obtained with a number of pairs greater than 30 at each lag distance, a nugget variance closed to the origin and a high correlation coefficient of 0.95. The best fitted model was an isotropic spherical model (nugget=0.36%, sill=1.99%, nugget/sill=0.18%).

To evaluate the effectiveness of Kriging interpolations, the estimated values of the soil parameters under investigation can be compared against the measured values, an operation called cross-validation analysis. Therefore, based on the best-fit variogram model, a cross validation was run to evaluate the accuracy of OK interpolation for the SOM data set (Figure 11).

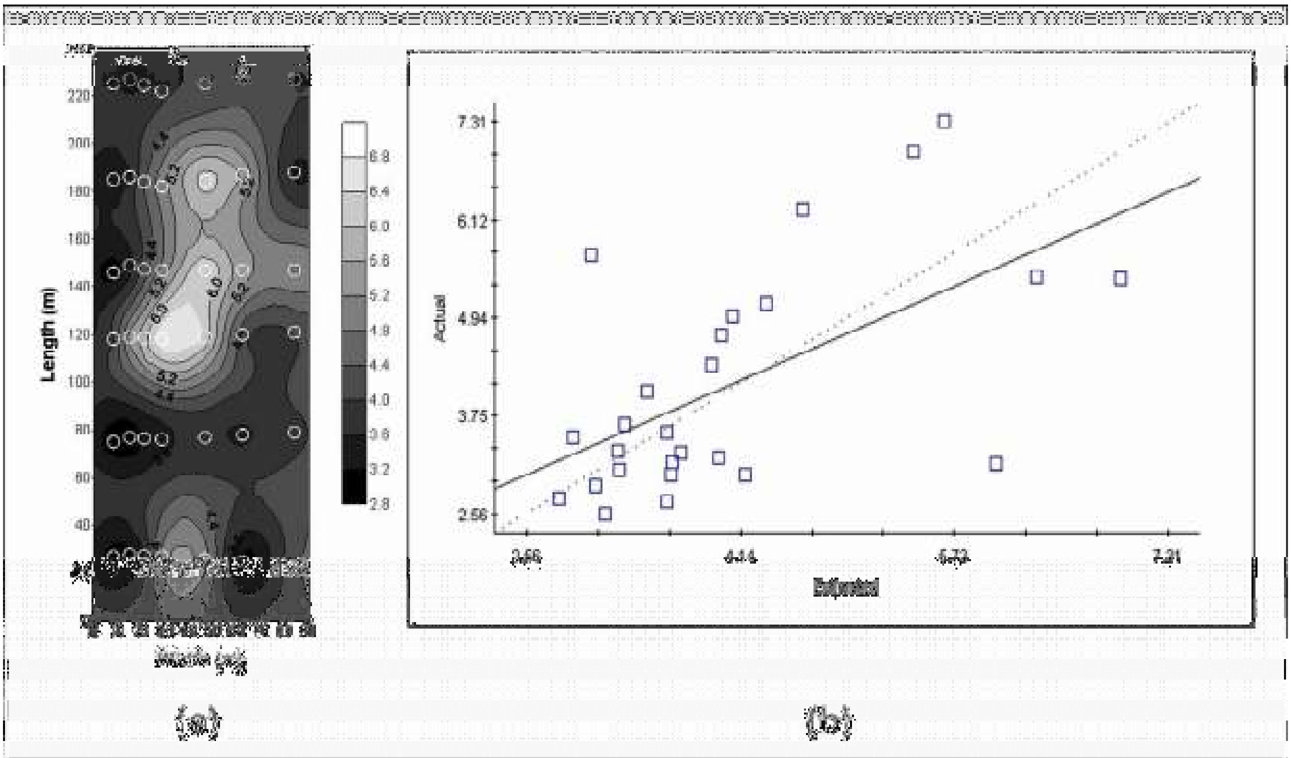

Figure 11. Location of sampling points and SOM isolines (in %) using Ordinary Kriging (a) and the associated cross validation analysis (b).

The regression coefficient, that represents the measure of goodness of fit, is 0.723. A perfect fit would have a regression coefficient – also called slope – of 1.00 and the best-fit line would coincide with the dotted 45 degree line on the graph. The standard error (SE) of the regression coefficient is 0.202, the proportion of variation explained by the best-fit line (r^2) is highly significant with 0.35, which is acceptable since a good validation of a spatial structure should provide an $r^2 > 0.2$. The y intercept is 1.18 and the SE prediction is 1.061. The results are satisfactory and even better than the one obtained for ^{137}Cs spatial distribution with a regression coefficient of 0.6 and an r^2 of 0.21 (Mabit and Bernard, 2007).

Based on descriptive statistics and considering that lognormal kriging performed better when the dataset had a coefficient of skewness larger than one, the data were not transformed and OK was used to map the spatial distribution pattern of SOM (Figure 11), the same had been done for ^{137}Cs in a previous study (Mabit and Bernard, 2007). A similar map was produced using the inverse distance weighting power 2 (IDW2) for interpolation. Based on these maps, the total organic matter content of topsoil (0- 20 cm depth) in the field and its distribution into different classes were calculated.

Both interpolation techniques produced similar estimated SOM contents in topsoil (0-20 cm) of the whole field with 213 and 211 tonnes for OK and IDW2, respectively (Table 5). However, the relative importance of the different SOM content classes differs considerably from one interpolation technique to the other. For the SOM class areas obtained from OK, the 3.5-4.0%, 4.0-4.5%, 5.5-6.0% and 6.0-7.3% classes covered larger areas than those obtained from IDW2, while the opposite occurred in the 4.5-5.0% and 5.0-5.5% classes. Similar results were obtained when test with different interpolation models for ^{137}Cs (Mabit and Bernard, 2007).

Table 5. Areas of SOM classes obtained from OK and IDW2 techniques and the associated SOM budgets.

SOM classes (%)	Area of SOM class evaluated by OK (m^2)	Area of SOM class evaluated by IDW2 (m^2)
2.4 – 3	53	216
3 – 3.5	1712	1758
3.5 – 4	7091	6673
4 – 4.5	5914	5356
4.5 – 5	2610	3786
5 – 5.5	2049	2546
5.5 – 6	1342	908
6 – 7.3	829	357
Total SOM content (t)*	213	211

* *The SOM budget was established for the 0-20 cm soil depth using an average bulk density of the topsoil of 1.12 t m^{-3} (n = 42) on the 2.16 ha field.*

4.4.4. Discussion

The use of ^{137}Cs as a soil redistribution tracer has been reported worldwide over the last four decades and the potential of using it in combination with other indicators and soil properties has been tested in a wide range of environment. In this study, the significant relationship between SOM and ^{137}Cs soil surface inventory highlights the linkage between erosion processes and spatial redistribution of SOM in the topsoil. Other studies conducted under varied agro-environmental conditions also reported a significant relationship – generally linear – between SOM, ^{137}Cs and soil erosion/sedimentation rates. Their results also showed that content of SOM decreased when rate of soil erosion increased. Concretely, based on topographic locations, eroded areas with low ^{137}Cs activities had low SOM content and deposition areas, identified by high ^{137}Cs levels, had high SOM accumulation.

In this case study, the spatial autocorrelation and the similarities of SOM and soil redistribution map as evidenced by ^{137}Cs measurements (Mabit *et al.,* 2008) suggest the potential use of cokriging in future studies. Cokriging is an interpolation technique that allows one to use a more intensively sampled covariate in the estimation of values for a related variate. Therefore, if similar conditions are found in other sites, ^{137}Cs could be considered as the primary variable and SOM as a covariate. If the primary variate is difficult or expensive to measure (e.g ^{137}Cs demands laboratories equipped with gamma spectrometer) and it is correlated with a more available covariate (in this case the SOM), cokriging can facilitate and improve interpolation estimates without the need for more intensive sampling of the primary variate.

To explain the SOM redistribution in our experimental field, another erosion process should also be considered. In the study area, approx. 30% of the annual precipitation falls as snow. This accumulated snow melts rather rapidly during spring time and generates an intensive runoff over thawing and highly erodible soils. The erosion resulting from this process may account for more than 80% of the annual soil loss under such conditions.

Based on previous studies, the topography and the slope factor - through water erosion processes - is one of the main factors influencing SOM and ^{137}Cs redistribution in the landscape. In our studied field with relatively flat topography (only two meters elevation variation), the soil and SOM redistribution should not be linked only to water erosion processes but also to tillage erosion. Indeed, widespread adoption of mechanized agriculture, that promotes more intensive continuous tillage, accelerates SOM oxidation and predisposes soils to increased erosion. Tillage – especially 30 cm deep conventional tillage which dominates in the study area – is one of the major practices that affect SOM. It actually increases runoff during rainstorms, destroys natural soil aggregates, leaves no residues on the soil surface to increase rainfall erosivity, and disturbs most of the biota – both in biomass and diversity – which actions on porosity and aeration of soil, Moreover, it reduces the decomposition of organic matter, retards of root penetration and water infiltration, and exacerbates the soil pulverization during dry period. In addition, tillage erosion, which is generally not included in the studies on lateral SOM fluxes, increased the flux as well as the area over which these processes take place. As the SOM and the soil redistribution tracer (^{137}Cs) are moved by the same mechanisms during the soil erosion processes, it is likely that in the present study, SOM redistribution is the result of combined effect of long term water (both rainfall and snowmelt erosions) and tillage erosion. If water erosion is still considered to be the major geomorphic process of landform evolution on agricultural land, however there is a growing recognition that tillage erosion which linkes to the increased mechanization of the modern agriculture plays an important role in arable soil redistribution.

Assessing soil quality and evaluating soil carbon content are of pressing concern for soil protection and mitigation strategies for global warming. Approaches to increase carbon sequestration have converted many soils from sources to sinks for atmospheric CO_2. Is soil erosion a carbon sink or a carbon source? This complex and controversial question still needs scientific investigation to be answered. More specifically, the spatio-temporal dynamics of organic matter in relation to soil erosion should be more deeply investigated as soil carbon responds gradually to changes in agricultural management such as crop rotation, returning residue, fertilizer input, manure application or tillage. The study of SOM redistribution, at different scales ranging from plots to watersheds, using geostatistics and erosion study, using isotopic soil tracers like ^{137}Cs, can help farmers and policy-makers to develop targeted strategies for soil management and protection.

4.4.5. Conclusion

Both classical statistics and geostatistics confirmed the existence of a geostatistical spatial dependence of the SOM data. OK interpolation provided a better cross validation than IDW2, although both techniques produced similar estimated SOM content in the topsoil. The fact that the spatial pattern of SOM distribution was similar to that of soil redistribution assessed from ^{137}Cs data (SSU annual report 2006) supports the idea of a significant relationship between SOM and soil redistribution.

This study thus confirms that erosion appears as a redistribution process that may influence soil quality and the productivity of agricultural systems in the mid/long term. However, further research is needed to fully understand the impact of soil erosion on C dynamics in the landscape as well as to design appropriate conservation strategies.

4.4.6. References

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4.5. Reducing Time for Extraction of Water from Soil and Plant Samples through Cryodistillation Process [4]

Sasa Linic, Peggy Macaigne and Joseph Adu-Gyamfi

The vacuum cryodistillation technique is widely used for plant and soil water extraction and investigations of water use efficiency, estimation of soil evaporation and plant isotopic signatures. The cryodistillation device in the Agency's Laboratories (Seibersdorf) is currently designed to process eight samples at one time for sixteen hours. Recent improvements and fine-tuning of the methodology helped reduce the time for extraction from sixteen to four hours without affecting the efficiency of extraction. This reduction in time helps to extract more samples whilst maintaining the efficiency and quality of the extraction. Using this improved methodology, approximately 165 soil and plant samples have been analyzed to support on-going coordinated research project on "Managing irrigation water to enhance crop productivity under water-limiting conditions"

4.6. Integrating Soil Water Measurements with ^{13}C and ^{18}O isotopic tracers to evaluate wheat lines for tolerance to pre- and post- anthesis water stress [5]

Adu-Gyamfi J J, Linic S, Arrillaga J L and Heng L K

4.6.1. Introduction

Identifying wheat genotypes with increased water use efficiency (WUE) and high biomass in different environments where water scarcity occurs is the ultimate goal of any programme aimed at enhancing wheat yields in drought-prone environments. The two drought scenarios that affect wheat yields are pre-anthesis and post anthesis water stress. The carbon isotope discrimination technique (the isotopic ratio of ^{13}C to ^{12}C, ^{13}) in plant tissues is increasingly being used as surrogate of water use efficiency and has emerged as powerful tool to evaluate C_3 plants with increased WUE in drought prone environments, examining the balance between net photosysnthesis (*A*) and stomatal conductance to water vapour(*gs*).

Although the relationship between $^{13}\Delta$ and water use efficiency is well documented, it has been suggested that the ratios of ^{18}O to ^{16}O (δ $^{18}\Delta$) varies with transpiration rate, which is closely related to stomatal conductance (gs) and could therefore be used as an additional indicator (besides $^{13}\Delta$) of crop tolerance to drought. Changes in plant photosynthesis associated with increased atmospheric CO_2 concentrations can be detected in the ^{13}C and ^{18}O isotope composition in plant organic matter. Thus the combined ^{13}C and ^{18}O isotopic composition in leaves or grain can be used in a long-term integrators of plant response to photosnthesis.

Accurate and reliable estimation of soil water is vital for effective irrigation scheduling to improve crop-water productivity. To date, a substantial suite of indirect soil water sensors and technologies are available from many manufactures for soil water content measurements compared to the direct soil sampling for water content (gravimetric measurements) which is time consuming, laborious and often destructive. However, few studies have related soil water measurements using different soil water sensor gauges with isotopic signatures of carbon and oxygen to evaluate wheat plants to water stress at different growth stages.

The objectives of the study were to (i) compare the performance of the nuclear and capacitance-based soil water sensors and relate to the performance of two wheat varieties under early (pre-anthesis) and

[4] *Project 2.1.1.2 Technologies and Practices for Sustainable use and management of water in Agriculture Environments—Activity 4*

[5] *Project 2.1.1.5 Integrated Soil-Plant Approaches to Increasing Crop Productivity in Harsh Environments—Activity 3*

terminal (post-anthesis) water-stressed environments (ii) relate soil water measurements using different soil water senor gauges with biomass and isotopic signatures of carbon and oxygen in plant dry samples to evaluate wheat plants for their tolerance to water stress at different growth stages under field conditions.

4.6.2. Materials and methods

4.6.2.1. Experimental Set-up

A field experiment was carried out on Seibersdorf soil (classified as *Dystric Eutrocrepts*) in IAEA's Seibersdorf Laboratories. The experimental field had twelve plots (excluding 2 plots without crops) each plot measuring 3 × 5 m. Aluminum access tubes (to a depth of 70 cm) for the neutron moisture gauge and plastic tubes (70 cm) for soil moisture measurements using the Diviner and the EnviroScan were installed in all plots to monitor the changes of soil water status within the plant root zone during the growth period. In addition, sensors for measuring soil moisture using the time domain reflectometer (TDR) were installed in 6 of the experimental plots. An automatic weather station (iMETOS) recording hourly and daily temperature, relative humidity, solar radiation, daily precipitation, leaf wetness and wind speed was also installed. Two spring wheat (*Triticum aestivum* L.) varieties (SW Kronjet – V_1 and Xenos – V_2) supplied by the Probstorf Seed Breeding Station, Austria were planted in the 3 × 5 m plots in a randomised split-plot design with 3 replications and two water regimes (post-anthesis water stress and pre-anthesis water stress) (Figures 12 and 13).

Figure 12. Fellows sowing wheat seeds in a field experiment to evaluate wheat varieties for tolerance to water stress using isotopic tracer techniques

Figure 13. Wheat plants in the field at (a) vegetative growth stage (b) maturity

4.6.2.2. Irrigation and Soil Water Measurements

Soil moisture content was monitored to a depth of 70 cm (at 10 cm intervals) every week using the Diviner 2000, EnvironScan, time-domain reflectometer (TDR) and neutron moisture probes (Troxler 4300 and CPN) for the purpose of irrigation scheduling and estimating water uptake by the plant root system. In addition, two soil moisture sensors (Decagon 10HS) and a soil matrix potential sensor (MPS-1) from the Automatic weather station were installed to a soil depth of 20 cm for continuous monitoring of soil moisture and soil matrix potential. The two water treatments (i) pre anthesis (plants were stressed till flowering and thereafter received adequate irrigation) and (ii) post anthesis (plants received adequate water till flowering and thereafter were stressed till maturity) began 17 days after sowing (DAS). The post-anthesis treatment received supplementary irrigation by manually applying water through a shower sieve at the rate of 35 L/min for 2 or 3 mins depending on the soil moisture readings. (Figure 14a and b)

4.6.2.3. Plant sampling and analysis

Plants were sampled at 17 (beginning of water treatment), 28, 38, 50 (tillering) and 87 (maturity) days after sowing. An area of 1 row (20 cm) × 25 cm was sampled at 17 and 28 DAS, 2 rows × 50 cm at 38 and 50 DAS. The above and below-ground biomass was taken at each sampling day. At final harvest, 8 rows × 2 m (for grain yield) and 4 rows × 2 m (for shoots) of the above ground biomass were taken. At each sampling period, plants were separated into roots, shoot, spikes, and grain (if available), and oven-dried at 70°C to a constant weight. Roots were thoroughly washed with tap water then with distilled water and oven-dried. The above- and below-ground biomass was weighed, finely ground and a portion of the ground sampled was analyzed for C, N, ^{13}C concentrations with an Isotope Ratio Mass Spectrometer (Isoprime GV Instruments). The $\delta^{18}O$ concentrations in bulk grain material was measured by online pyrolysis to CO using a Finnigan TC/EA coupled to the Finnigan Delta Plus XP Isotope Ratio Mass Spectrometer.

The $\delta^{13}C$ and $\delta^{18}O$ concentrations of the plant sample were calculated from the isotope-ratio measurements ($R = {}^{13}C / {}^{12}C$ or $R = {}^{18}O / {}^{16}O$) of the sample and a standard by the following equation:

$$\delta^{13}C\ (‰) = \{(R_{sample} / R_{standard}) - 1\} \times 1000 \quad (1)$$

$$\delta^{18}O\ (‰) = \{(R_{sample} / R_{standard}) - 1\} \times 1000 \quad (2)$$

where the secondary standard were Vienna PDB or Vienna Standard Mean Ocean water (V-SMOW).

The $\Delta^{13}C$ isotope discrimination of the plant sample was calculated from $\delta^{13}C$ and measurements by the following equation:

$$\Delta\ (‰) = \{(\delta^{13}C_{air} - \delta^{13}C_{plant}) / (1 + \delta^{13}C_{plant})\} \times 1000 \qquad (3)$$

where $\delta^{13}C_{air}$ is the $\delta^{13}C$ value of atmospheric CO_2 (–8 ‰) and the $\delta^{13}C_{plant}$ is the measured value of the plant material.

Figure 14 (a). Monitoring soil water in the filed using a soil moisture neutron probe

Figure 14 (b). A fellow monitoring soil water in the field using the Diviner

4.6.3. Results

4.6.3.1.Soil Characteristics and Weather conditions

The total rainfall during the growing season (May to August) was 582.2mm (with the highest precipitation of 80mm recorded in July) and average temperature was 18.7°C, ranging from 10°C in May to 28°C in July during the crop growing season. The solar radiation was highest in July with an average of 319.9 W/m² and the soil water content at 20 cm soil depth ranging from 11-29% (Figure **15**).

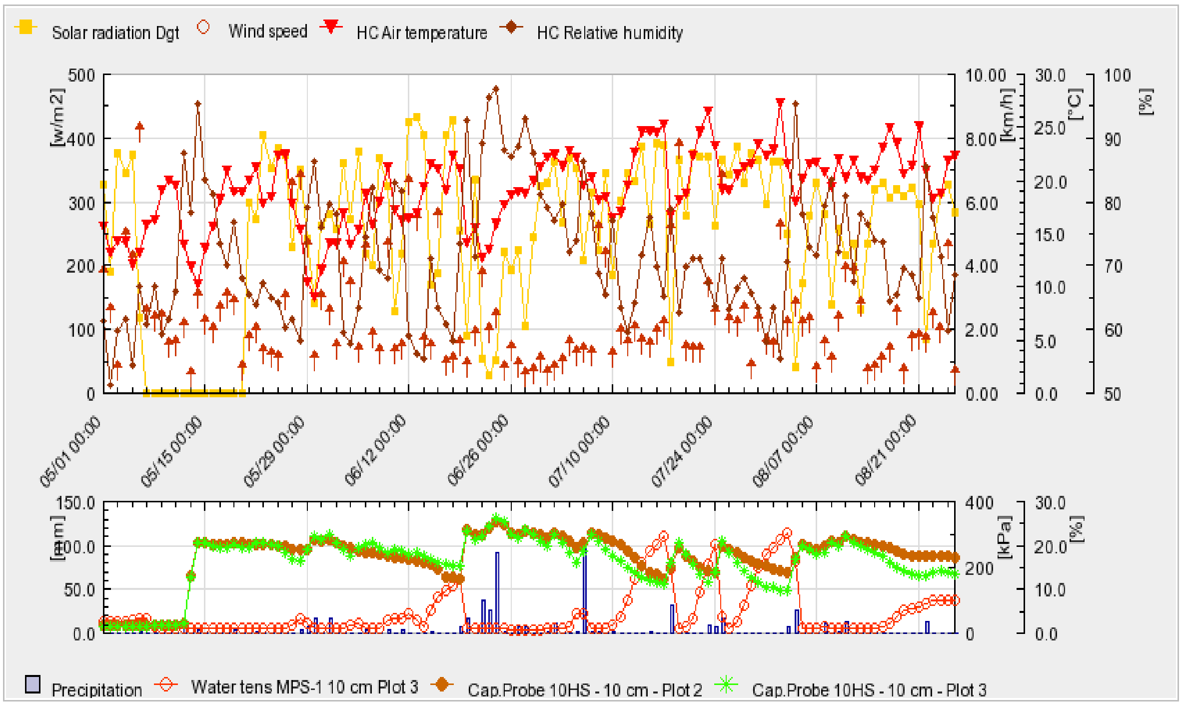

Figure 15. Continuous monitoring of daily temperature, relative humidity, solar radiation, wind speed, rainfall and soil moisture(using the Decagon 10HS) during the experimental period

4.6.3.2.*Comparison of nuclear and capacitance-based (TDR, EnviroScan, Diviner) soil water monitoring sensors under pre- and post anthesis water stress*

Figure 16 shows comparative values (%) of soil water measured using the neutron probe, Diviner, Enviroscan and TDR (Minitrace and Trace) in 4 of the 12 plots at 40 cm depth. Estimates of soil water content using the neutron probe were similar to that of the TDR and not to the Environscan.

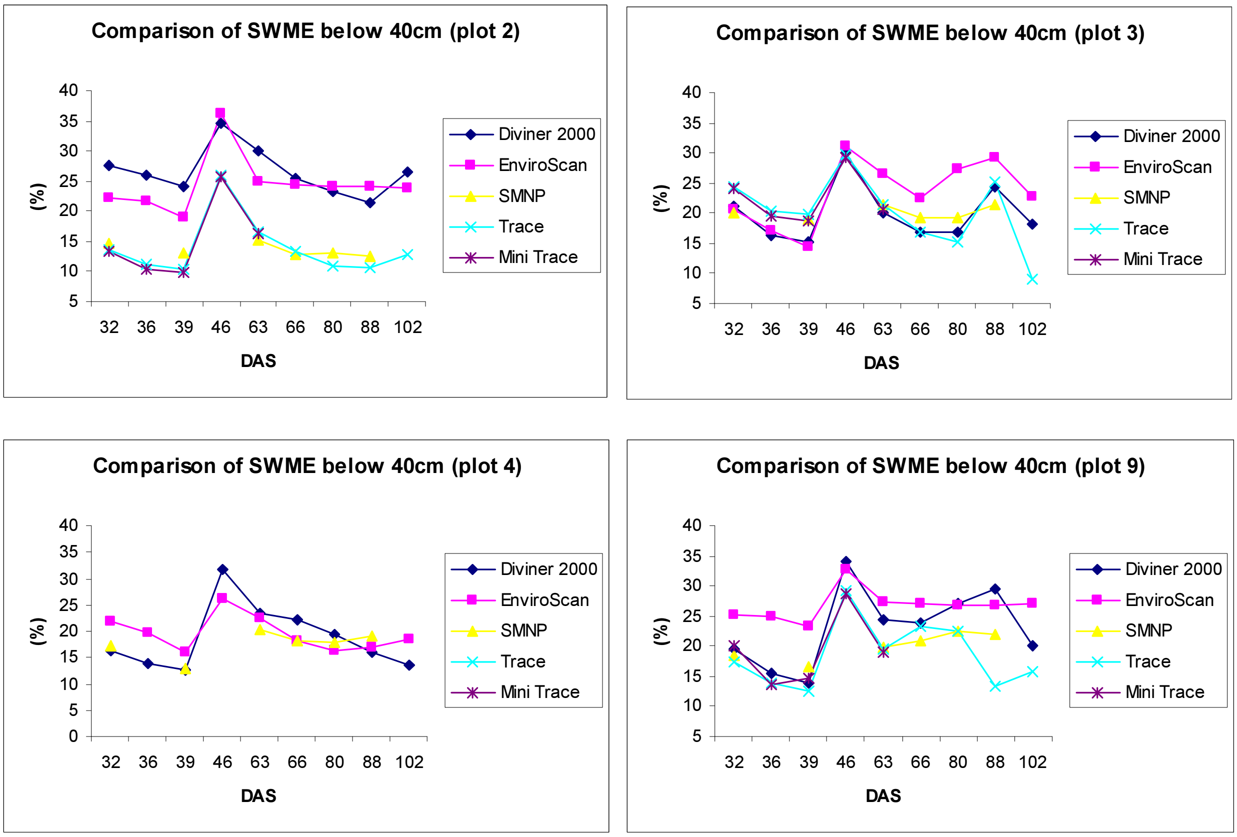

Figure 16 Comparison of soil water monitoring equipments (SWME) to estimate soil moisture in 4 different plots in the field during the experimental period.

4.6.3.3. Biomass production of wheat varieties under water stress

Biomass increased steadily from 17 DAS (first sampling) to 87 DAS (final sampling). Pre-anthesis water stress had a more severe effect on biomass than the post anthesis water stress treatment (Figure 17). Total above ground biomass (Mg ha^{-1}) was 7.2 for V_1 and 6.6 for V_2 in the post anthesis, and 5.3 for V_1 and 4.6 for V_2 in the pre-anthesis treatments compared to the control (10.4). Grain yields (Mg ha^{-1}) were 3.04 for V_1 and 3.06 for V_2 in the post anthesis and 2.4 for V_1 and 1.94 for V_2. No significant differences in grain yield was observed for V_1 and V_2 in the post anthesis treatment, however the difference in grain yield between V_1 and V_2 for the pre-anthesis treatment was significant (Figure 18). The harvest index (ratio of grain yield to biomass) ranged from 0.46–0.50 for the water stressed treatments and 0.59 for the control plants.

4.6.3.4. Carbon isotope discrimination and Oxygen-18 in bulk dry samples

Figure 18 shows the influence of the water-stressed treatments on $\Delta^{13}C$ and $\delta^{18}O$ in grain at final sampling. The pre- anthesis water-stressed treatment resulted in less ^{13}C discrimination (17.79–17.99‰) compared with the values (18.07–18.59 ‰) for the post anthesis water-stressed treatment. The $\Delta^{13}C$ values were lower for V_1 than for V_2 irrespective of the treatment. For $\delta^{18}O$, the values were higher (10.2 ‰) in the post anthesis than the pre-anthesis treatment (9.53. ‰). The values for $\delta^{18}O$ in grain reflected more on the grain yield and biomass than that for $\Delta^{13}C$.

Figure 19 shows the relationships between grain yield and $\delta^{18}O$ and $\Delta^{13}C$. There was a strong and positive correlation between grain yield and $\delta^{18}O$ (R^2=0.958) compared to that between $\Delta^{13}C$ and grain yield. (R^2=0.071). Similar results were observed for biomass. Our data showed that there was a weak, but positive correlation (R^2=0.17) between $\delta^{18}O$ and $\Delta^{13}C$. The data clearly support the hypothesis that the ratios of ^{18}O to ^{16}O ($^{18}\Delta$) that varies with transpiration rate, and is closely related to stomatal conductance (gs), could be a better indicator to evaluate the tolerance of wheat plants to water stress than the $\Delta^{13}C$. However the cost of analysis of $\delta^{18}O$ composition in dry mature grain materials by online pyrolysis to CO using a Finnigan TC/EA coupled to the Finnigan Delta Plus XP Isotope Ratio Mass Spectrometer could be a bottleneck.

4.6.3.5.Nitrogen amount in grain

The water-stressed treatments had no significant effects on N concentrations in grain but the N amount in grain was lower in pre-anthesis water-stressed plants than that of the post anthesis (**Figure 20**) and the wheat genotype SW Kronjet (V_1) accumulated more N in grain than was more tolerant to water stress than Xenos (V_2)

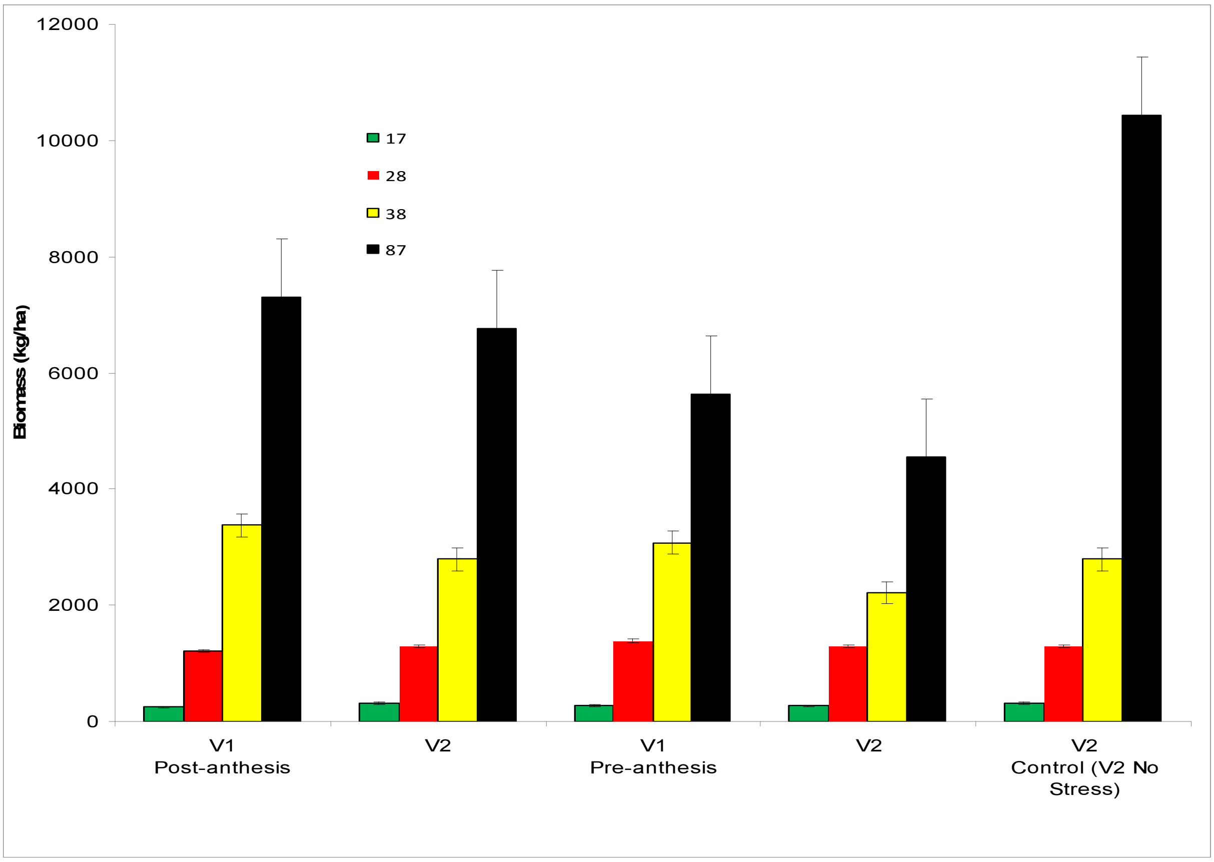

Figure 17. Aboveground biomass at 17, 28, 38 and 87 days after sowing (DAS) for the two wheat varieties(V_1—SW Kronjet and V_2--- Xenos) subjected to pre-anthesis and post anthesis water stress. The control plants (V_2) were not subjected to stress during the whole experimental period

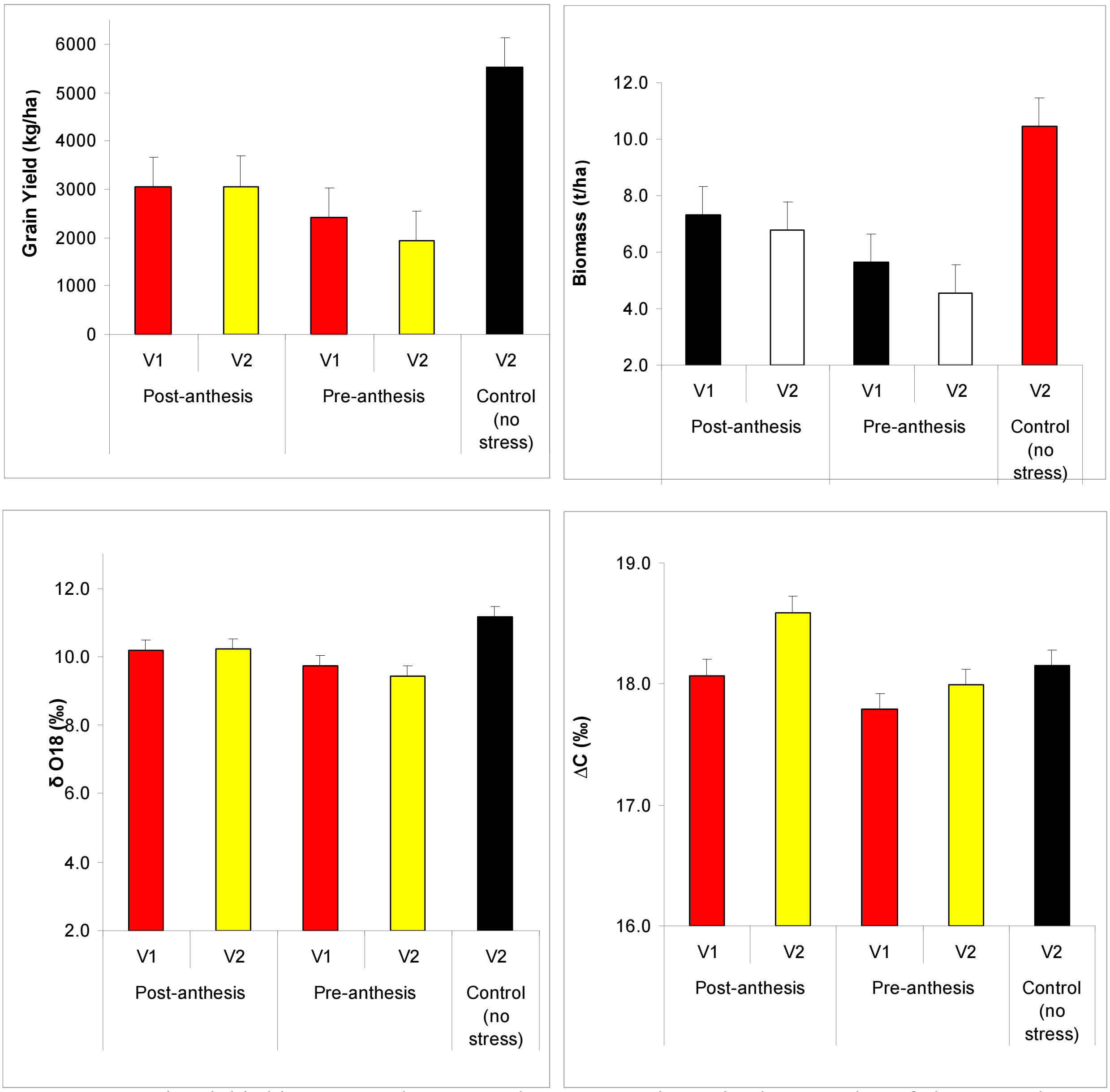

Figure 18. Grain yield, biomass, carbon-13 and oxygen-18 in grain dry samples of the two wheat varieties (V_1 and V_2) under pre-anthesis and post anthesis water stress.

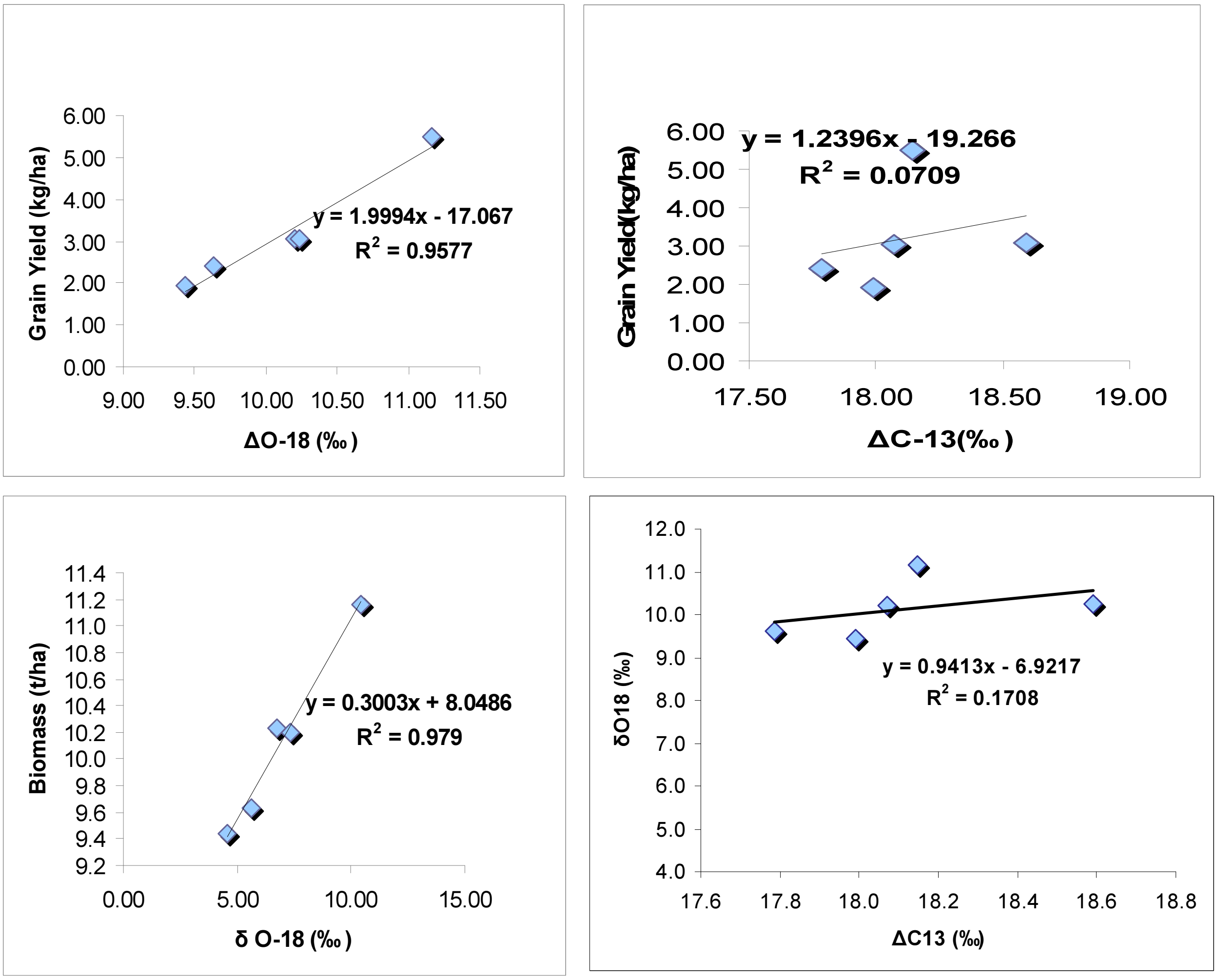

Figure 19. Relationship between grain yield, O-18 and C-13

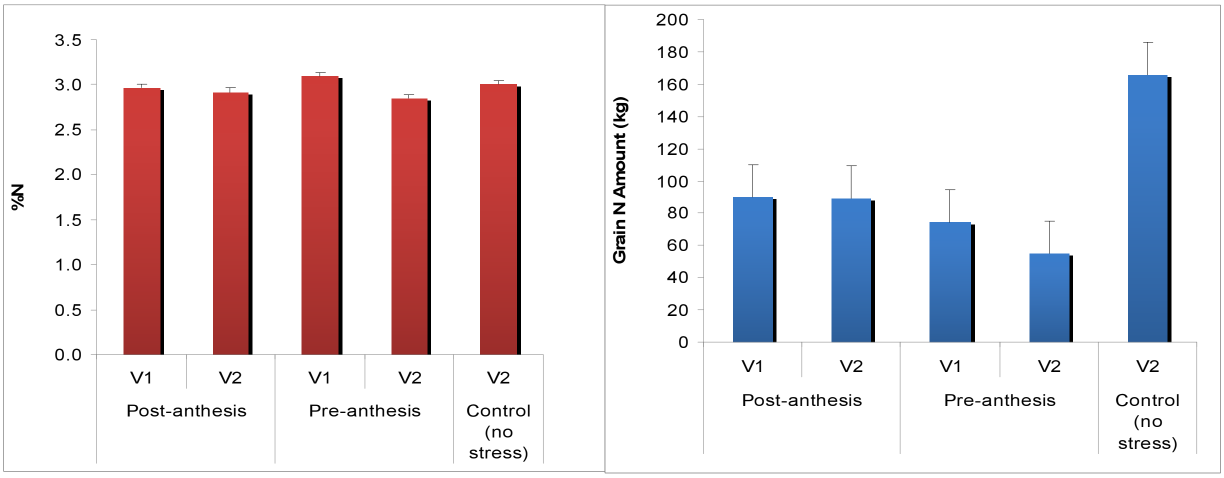

Figure 20. Nitrogen concentrations and content in grain of wheat varieties subjected to pre-anthesis and post anthesis water stress.

4.6.4. Tentative Conclusions

(1) Pre-anthesis water-stress significantly affected wheat biomass and grain yield more the post-anthesis water-stressed treatments. The wheat genotype SW Kronjet (V1) was more tolerant to water stress than Xenos (V2).

(2) Enviroscan seems to overestimate the soil water content compared to the other devices and that estimates of soil water content using the neutron probe were similar to that of the TDR.

(3) The strong and positive correlation between grain yield and δ18O (R2=0.958) compared to that between Δ13C and grain yield. (R2=0.071) indicate that the ratios of 18O to 16O (18Δ) which is directly related to biomass and grain yield, could be a better indicator to evaluate wheat plants of water stress than the Δ13C.

4.7. A new weather station and soil moisture sensor for field experiments at Seibersdorf [6]

Joseph Adu-Gyamfi, Lee Heng and José Luis Arrillaga

A new weather station (iMETOS ag station from Pessl Instruments) was setup and installed in the Seibersdorf field experimental station (**Figures 21 and 22**). The weather station records temperature, relative humidity, dew point temperature, leaf wetness, rainfall, global radiation and wind speed. These data will be compared with an existing weather station installed nearly twenty years ago. The iMetos was also expanded to include soil moisture sensors and soil matric potential sensor (Decagon 10HS and MPS-1, respectively). The latter will also be used as part of the comparison of different soil moisture monitoring sensors (TDR, EnviroScan, Neutron Probe and Diviner) available in the field. The whole weather station and soil moisture sensor setup will be useful in providing evapotranspiration data and irrigation scheduling for the field experiment on 'Integrating soil water measurements and isotope tracer (^{13}C, ^{18}O and ^{2}H) techniques to evaluate wheat lines for tolerance to drought under pre- and post-anthesis water stress'. The study aims to relate soil water measurements with isotopic signatures of carbon and oxygen in plant leaves to select wheat lines tolerance to water stress at different growth stages and to compare the reliability of the different soil water monitoring equipments to estimate plant available water for wheat plants grown under different water stressed

[6] *Project 2.1.1.5 Integrated Soil-Plant Approaches to Increasing Crop Productivity in Harsh Environments—Activity 3*

conditions plus to provide quantitative information on the use of isotope tracer techniques to evaluate wheat plants for tolerance to water stress at the different growth stages. The weather and soil data also will be useful for fellowship training in soil moisture instrumentation and soil water balance. The iMetos is powered by rechargeable batteries and a solar panel. It is a wireless internet based datalogging system which makes it convenient to view or download the data anywhere, anytime.

Photo 21. The imetos weather station and Decagon soil moisture sensors to be installed in the filed in the field at the Agency's Laboratory, Seibersdorf

Photo 22. The new soil moisture device 10HS being installed on the field

4.8.Determination of nitrogen uptake and fertilizer use efficiency in maize (*Zea Mays* L.) using the ^{15}N labeling method [7]

Martina ŠTURM and Joseph Adu-Gyamfi. Collaborative work bewteen Jožef Stefan Institute, Department of Environmental Sciences, Jamova cesta 39, SI-1000, Ljubljana, Slovenia and the Soil Science Unit

4.8.1. The Challenge

There is an increasing concern for maximizing the efficiency of fertilizer nitrogen (N) use in crop production systems and the ^{15}N techniques have been used extensively to study the uptake of applied N by plants and the nitrate concentration in soils at different depths. The ^{15}N labeling method, the isotopic signature of the enriched tracer can be pre-determined to ensure significant difference in atom % ^{15}N between source and background level, even when fractionation occurs. This technique has been used extensively to trace fate of soil nitrate in cropping systems.

4.8.2. Experimental Design

An experiment was set up on a field at the International Atomic Energy Agency's Laboratories, Seibersdorf. Maize (*Zea Mays* L.) was grown on 1 m^2 plots with 3 replications The soil used was Seibersdorf soil (Typic Eutroscrepts) a with a coarse clay loam texture . Some of the physical characteristics of the soil used are particle size distribution (13.0 % clay, 15.6% silt and 71.4% sand), permanent wilting point 7.08 (% vol), bulk density (1.6 g. cm^{-3}) particle density (2.61 g. cm^{-3}) and water content at saturation 48.2 vol %. The soil pH (KCl) was 7.50 and had 7.91 g.kg^{-1} organic C. The soil used had a total N 0.60 g.kg^{-1} , total P 906 mg.kg^{-1}, available P 233 mg.kg^{-1} mg/kg (Bray P2) and 26.1 g.kg^{-1} (Olsen P), EC (25^{o}C) 130 µS.cm^{-1}., total C 17.5 g kg^{-1} OC 1.1 g kg^{-1} and cation exchange capacity (CEC) as measured by the cobalt hexamine method was 17.5 cmol(+)kg^{-1}. Labelled $K^{15}NO_3$ (5.29 at % ^{15}N excess) was applied in solution at a rate of 100 kg N ha^{-1} and phosphorus at 40 kg P ha^{-1} kg P/ha, The soil moisture neutron probe (SMNP), tensiometers and Time domain reflectometry (TDR) were used to monitor the soil moisture content.

Three maize plants from each plot were sampled at 15, 36, 63, 79, and 99 days after sowing (DAS) separated into roots, shoots and cobs, weighed, dried and grinded for analysis. Soil samples were taken at 8 days before sowing (-8 days), 0, 36, 79 and 99 DAS at 0-20 and 20-40 cm depth Soil and plant samples were analyzed for total N and ^{15}N using a continuous flow IRMS Europa 20-20 with ANCA-SL preparation module (PZD Europa Ltd, U.K.), connected to an elemental analyzer. Nitrogen uptake (i.e. N yield), the portion of N derived from the fertilizer (% Ndff) and derived from soil (% Ndfs), fertilizer N yield and % fertilizer use efficiency were calculated for each replicate. Results were verified statistically with Student`s t-test using the Statistica 6.0. Significant differences are given on a 95 % level.

4.8.3. Results

4.8.3.1.Soil and Plant N

Total soil nitrogen (N) concentrations did not vary significantly ($p>0.05$) at 0-20 cm and 20-40 com soil depth during the growing period (**Table 6**), whereas enrichment with ^{15}N increased heavily at both depths after the addition of the enriched fertilizer, compared to initial soil sampling (**Figure 23**). The N content as well as ^{15}N enrichment was greater in upper than the lower soil layers. Fluctuations in N

[7] *Project 2.1.1.5 Integrated Soil-Plant Approaches to Increasing Crop Productivity in Harsh Environments—Activity 4*

and ^{15}N concentration during the growing season after fertilization are not statistically significant and are explained by natural soil heterogeneity.

Table 6: N and ^{15}N concentrations in soil from 0-20 cm and 20-40 cm depth at -8 days before (8) and 36, 79 and 99 days after sowing.

Days after sowing	%N (dry basis)		at % ^{15}N excess	
	0-20 cm	20-40 cm	0-20 cm	20-40 cm
8	0.41 ± 0.02	0.33 ± 0.01	0.003 ± 0.000	0.003 ± 0.000
36	0.41 ± 0.01	0.37 ± 0.04	0.017 ± 0.006	0.011 ± 0.003
79	0.41 ± 0.01	0.38 ± 0.02	0.013 ± 0.001	0.007 ± 0.000
99	0.45 ± 0.01	0.39 ± 0.03	0.018 ± 0.003	0.008 ± 0.003

Data are means ± S.D. (n=3).

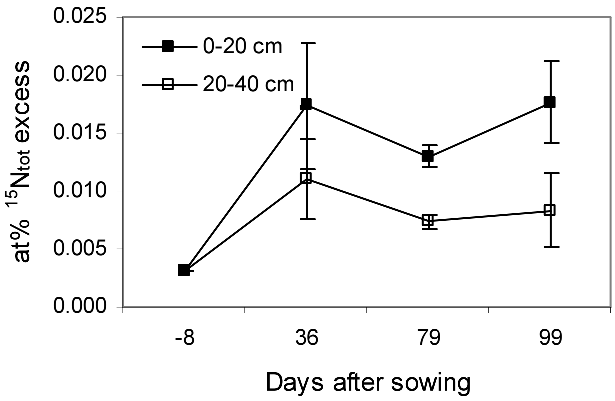

Figure 23 at % 15N excess in soil at 8 days before and 36, 79 and 99 days after sowing.

Dry matter accumulation increased with DAS whereas there was a decrease in N concentration (%) in different maize parts during the growing period (**Figure 24 a and b**).

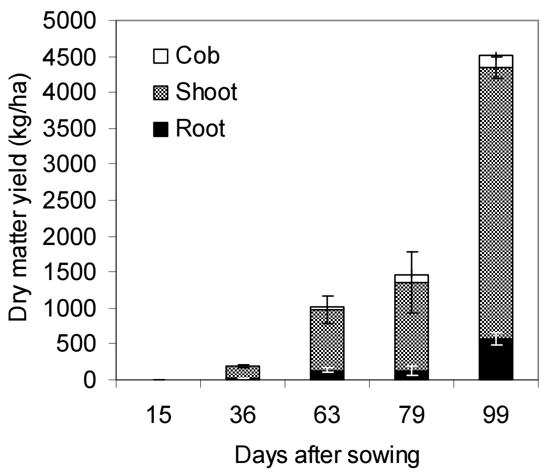

Figure 24a. Dry matter yield in different parts of maize at 15, 36, 63, 79 and 99 days after sowing.

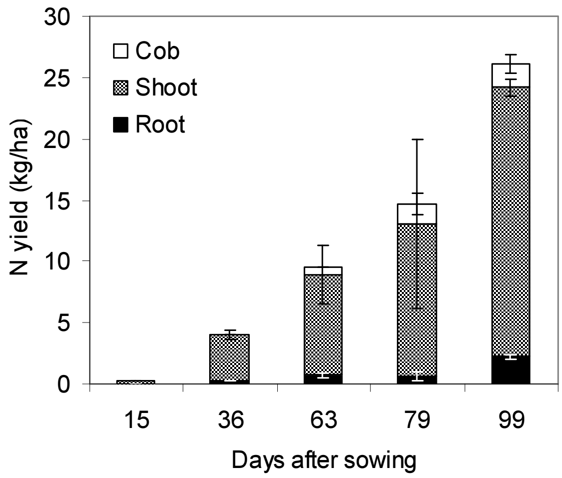

Figure 24b. Nitrogen yield in different parts of maize at 15, 36, 63, 79 and 99 days after sowing.

At final harvest, about 92 % of N taken up by maize was distributed to the aboveground parts of maize (Figure 24b).Significant intra-plant variations ($p<0.05$) in N concentration and % ^{15}N excess were observed. Highest N concentrations were observed in cobs and lowest concentrations in roots; whereas highest enrichments with ^{15}N were recorded in shoots and lowest in roots (Figure 25).

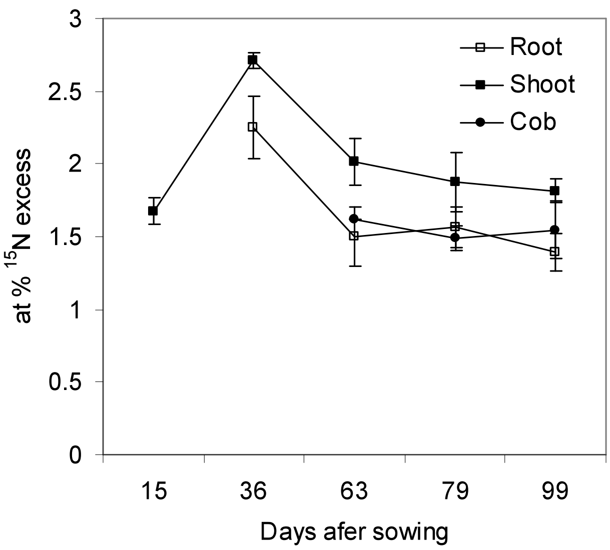

Figure 25. Intra-plant and temporal variations of at % ^{15}N excess in maize at 15, 36, 63, 79 and 99 days after sowing.

N uptake and atom % ^{15}N excess in shoots increased markedly from 15 to 36 DAS (from 0.2 to 4 kg N/ha and 1.674 to 2.708 at % ^{15}N excess, respectively). Enrichment with ^{15}N decreased after 36 DAS, with growth period in all maize parts, which can be explained by increased contribution of soil N, which is highly depleted with ^{15}N compared to the total plant N during the growth period (Figures 26 and 27). Using the ^{15}N-labelled fertilizer the proportion of plant N derived from soil N (Ndfs) and from fertilizer N (Ndff) was calculated. The %Ndff by maize was 33.3 %, whereas the %Ndffs was 66.7 % .The fertilizer plant N recovery was about 9 %.

Figure 26 A fellow from Slovenia sampling soil water for ^{15}N-nitrate analysis in the field

Figure 27. Field experiment to determine nitrogen uptake, fertilizer-N and water use efficiency

4.8.4. Conclusion

Experiments with ^{15}N labeled fertilizers, though relatively expensive compared to non-isotope methods, provide precise and quantitative data on the fertilizer use efficiency. The ^{15}N method, used on the presented maize experiment, provides a direct and quick means to obtain the needed information that is valuable for the design of better fertilizer N strategies as well as for the provision of sound recommendation for the application of fertilizer N.

4.9.Summary of the Results on Refining Radioactive P-32 Isotopic Tracer Techniques for Quantifying Plant Available Soil Phosphorus Fractions and Evaluating Genotypes with Different Ability to Access Soil Phosphorus [8]

A detailed report was presented in the **SSU Activities Report 2008** and the manuscript has been submitted for publication. The protocols for fractionation of soil P to elucidate P acquisition from different soil P pools developed and fine-tuned in the Seibersdorf Laboratories is currently used by participants of the CRP on "***Selection and Evaluation of Food (Cereal and Legume) Crop Genotypes Tolerant to Low Nitrogen and Phosphorus Soils Through the Use of Isotopic and Nuclearrelated Techniques (D1.50.10)*** to evaluate and select maize, common bean and rice for their ability to explore P from the different soil P pools**.** Below is the summary of the results.

4.9.1. Phosphorus acquisition from sparingly soluble forms by maize and soybean in low- and medium-P soils using ^{32}P

J J Adu-Gyamfi, *M Aigner, D Gludovacz and S Linic*

Abstract

A glasshouse pot experiment was conducted to evaluate the differential ability of maize (*Zea mays*) and soybean (*Glycine max*) to utilize soil phosphorus (P) for plant growth from total-P, available-P and inorganic (Ca-P, Al-P, and Ca-P) soil P pools using a carrier-free ^{32}P solution. A maize variety (DK 315) and a soybean variety (TGX 1910-4F) were grown in pots containing 1 kg of a low available P (Hungarian) and a medium available P (Waldviertel) soils labeled with ^{32}P for 42 days or without ^{32}P (unlabelled) for 42 and 60 days. The shoot and root biomass of maize and soybean were significantly greater when grown on the Waldviertel than on the Hungarian soils (**Figure 28)**

[8] *Project 2.1.1.5 Integrated Soil-Plant Approaches to Increasing Crop Productivity in Harsh Environments—Activity 5*

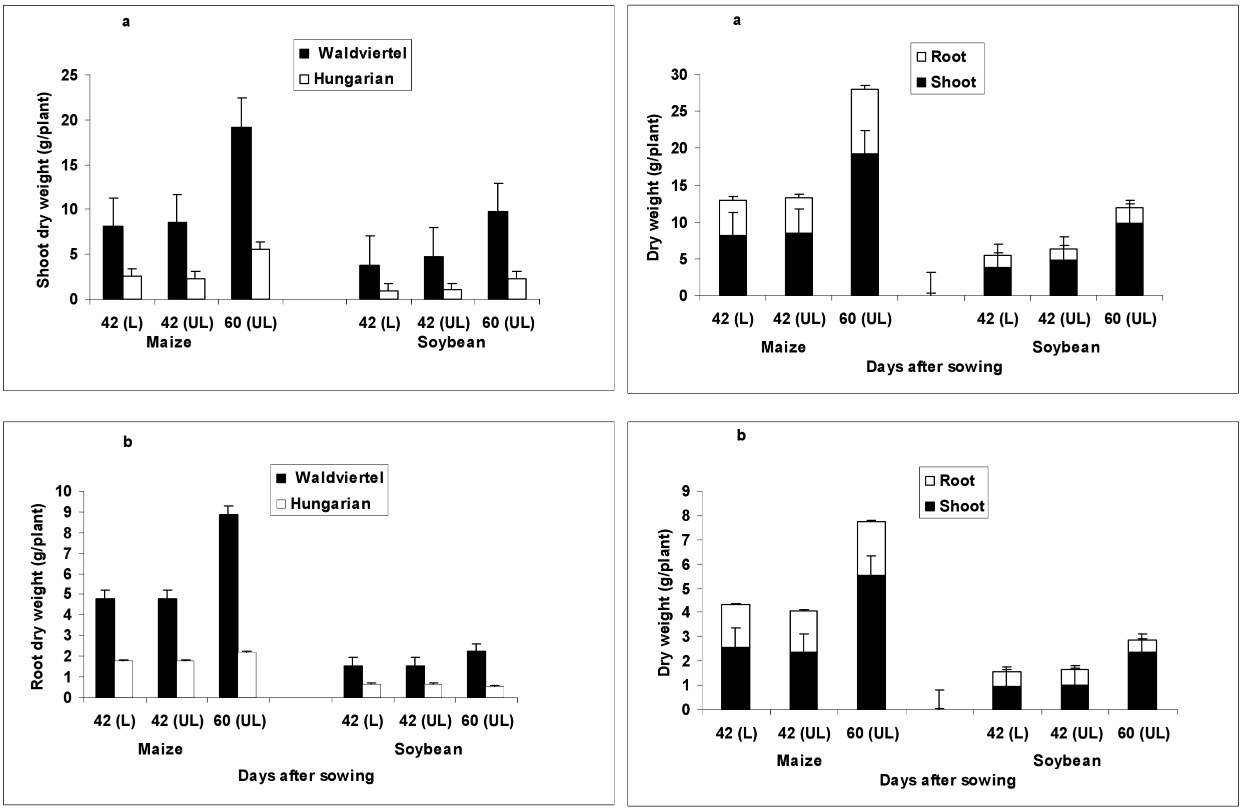

Figure 28 Dry weight of shoot (a0 and roor (b) for maize and soybean grown in Waldviertel and Hungarian soils labelled (L) and unlabelled (UL) with 32P

The shoot P concentrations were higher for soybean (1.7-2.2 g kg^{-1}) than for maize (1.1-1.4 g kg^{-1}). The total radioactivity (dpm x 10^6) was higher in plants grown in Waldviertel than in Hungarian soil and the values reflected on the plant P uptake and shoot biomass of soybean and maize. The L- values (µgP .g $soil^{-1}$) of maize and soybean were higher in Waldviertel (72-78) than in Hungarian (9.6-20) soil. No significant differences in L-values were observed for maize and soybean grown on the Waldviertel, but for the Hungarian soil, the L-values were higher for maize (20.0) than for soybean (9.6) suggesting that in this low-P soil, maize was more efficient than soybean to take up soil P. The available P (Bray II) and the Ca-P were the fractions most depleted by plants followed by the Fe-P fractions in the two soils, but differences between the crops were not significant (**Figure 29**)

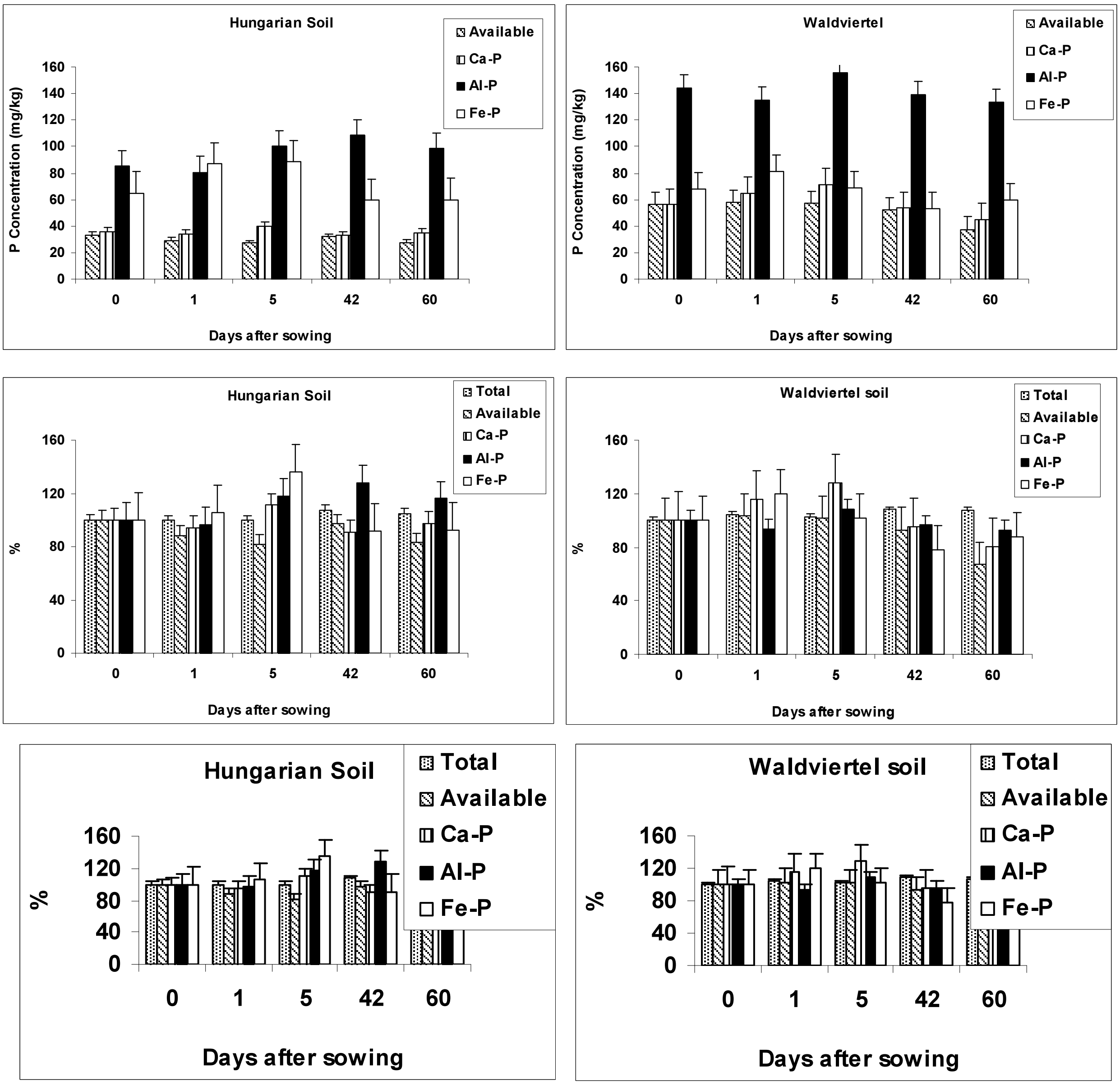

Figure 30 –The inorganic P pools (Ca-P, Al-P and Ca-P) and available-P extracted from the two soils at 0,1,5, 42 and 60 DAS

When soil P is limited, maize and soybean are able to access P mainly from the available P (Bray II), Fe- and Ca-P sparingly soluble fractions and not Al-P from the soil.

4.10. High temperature effects on photosynthate partitioning and sugar metabolism during ear expansion in maize (Zea mays L.) genotypes (Plant Physiology and Biochemistry, 48:124-130)

Ryuichi Suwa[1], Hiroaki Hakata[1], Hiromichi Hara[1] Hany A. El-Shemy[2],, Joseph J. Adu-Gyamfi[3], Nguyen Tran Nguyen[1], Synsuke Kanai[1], David A. Lightfoot[4], Pravat K. Mohapatra[5], Kounosuke Fujita[1]
***Collaborative work with**:*

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[2]Faculty of Agriculture, Cairo University, Giza 12613, Egypt
[3] International Atomic Energy Agency (IAEA), Wagramer Strasse 5, A-400 Vienna, Austria
[4]Plant Biotechnology and Genomics Core Facility, Southern Illinois University, Carbondale, USA
[5]School of Life Science, Sambalpur University, Jyoti Vihar, Sambalpur 768019, India

Climate changes that may include global warming do impact agriculture worldwide . One consequence has been cyclical depressions of crop production in both temperate and tropical regions, especially in maize (*Zea mays* L.; corn). Short hot and dry spells before, or during, silking have an inordinately large effect on maize (*Zea mays* L.;corn) grain yield. New high yielding genotypes could be developed if the mechanism of yield loss were more fully understood and new assays developed. The aim here was to determine the effects of high temperature (35/27°C) compared to cooler (25/18°C) temperatures (day/night). Stress was applied for a 14d-period during reproductive stages prior to silking. Effects on whole plant biomass, ear development, photosynthesis and carbohydrate metabolism were measured in both dent and sweet corn genotypes.

Results showed that the whole plant biomass was increased by the high temperature. However, the response varied among plant parts; in leaves and culms weights were slightly increased or stable; cob weights decreased; and other ear parts of dent corn also decreased by high temperature. Photosynthetic activity was not affected by the treatments. The ^{13}C export rate from an ear leaf was decreased by the high temperature treatment. The amount of ^{13}C partitioning to the ears decreased more than to other plant parts by the high temperature. Within the ear decreases were greatest in the cob than the shank within an ear. Sugar concentrations in both hemicellulose and cellulose fractions of cobs in sweet corn were decreased by high temperature, and the hemicellulose fraction in the shank also decreased. In dent corn there was no reduction of sugar concentration except in the in cellulose fraction, suggesting that synthesis of cell-wall components is impaired by high temperatures. The high temperature treatment promoted the growth of vegetative plant parts but reduced ear expansion, particularly suppression of cob extensibility by impairing hemicellulose and cellulose synthesis through reduction of photosynthate supply. Therefore, plant biomass production was enhanced and grain yield reduced by the high temperature treatment due to effects on sink activity rather than source activity. Heat resistant ear development can be targeted for genetic improvement.

4.11. Evaluating rice varieties tolerant to different salinity levels in soil and solution culture using carbon isotope discrimination.

J Adu-Gyamfi (Soil Science Unit) , S Bado and R Afza (Plant Breeding Unit)

Collaborative work between the Plant Breeding and Soil Science Units

4.11.1. The Challenge

Reliable and repeatable screening techniques are the mainstay of any successful breeding programme for abiotic stress in rice. Though screening techniques vary with growth stages, type and time of stress imposed; ideally the technique should be rapid, reproducible, easy, accessible and affordable to the end users. The screening techniques become more crucial and challenging when mutation techniques are used to obtain a salt tolerant mutant as large mutated populations must be screened. PBU has been working on different screening techniques for salinity with the goal of the establishment of an integrated efficient screening protocol. The hydroponics screening techniques for salt tolerance, currently used at the PBU screen houses, are based on growing the seedlings in water containing varying concentrations of salt.

4.11.2. The Experiment

A collaborative study between the Plant Breeding and the Soil Science Units was initiated to compare a soil and hydroponics culture screening techniques aimed to give breeders the choice as the soil based assay is a more practical method for growing paddy and upland rice by farmers. In this study, the hydroponics (nutrient solution) culture systems was compared with system involving the growing of the plants in soil in which predetermined concentrations of salt had been similarly introduced. The comparisons were based on morphological data collected at the different stages of growth and development at the seedling stage.

Seeds of four different rice varieties (Pokkali, salt and drought tolerant; Bicol, moderately tolerant, IR29, salt susceptible from International Rice Research Institute (IRRI) and STDV, moderately tolerant mutant developed in the Plant Breeding Unit varying in their level of salt tolerance were pre-germinated in Petri dish for a week with distilled water. The one month old seedlings were transplanted either in soil or hydroponic culture. In hydroponic system, the pre-germinated seeds were transplanted in plastic-plugged equidistant holes trays with a piece of sponge in hydroponic systems. A nutrient (Yoshida) solution was used and, the plants were exposed to different concentrations of salinity using NaCl (0, 6 and 12dsm^{-1}) after two weeks. The pH was maintained at 5.0 and the nutrient solution was renewed every 2 d. For soil experiment, the Seibersdorf soil (classified as *Dystric Eutrocrepts*) was a homogeneous (1:1) mixture of sieved soil and quartz sand, supplemented with N and P (100, 40 kg ha^{-1}, respectively) fertilizers. About 160 kg of soil was used to fill an aluminium tank (200 x 100 x 9cm), and puddle before transplanting the seedlings.

The experiment was a randomized complete block design with 3 replications and the 4 varieties were transplanted in the aluminium tasks filled with soil. In all there were 50 seedlings per variety in 3 replicates. Three salinity treatments using NaCl (0, 6, and 12dsm^{-1}) were initiated in the 3 tanks. The plants were kept submerged by adding tap water or Yoshida nutrient solution daily.

4.11.3. Sampling and Analysis

Plants in both solution and soil cultures were sampled at 8, 16, and 32 days after treatment (DAT), washed with water (1-2 minutes), and the fresh weight and plant height were recorded. Samples were then oven-dried at 70°C to constant weight and dried, weighed, and a portion of the dry weight was analyzed for C, N, and ^{13}C concentrations with an Isotope Ratio Mass Spectrometer (Isoprime GV Instruments).

4.11.4. Results

The above-ground biomass of the 4 rice varieties was higher when grown under hydroponic system than the soil culture (**Figure 31**). The salinity effect was more severe at 16 DAT than at 8 days. In the Hydroponic culture dry matter (g $plant^{-1}$) decreased from 1.4–0.9 (Pokkali), 0.8–0.4 (Bicol), 0.6–0.3 (STDV) and 0.5–0.2 (IR29). Similar results were observed for the soil culture, confirming the tolerance of Pokkali and susceptibility of IR29 under saline environments compared to the other varieties (Figure 12). Salinity caused a reduction in $\Delta^{13}C$ values compared to the control with the reduction being more severe in Pokkali (23.4-21.9‰) and less severe in IR 29 (23.4-22.7‰) suggesting that IR 29 is the most sensitive to salinity whilst Pokkali is tolerant to salinity **(Figure 32)**.

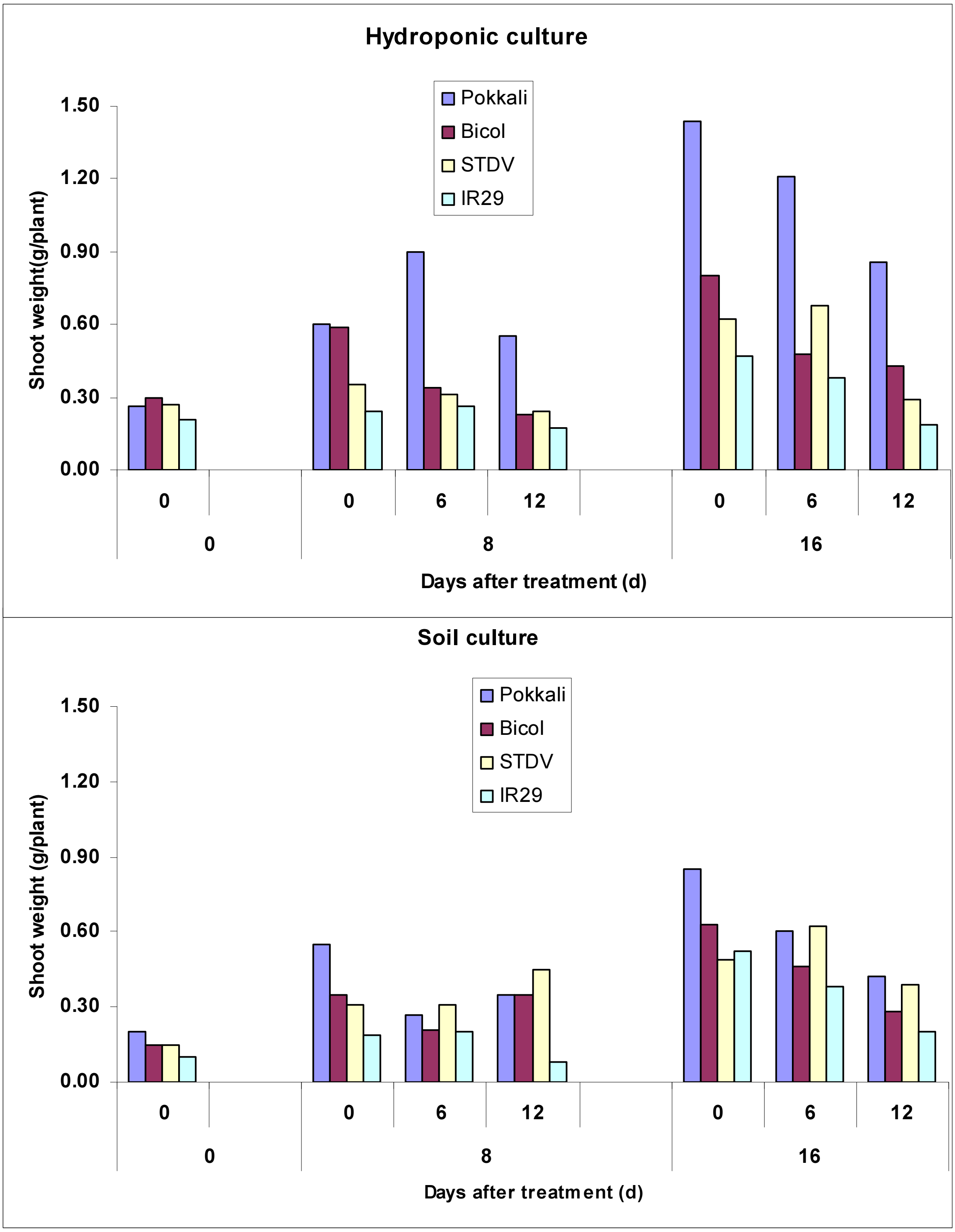

Figure 31 Aboveground biomass of 4 rice varieties (Pokkali, Bicol, IR29 and STDV) grown in soil culture, and hydroponics conditions under 3 salinity treatments (0, 6 and 12 dSm^{-1}). Plants were sampled at 0, 8 and 16 days after treatment.

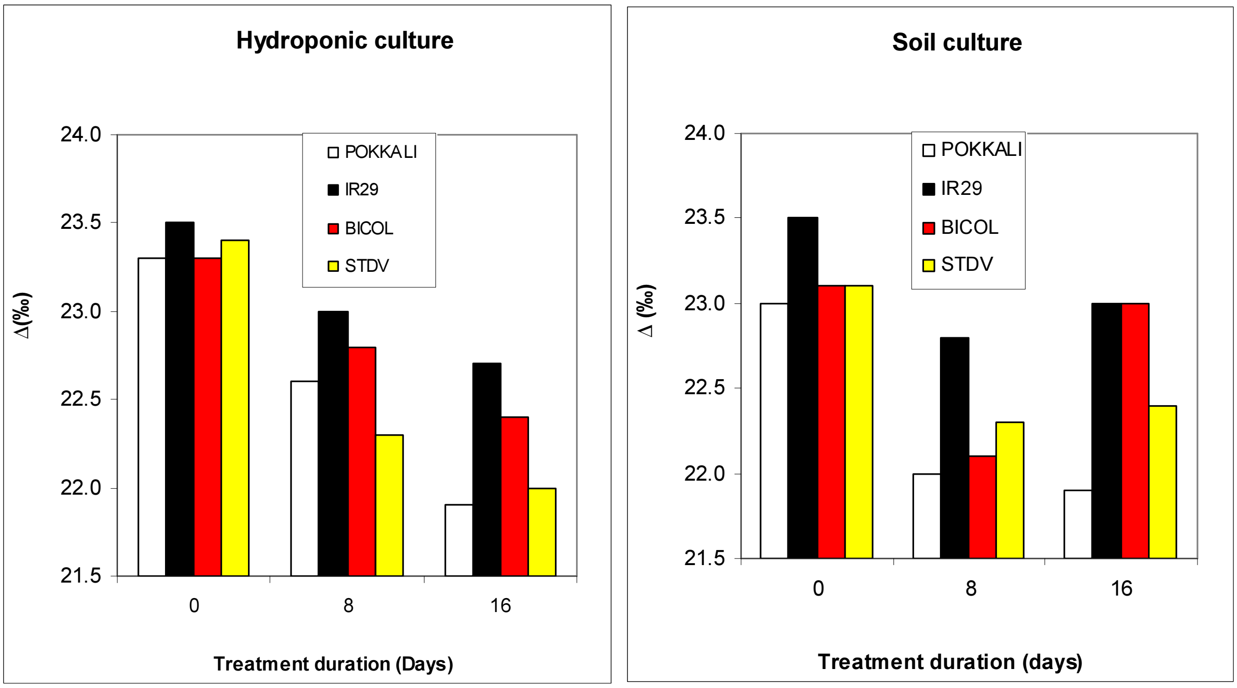

Figure 32 The carbon isotope discrimination in the above-ground biomass by the 4 rice varieties under different salinity conditions

Tentative Conclusions

Evaluating for salt tolerance in rice using soil culture (rather than hydroponics) was well established. Results from the carbon isotope dicrimination confrim the tolerance of pokkali to salinity at 16 days after salinity treatment in both hydroponics and in soil culture conditions. The mechanisms of salt tolerance is being investigated by analyzing the Na, K and Cl content in shoots and roots.

4.12. Status of Coordinated Research Project

4.12.1. Selection and Evaluation of Food (Cereal and Legume) Crop Genotypes Tolerant to Low Nitrogen and Phosphorus Soils Through the Use of Isotopic and Nuclear related Techniques (D1.50.10). Report on Mid-Term Review

Technical Officers: Joseph Adu-Gyamfi and Gerd Dercon

The overall objective of this CRP is to develop integrated crop, soil and nutrient management practices to increase crop production in marginal lands by identifying and promoting the development of food (cereal and legume) crop genotypes with enhanced nitrogen (N) and phosphorus (P) use efficiency and greater productivity in marginal lands. This CRP has a total of 17 participants with ten research contract holders (Burkina Faso, Brazil, Cameroon, China, Cuba, Ghana, Malaysia, Mexico, Mozambique and Sierra Leone), five agreement holders (UWAAustralia, WARDA-Benin, TSBF-Kenya, IITA-Nigeria, and INRA-France) and two technical contractors (University of Hanover-Germany, University of Pennsylvania- USA). The mid-term review, which was successfully conducted in September 2009 showed that the majority of the participants made significant progress during the first two years of the CRP in evaluating rice, maize, common beans, cowpeas and soybean genotypes in the laboratory, greenhouse and field for root traits conferring P and N acquisition. Major outputs from the CRP include:

1. Laboratory and field protocols for evaluation of root traits (architecture and morphology) contributing to enhanced N and P were developed in collaboration with Pennsylvania State University and are available online (http://roots.psu.edu)

2. Development of a new version of the SIMROOT model capable of simulating large diversity of root systems.

3. Protocols for fractionation of soil P using 32P to elucidate mechanisms of P acquisition from different soil P pools developed and fine-tuned in the Seibersdorf Laboratories.

4. Protocols for plant trait N deficiency-induced leaf senescence were tested and refined under field conditions as a criterion for selecting N efficient maize and rice genotypes. The protocols developed were used for rapid evaluation of 150-200 lines (landraces and cultivated) of rice, maize, common beans, soybeans and cowpeas collected from different environments and 20-30 lines with varying grain yield and root morphology were identified and selected for field validation. In addition, isotopic fractionation of soil phosphorus (using 32P) was used to evaluate and select maize, common beans and rice for their ability to explore P from the different soil P pools.

In summary, the CRP is on schedule. During the next two and half years, the activities of the CRP will focus on understanding some of the mechanisms through which certain genotypes are able to use soil and applied N and P efficiently for high productivity, and the CRP will assess the effects of these genotypes with enhanced N and P use efficiencies on cereal-legume cropping systems performance and their long term effects on soil productivity. It is proposed that the third RCM will be held in Maputo, Mozambique during 23-27 August 2010.

4.13. Technical support of activities related to CRP D1.20.11 [9] [10]

L Mabit (SSU)

The First RCM of CRP D1.20.11 entitled "Integrated Isotopic Approaches for an Area-wide Precision Conservation to Control the Impacts of Agricultural Practices on Land Degradation and Soil Erosion" was held from 9 to 12 June 2009 at IAEA's Headquarters in Vienna, Austria.

The overall aim of this CRP is to develop diagnostic tools for identifying critical areas of soil loss at the watershed scale and to focuses on the use of fingerprinting technologies, such as Compound Specific Isotope Analysis (CSIA), in combination with fallout radionuclides.

During the RCM of the CRP, L. Mabit made a presentation entitled 'Fallout radionuclides research activities conducted by the Soil Science Unit in relation to up scaling problems'. The main aim of the presentation was to highlight various tools and protocols to upscale the use of FRN to the watershed and basin scale. After an introduction on soil degradation and a brief review on the advantage and limitation of the use of ^{137}Cs, ^{210}Pb and ^{7}Be as soil tracers, three studies were presented to illustrate FRNs investigations at different spatial scales from field to basin scale for establishing soil redistribution. This presentation gave also a selective overview of current and previous research activities of the Soil Science Unit and the SWMCN Section.

A Seibersdorf Laboratory tour was also organized during the week for the participants of the CRP including a visit of the laboratory facilities (γ-detectors, soil sampling tools and soil sampling preparation).

[9] *Project 2.1.1.1 Soil Management and conservation for sustainable agriculture and environment - Task 2: Improve FRN methodologies to measure soil redistribution rates at a range of scales in agricultural landscapes with the use of geostatistic approach*

[10] *Project 2.1.1.1 Soil Management and conservation for sustainable agriculture and environment - Task 1: Providing services to Member states*

In the frame of the CRP D1.20.11 and in agreement with the CRP TO's of the SWMCN Section, it was decided to support FRN soil samples analyses and future data treatment by the CRP participant of the Atomic Energy Commission of Syria, Damascus, Syria. This analytical and technical support started during the last quarter of 2009.

4.14. Contributions to the TC programme – A Success Story

4.14.1. Turning Adversity into Opportunity: Farmers reaping the benefits from year-round production of income generating crops in Coastal Saline Lands of Bangladesh

Joseph Adu-Gyamfi, Ahmad Ali Hassan1, M-L Nguyen, Collaborative work between
1Bangladesh Institute of Nuclear Agriculture, Mymensingh, Bangladesh and the Soils subprogramme

4.14.2. The Problem

Rice is the major crop grown in the coastal areas of Bangladesh. Soil and water salinity is a major threat to crop productivity in these coastal areas. Soil salinization in the coastal areas is mainly due to sea water that moves inland along the tidal rivers, spills over to the land and salinizes soil and the shallow ground water. Approximately 90% of the arable lands in the coastal areas have been salinized through this process resulting in extended fallow period up to seven months after the rice harvest **(Figure 33).** To improve farmers' livelihoods it is therefore important to reduce this long fallow period and to have another crop grown and harvested to improve food security.

Figure 33 Salinized soil

Soil salinity increases from1.4 deci Semens per meter (dSm^{-1}, a measure of the severity of salt concentration in soils, the higher the value the more hazardous it can cause to crops) after the harvest of the rainy season rice in August to 12.9 dSm^{-1} in February. In addition, the salinity of the river water used for irrigation increases from 1.9 dSm^{-1} in August to 16.5 dSm^{-1} in February.

4.14.3. The Challenge

The main challenge is to develop appropriate water management practices aimed at the reclamation of these coastal saline soils to ensure year round crop productivity for enhanced food security and improved livelihoods of the people. Through IAEA TC Project "Increasing Agricultural Production in the Coastal Area through improved Crop, Water and Soil Management" and in collaboration with the Bangladesh Institute of Nuclear Agriculture, a new integrated technology to estimate soil water content for the timely and accurate application of brackish water and to improve plants' water use in the coastal area was tested.

4.14.4. Results and Impact

The soil moisture neutron probe proved to be efficient to estimate the soil water content in saline soils compared to the time domain reflectometer at two pilot sites (Satkhira and Noakhali). The carbon isotope discrimination (the isotope ratio of ^{13}C to ^{12}C in plant tissue), a surrogate of water use efficiency and a function of plant stomatal opening, was successfully used to assess the ability of different crops and crop genotypes tolerance to different range of soil and water salinity during the fallow period.

Using the integrated soil-water-plant approach that takes into account both soil water measurements and the carbon isotope discrimination technique, two short duration and salt tolerant/escape varieties of each of mung bean mustard, sesame, chickpea, groundnuts and wheat have been identified and are currently grown by 'champion farmers' at the two pilot coastal sites (Noakhali and Satkhira) after the harvest of the rainy season (*aman*) rice. Farmers who used to leave the coastal lands to urban centres for job and income security can now boast of new income generation that has helped to improve their livelihood **(Figure 34).** There is a need for this integrated package to be extended to other coastal salt affected areas in Bangladesh.

Figure 34 Turning adversity into opportunity: A farmer harvseting mung bean

4.15. Training manual on the use of FRN to assess erosion and sedimentation processes [11]

L. Mabit (SSU)

The preparation of a practical training manual on the use of FRNs (^{137}Cs, ^{7}Be, ^{210}Pb) to investigate erosion and sedimentation processes has been initiated under the leadership of L. Mabit.
The objective of this IAEA training course series publication supported by IAEA staff, selected members of the previous CRP D1.50.08 (*Assess the effectiveness of soil conservation measures for sustainable watershed management using fallout radionuclides*) and some other well known experts in this field will be to present to IAEA Member States basic training and advanced materials to deal with FRN. A total of 20 authors from 8 different Member States (Austria, Canada, Chile, Hungary, Morocco, Slovak Republic, Switzerland and United Kingdom) have been involved in the writing of this manual. This contribution will also complement F. Zapata's Handbook for the assessment of soil erosion and sedimentation using environmental radionuclides published by Kluwer Academic Publishers in 2002.

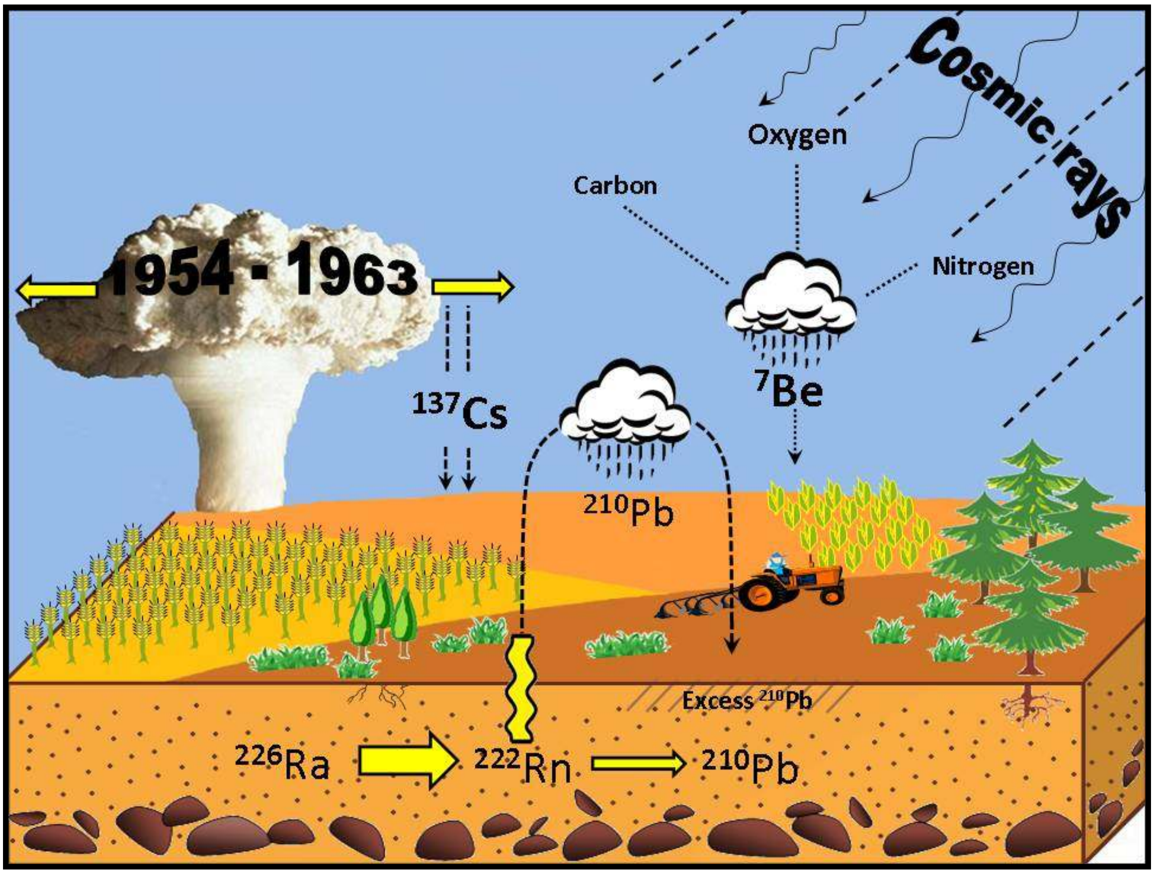

Figure 35 Origin of fallout radionuclides used as soil tracer in erosion and sedimentation studies

[11] *Project 2.1.1.1 Soil Management and conservation for sustainable agriculture and environment - Task 2: Improve FRN methodologies to measure soil redistribution rates at a range of scales in agricultural landscapes with the use of geostatistic approach*

Preliminary table of content:

Chapter I. Assessment of soil erosion and sedimentation: the role of fallout radionuclides.
Chapter II. ^{137}Cs: a widely used and validated medium-term soil tracer
Chapter III. The use of excess ^{210}Pb ($^{210}Pb_{ex}$) as a soil tracer
Chapter IV. The use of ^{7}Be as short term soil redistribution tracer: State of the art & guidelines based on existing experience
Chapter V. Conversion models and related software
Chapter VI. Case studies
VI.1. Combined use of ^{137}Cs and $^{210}Pb_{ex}$ to assess long term soil redistribution in a small agricultural field in Morocco
VI.2. The use of ^{7}Be and ^{137}Cs in soil redistribution evaluation in Chile
VI.3. The use ^{137}Cs (laboratory & in-situ measurements) in soil redistribution evaluation in Switzerland
Chapter VII. Trends in the use of ^{137}Cs, $^{210}Pb_{ex}$, ^{7}Be for documenting soil redistribution

In 2009, the SSU/SWMCN team welcomed the 2.5 months consultancy of Dr. M. Benmansour in Seibersdorf to support our team implementing this task. At the end of 2009, an advanced draft of the manual was completed. The 1st and 2sd quarters 2010 will be devoted to the final editing and compilation of the contributions by co-authors. The manual is to be completed at the end of the 3rd quarter 2010 and its publication is planned in 2011.

4.16. Use of phosphorus isotopes in improving phosphorus management in agricultural systems

M.-L. Nguyen, J. Adu-Gyamfi and F. Zapata

Recognizing the urgent need to address the soil P constraints for a sustainable intensification of agricultural production in developing regions of the world to ensure food security of the ever growing population, the Soil and Water Management and Crop Nutrition Section/Laboratory of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture decided to produce a manual on "**The Use of Phosphorus Isotopes for Improving Phosphorus Management in Agricultural Systems**" as a training and reference manual for soil scientists, agronomists, plant physiologists, crop scientists and other end-users in developing Member States. The purpose of these Guidelines is to provide a comprehensive coverage and up-to-date information on several topics related to P in soil-plant systems, also in agricultural systems and the environment. The manual is in the final draft stage to be submitted to the Publications Committee.

The Guidelines comprise five (5) Chapters. **Chapter 1** provides background information on the role of phosphorus (P) in soil-plant systems, and the need for sustainable P management strategies in agro-ecosystems. **Chapter 2** is an extensive review of several topics related to P in the soil-plant system, and also in agricultural systems and the environment. **Chapter 3** deals with a range of conventional (chemical) and nuclear and isotopic techniques for estimating P availability, fluxes and balances. Interpretations of soil P testing results for providing appropriate fertilizer recommendations are discussed. **Chapter 4** describes the use of P isotope tracer techniques for measuring the P recovery from applied P also an insight into radiation safety procedures for handling P radioisotopes and personal safety issues. **Chapter 5** includes four case studies, of which the first three illustrate the application of P radiotracer techniques to evaluate various P sources in acidic soils and the last one deals with assessments of N, P, and K management by nutrient balances and flows on peri-urban smallholder farms in southern Vietnam.

The principal officer responsible for this publication is Mr. M.L. Nguyen of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture with the support of Mr J. J. Adu-Gyamfi and Mr. F. Zapata. The contribution to the various Chapters by Prof. K.M. Goh, and Prof. G.J. Blair (New Zealand) is greatly acknowledged.

4.17. Isotope analyses

4.17.1. Stable isotope analyses

L Mayr

The Soil Science Unit performed 7749 stable isotope measurements during the year 2009 as shown in the Table 7. Most of the analyses were for supportive research and training with some 3000 for CRPs and TCPs.

Table 7 Stable isotope analytical support during 2009

Samples measured:

	^{15}N enriched	^{15}N nat. ab.	^{13}C nat. ab.	^{18}O nat. ab.	Total
CRP	183	262	458	0	903
Contr.	75	0	0	0	75
TC	788	0	202	0	990
Seibersdorf	312	246	552	1536	2646
Total	**1358**	**508**	**1212**	**1536**	**4614**

Measurements carried out:

(including standards, blanks, test samples, replicates)

	^{15}N enriched	^{15}N nat. ab.	^{13}C nat. ab.	^{18}O nat. ab.	Total
CRP	305	469	767	0	1541
Contr.	101	0	0	0	101
TC	1068	0	271	0	1339
Seibersdorf	500	563	1312	2393	4768
Total	**1974**	**1032**	**2350**	**2393**	**7749**

4.18. Radioisotopic analyses [12]

A Toloza (SSU) and L Mabit (SSU)

In 2009, using the SSU γ-detector (HPGe coaxial detector, relative efficiency of 115%, Minimum Detectable Activity for ^{137}Cs of 0.2 Bq kg^{-1}) our team performed 360 radioisopic measurements for supportive research activities for Member States. The counting times ranged between 10 000 and 50 000 for an average of 30 000 seconds/sample.

The SSU analysed 90 samples in the frame of collaboration with the Center for Agricultural Land Management and Agrohydrology Department for Agronomy, Biotechnical Faculty (Ljubljana, Slovenia); 20 samples to support the Syrian participant of the CRP D1.20.11 (IAEA contract No.: 15532); 30 samples to support the local team of the Ministère de l'Energie et de l'Eau & Direction Nationale de l'Energie (Bamako, Mali) according to the work plan of the TCP MLI 5022; and 160 analyses of ^{137}Cs and geogenic radioisotopes contents for our collaborative project in Yemen with the University of Tubingen (Tubingen, Germany).

Out of this external network support, 60 additional measurements were also conducted for calibration, background and quality control purposes. The Table 8 summarizes the 2009 radioisotopic analytical services provides by the SSU.

In 2009 also gamma spectrum of samples measured for ^{7}Be contents in 2008 were reanalysed and updated with a new calibration procedure (mixed gamma containing: Am-241, Cd-109, Co-57, Ce-139, Hg-203, Sn-113, Sr-85, Cs-137, Co-60, Y-88. Total activity 40 kBq) using three different Petri dish geometries (80, 100 and 120 ml).

Table 8. Number of FRN and geogenic radioisotopes analysis performed in 2009

	^{137}Cs	^{40}K	^{226}Ra	^{232}Th	**Total**
Matrix	*soil*	*soil*	*soil*	*soil*	
External Network	180	40	40	40	**300**
Seibersdorf	30	10	10	10	**60**
					360

[12] *Project 2.1.1.1 Soil Management and conservation for sustainable agriculture and environment - Task 1: Providing services to Member states*

4.19. External Quality Assurance: Performance of IAEA-participants in IPE2009.2 on the ^{15}N-enriched test sample:

Martina Aigner

The second Proficiency Test (PT) on ^{15}N and ^{13}C in plant materials jointly organized by the University of Wageningen, The Netherlands and the IAEA Soil Science Unit Seibersdorf, Austria has been successfully completed. The Wageningen Evaluating Programs for Analytical Laboratories (WEPAL, http://www.wepal.nl) is accredited for the organization of Interlaboratory Studies by the Dutch Accreditation Council.

Fifteen IAEA-funded stable isotope laboratories participated in PT-round "IPE 2009.2", three more than in 2008.

It was agreed between the Soil Science Unit and the PT-organizer to include one ^{15}N-enriched plant material (0.5 to 2.5 atom %, i.e. 370 to 6000 δ ‰ "delta per mille") per year into the IPE test sample set. A bulk amount of uniformly ^{15}N-enriched plant material was produced by the FAO/IAEA Soil Science Unit and sent to WEPAL for milling, homogenization and bottling through the routine test sample production process for PTs. This ^{15}N-enriched material was sent out together with 3 other - not enriched - plant samples. Participants were invited to perform analysis of any determinand offered in the WEPAL IPE scheme including ^{15}N (enriched and/or natural abundance level), total N (N-elementary), Kjeldahl-N, ^{13}C and total C (C-elementary). The participation fee for one round of PT in 2009 (round IPE2009.2) was covered by the IAEA.

Twenty-four participants that were registered in the "IAEA Soil Science Unit PT scheme" in previous years were provided with the WEPAL test sample set IPE 2009.2 consisting of the four test samples of 20 g plant material each. Fifteen laboratories reported isotope abundance data within the deadline (Figure 36). The Soil Science Unit also participated in this round of PT. A special IAEA-evaluation report for the results of the ^{15}N enriched test sample was provided to all participants in October 2009. Certificates for successful participation were submitted to laboratories fulfilling the requirements for high analytical standards established by the IAEA-Soil Science Unit.

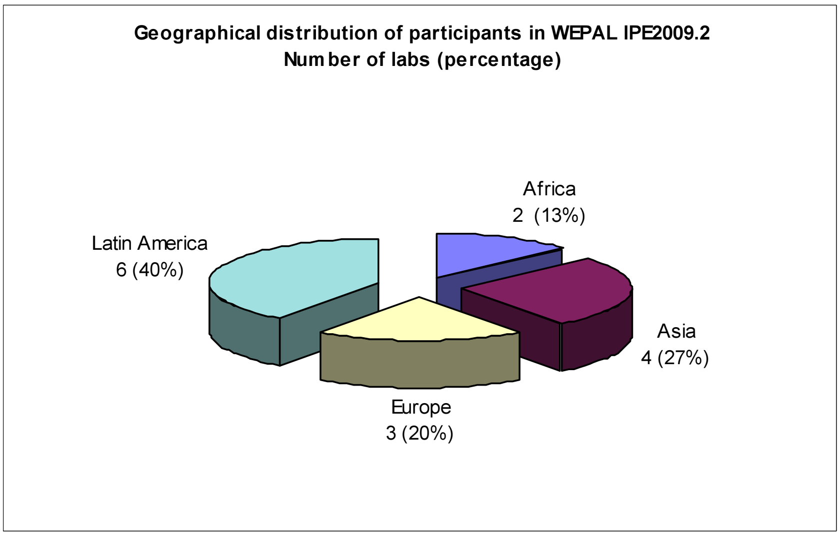

Figure 36 Geographical distribution of IAEA participants

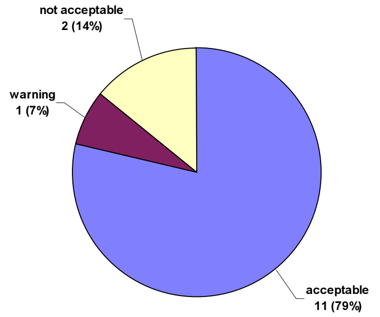

Figure 2- ^{15}N abundance determination

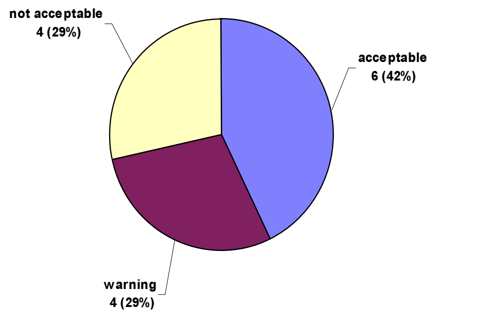

Figure 3 – total N determination (N-elementary and N-Kjeldahl)

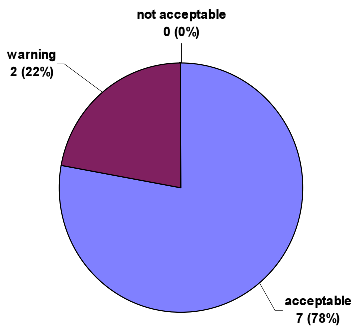

Figure 4 - ^{13}C abundance determination

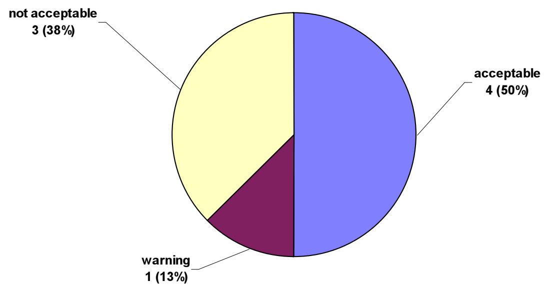

Figure 5 - total C determination

Figure 37 Performance of IAEA-participants in IPE2009.2 on the ^{15}N-enriched test sample.

4.19.1. Conclusion

Still some laboratories were confused about how to report their ^{15}N-data correctly and some reported total N and C in [weight %] instead of [g/kg]. These laboratories might have analysed correctly, but calculated and reported the results wrongly. It is of high importance for the analyst to know, in which unit the data should be provided, how to calculate the isotope abundance correctly and to get a feeling for the order of magnitude of the reported data (Figure 37).

To simplify the evaluation, from next PT- round on, only reporting of ^{15}N results as "delta per mille" (δ ‰) will be accepted by WEPAL. An Excel-spreadsheet will be provided to the participants for conversion from atom % to delta ‰ of ^{15}N-results.

The big advantage of comparing analytical data to those of a large and increasing number of analytical laboratories worldwide will provide high confidence in the laboratory's analytical performance and is an invaluable tool for external quality control. It is hoped that in the future more stable isotope laboratories will make use of this opportunity to assess their analytical performance and provide evidence of the sustainable high quality of their analytical data.

5. APPENDICES

5.1. Staff Publications

5.1.1. Journal Articles

Høgh-Jensen, H., Kamalongo, D., Myaka, F. A., **Adu-Gyamfi, J.J**. (2009). Multiple nutrient imbalances in ear leaves of on-farm unfertilized maize in eastern and southern Africa. African Journal Agriculture Research, 4(2), 107-112.

Mabit, L., Bernard, C. (2009). Spatial distribution and content of soil organic matter in an agricultural field in Eastern Canada, as estimated from geostatistical tools. *Earth Surface Processes and Landforms* (In press).

Mabit, L., Klik, A., Benmansour, M., **Toloza, A.,** Geisler A., Gerstmann, U.C. (2009). Assessment of erosion and deposition rates within an Austrian agricultural watershed by combining ^{137}Cs, $^{210}Pb_{ex}$ and conventional measurements. *Geoderma* 150 (3-4), 231-239.

Shakhashiro, A., **Mabit, L.** (2009). Results of an IAEA inter-comparison exercise to assess ^{137}Cs and total ^{210}Pb analytical performance in soil. *Applied Radiation and Isotopes*, 67(1), 139-146.

5.1.2. Conference Proceedings/Abstracts / Reports

Adu-Gyamfi, J.J., Aigner, M., Gludovacz, D. (2009). Variations in Phosphorus acquisition from sparingly soluble forms by maize and soybean in low-P and medium-P soil using ^{32}P. Proceedings of XVI International Plant Nutrition Colloquium. http://repositories.cdlib.org/ipnc/xvi/1317

Adu-Gyamfi., J.J, Kenzhebayeva, S., Ram, T., Nguyen, M.L. (2009). Selection of wheat and rice genotypes for high agronomic water use efficiency in water scarce and salinity environments using the carbon isotope discrimination. In: Proceedings of 3rd International Conference on Integrated Approaches to Improve Crop Production Under Drought-Prone Environments, Interdrought-III, Abstract.

Mabit, L., Klik, A., **Toloza, A.,** Benmansour, M., Geisler A., Gerstmann, U.C. (2009). Measurements of the effectiveness of conservation agriculture at the field scale using radioisotopic techniques and runoff plots. In: Geophysical Research Abstracts (USB), Volume 11, European Geosciences Union – General Assembly 2009. Abstract EGU2009-4507. pdf, 2 pages.

5.1.3. Chapters in books and IAEA publications

Adu-Gyamfi, J.J., Kenzhebayeva, S., Dovchin, Z., Ram, T. (2009). Interactive effects of water stress and salinity on ^{13}C isotope discrimination in rice, wheat and maize cultivars. IAEA Publication, IAEA-TECDOC (In press).

Adu-Gyamfi, **J.J.,** Sumah, F., Kenzhebayeva, S., Ram, T. (2009). Effect of N and P availability on ^{13}C isotope discrimination in wheat and rice. IAEA Publication, IAEA-TECDOC (In press).

Mabit, L. (2009). Map of soil movement and sediment budget established using FRN and geostatistics. IAEA Publication IAEA-TECDOC (In press).

Mabit, L., Klik, A., **Toloza, A.,** Geisler A., Gerstmann, U.C. (2009). Combined use of caesium-137 methodology and conventional erosion measurements in the Mistelbach watershed (Austria). IAEA Publication IAEA-TECDOC (In press).

Mabit, L., Klik, A., **Toloza, A.** (2009). Radioisotopic measurements (^{137}Cs and ^{210}Pb) to assess erosion and sedimentation processes: Case study in Austria. In: Land Degradation and desertification: Assessment, Mitigation and Remediation. Zdruli, P., Pagliai, M., Kapur, S., Faz Cano, F. (Eds)., Springer. Publ. (In press).

Shakhashiro, A., **Mabit, L.** (2009). Analytical performance of 14 laboratories taking part in proficiency test for the determination of Caesium-137 and total Lead-210 in spiked soil samples. IAEA Publication IAEA-TECDOC (In press).

5.1.4. Other publications and material

Adu-Gyamfi, J.J. (2009). Coordinated Research Report Mid-year review of CRP "Selection and evaluation of food crop genotypes tolerant to low nitrogen and phosphorus soils through the use of isotopic and nuclear-related techniques" CPR No.1290 RCS.

Aigner, M. (2009). Quality Assurance report on the Joint WEPAL / IAEA Proficiency Test IPE 2009.2 for the Measurement of ^{15}N and ^{13}C Isotopic Abundance and total Nitrogen- and Carbon concentration in Plant Materials. IAEA-SSU Internal Publication. 12 pages + Annexes.

Hood-Nowotny, R., **Mayr, L.,** Islam, A., Robinson, A., Caceres, C. (2009). Routine isotope marking for the Mediterranean fruit fly (Diptera: Tephritidae). *Journal of Economic Entomology*, 102(3), 941-947.

5.2. Staff Travels

Staff Member	Destination	Period	Purpose of Travel
Mabit, Lionel	Vienna, Austria	19-24 April	The SSU provided an update of the R&D investigation in the Mistelbach watershed using Caesium-137 (^{137}Cs) and unsupported Lead-210 ($^{210}Pb_{ex}$) at the general assembly of the European Geosciences Union.
	Basel, Switzerland	14 October	Lionel Mabit was invited as the guest speaker for a seminar by the Department of Environmental Sciences, Institute of Environmental Geosciences, Basel University, Basel, Switzerland. The main aim of his seminar entitled '*The use of fallout radionuclides (FRNs) to assess erosion and sedimentation processes from field to basin scale*' was to highlight various tools and protocols to upscale the use of FRNs to the watershed and basin scale. This presentation also gave a selective overview of current and previous research activities of the Soil Science Unit (SSU) of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture.
Hardarson, Gudni	Lunuwila, Sri Lanka	28 September – 3 October	Guide the counterpart on the overall implementation of a new TC project, including training, procurement and expert services. Train the project team on the use of nuclear techniques in quantification of crop nutrition.

Staff Member	Destination	Period	Purpose of Travel
Adu-Gyamfi, Joseph	**Freetown, Sierra Leone (Figure 38)**	16-20 March	To assess counterpart infrastructure and equipments in Laboratory and to discuss start up and implementation of a newly approved Technical Cooperation project (SIL/5/012) "Managing Irrigation Water for a Dry Season Sorghum/Legume Intercropping System for Income Generation and Soil Health".
	Sacramento, CA, USA **and**	26-30 August	To participate and present a poster on 'Phosphorus acquisition from sparingly soluble forms by maize and soybean in low-P and medium-P soils, using ^{32}P', at the 16th International Plant Nutrition Colloquium in Sacramento.
	University of Wyoming, Laramie, USA (Figure 39)		To learn more about the cryodistallation method for extracting water from soil and plant samples for ^{18}O and ^{2}H analysis with the aim of improving the efficiency of the cryodistillation equipment currently used at the Soil Science Unit
	Cotonou, Benin	19-23 October	To participate and provide technical assistance to stakeholders at the start-up workshop, review/ assess the operational capabilities and status of the laboratory and develop an inventory of existing equipment for field experiments

Figure 38 Farmers' practices on land preparation (slash and burn) for cultivation of upland rice in Sierra Leone

Figure 39 A cryodestillation water extraction line at the Stable Isotope Facility Laboratory, University of Wyoming, WY, USA

5.3. External Collaborations and Partnerships

Effective collaborations and partnerships are essential for enhancing research activities. The SSU established collaborations with external partners from Member States on the following projects:

Institutions	Topics
Centre national de l'énergie, des sciences et des techniques nucléaires (CNESTEN), Rabat, Morocco.	Investigation using radioactive tracers (^{137}Cs & $^{210}Pb_{ex}$) and classical spatialisation concept to document soil redistribution rates in Morocco
Center for Agricultural Land Management and Agrohydrology Department for Agronomy, Biotechnical Faculty, Ljubljana, Slovenia.	Measurements of erosion and sedimentation magnitude using radio-isotopic approaches in Šalamenci watershed
Institute of Mountain Hazards and Environment, Chinese Academy of Sciences and Ministry of Water Resources, Chengdu, Sichuan, China.	Measurement of sedimentation rates using ^{137}Cs and $^{210}Pb_{ex}$ and evaluated by classical sedimentation models
Centre national de l'énergie, des sciences et des techniques nucléaires (CNESTEN), Rabat, Morocco.	

Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec, Québec, Canada.	Spatial variability of soil organic matter content and soil quality using geostatistical

	approach
University of Tubingen, Institute of Geography, Tubingen, Germany.	Preliminary radio-isotopic tests before soil redistribution investigation on agricultural terraces in Yemen
International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria.	First application of nuclear techniques (FRN) in the derived savanna of Nigeria for estimating medium-term soil redistribution rates
Bundesanstalt fuer Geowissenschaften und Rohstoffe (BGR), Hannover, Germany.	
Institute of Soil Science and Land Evaluation & Institute of Plant Production in the Tropics and Subtropics, University of Hohenheim, Stuttgart, Germany.	
University of Exeter, Department of Geography, Exeter, United Kingdom.	
Department of Agricultural Applications, Atomic Energy Commission of Syria (AECS), Damascus, Syria.	Gamma analytical support of IAEA Contract No.: 15532 in the frame of the CRP D1.20.11
Ministère de l'énergie, et de l'eau (MMEE) - Direction nationale de l'énergie (DNE), Bamako, Mali.	Accuracy of gamma measurements (Proficiency Test) and analytical support in the frame of the TCP MLI 5022
Environmental Science Program and Quesnel River Research Centre, University of Northern British Columbia, Prince George, British Columbia, Canada	Training manual on the use of Fallout Radionuclides to assess erosion and sedimentation processes
Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec, Québec, Québec, Canada.	
Institut de Recherche et de Développement en Agroenvironnement, Sainte-Foy, Québec, Canada.	
Universidad Austral de Chile, Facultad de Ciencias Instituto de Fisica, Valdivia, Chile.	
Radioanalytical Reference Laboratory, Central Agricultural Office Food and Feed Safety Directorate, Budapest, Hungary	
Centre national de l'énergie, des sciences et des techniques nucléaires (CNESTEN), Rabat, Morocco.	
Institut National de la recherche Agronomique (INRA), Rabat, Morocco	
Soil Science and Conservation Research Institute, Bratislava, Slovak Republic.	
Institute of Environmental Geosciences, Department of Geosciences, University of Basel, Basel, Switzerland	
University of Exeter, Department of Geography,	

Exeter, United Kingdom.	
School of Geography, University of Plymouth, Plymouth, United Kingdom.	
Department of Horticulture, Pennsylvania State University, USA	(i)Developing laboratory and field protocols (including computational root modelling) for evaluating root traits (architecture and morphology) contributing to enhanced N and P). http://www-nawab.iaea.org/nafa/swmn/news-swmcn.html and http://roots.psu.edu
Agricultural Research Institute of Mozambique – IIAM, Ministry of Agriculture and Fisheries, Maputo, Mozambique	Nodulation and N_2 fixation by P efficient common bean genotypes in low P environments
Departments of Renewable Resources and Botany, University of Wyoming, Laramie, USA	Measurements of ^{18}O in plant dry samples to evaluate tolerance of wheat plants to water stress environments
Agronomy Department, University of Ljubljana, Slovenia	Monitoring nitrate leaching under intensive farmer managed fields in a Slovenia catchment
Institute of Terrestrial Ecosystems (ITES)Swiss Federal Institute of Technology (ETH), Zurich, Switzerland	Neutron radiography techniques for in-situ measurements of root architecture and development
Graduate School of Biosphere Sciences, Hiroshima University, Hiroshima, Japan	Effects of abiotic stress (temperature, nutrients, increased CO_2 concentrations and water) on photosynthate partitioning using ^{13}C and ^{15}N

6. CO-ORDINATED RESEARCH PROJECTS (CRP) AND TECHNICAL COOPERATION PROJECTS (TCP)

CRP Title	Scientific Secretary
Selection and Evaluation of Food (Cereal and Legume) Crop Genotypes Tolerant to Low Nitrogen and Phosphorus Soils through the Use of Isotopic and Nuclear related Techniques (2006-2011)	Adu-Gyamfi, Joseph
TCP Title	**Technical Officer**
Effect of Biofertilizer and Inorganic Fertilizer Uses on the Growth and Yield of Maize and Bean in Ferralitic Soils of Huambo (ANG5005)	Hardarson, Gudni

Increasing Agricultural Production in the Coastal Area through Improved Crop, Water and Soil Management (BGD5026)	Adu-Gyamfi, Joseph in collaboration with the Plant Breeding and Genetics Section
Integrated Watershed Management for the Sustainability of Agricultural Lands (CHI5048)	Mabit, Lionel in collaroration with the Food and Enironment Protection Section
Improving Crop Productivity and Combating Desertification (ERI5004)	Adu-Gyamfi, Joseph in collaboration with the Plant Breeding and Genetics Section
Improvement of Yield in Plantain and Cassava through the Use of Legume Cover Crops (IVC5029)	Hardarson, Gudni
Isotope Techniques for Assessment of Water and Nitrogen Use Efficiency in Cow-Pea/Maize Intercropping Systems (KEN5026)	Adu-Gyamfi, Joseph
Use of Environmental Radioisotopes for the Assessment of Soil Erosion and Sedimentation in the Province of Antananarivo, Madagascar (MAG5014)	Mabit, Lionel
Assessment of Soil Erosion and Sedimentation in the Niger Watershed with the Use of Radioisotopes, Phase I (MLI5022)	Mabit, Lionel
Application of Isotopes in Soil and Plant Studies (MON5014)	Hardarson, Gudni
Contribution of Nitrogen Fixing Legumes to Soil Fertility in Rice-based Cropping Systems (SIL5008)	Hardarson, Gudni
Protecting Groundwater and Soil against Pollutants Using Nuclear Techniques (SLO5002)	Adu-Gyamfi, Joseph in collarboration with the Food and Environment Protection Section
Increasing Productivity of Selected Crops Using Nuclear Related Techniques (SUD5030)	Adu-Gyamfi, Joseph In collaboration with the Plant Breeding and Genetics Section
Improving Maize and Yam-Based Cropping Systems and Soil Fertility (BEN 5005)	Adu-Gyamfi, Joseph
Managing Irrigation Water for a Dry Season Sorghum/Legume Intercropping system for Income Generation and Soil Health (SIL 5012)	Adu-Gyamfi, Joseph

7. TRAINING ACTIVITIES

7.1.Fellows

Name	Country	Area of Training	Period
Domingos Moises Chongolola Sanguvila (ANG09009)	Angola	Use of nuclear techniques in quantification of biological nitrogen fixation and rhizobial inoculation of grain legumes. The training requested is related to the IAEA's TC project entitled: Effect of Biofertilizer and Inorganic Fertilizer Uses on the and Yield of Maize and Bean in Ferralitic Soils of Huambo Grow	20 April to 20 July
Hasanuzzaman Md. (BGD07018)	Bangladesh	Training in new developments in soil water and monitoring technology including field use of hydroprobes (Neutron probe) and Time Domain Reflectometry to estimate soil moisture under saline conditions The training requested is related to the IAEA TC project BGD5026	14 April to 14 September
Gebremariam Samuel Bereket (ERI08010)	Eritrea	(i) The use of N-15 stable isotope techniques to quantify the contribution of nitrogen by grain legumes in cereal-based cropping systems (ii) N-15 detection techniques and interpretation of data (iii) the use of the carbon isotope discrimination the use of the carbon isotope discrimination techniques to evaluate crop plants tolerant to drought conditions The training requested is related to the IAEA's TC project entitled: Improving Crop Productivity and Combating Desertification (ERI5004).	6 April to 6 July
Sintim Joshua Osei (GHA07007)	Ghana	(i) Training on soil water monitoring using neutron probe (ii) Soil water balance calculations - to bring soil water data from Ghana 5032 project as part of training (iii) Processing weather data - to bring weather data from Ghana 5032 project along The training requested is related to the IAEA's TC project entitled: Enhancing Production and Use of Cassava(GHA5032)	16 April to 16 July

Kwena Kizito (KEN09015)	Kenya	1. Group training on theory and practical exercises on biological nitrogen fixation (BNF), rhizobial technology and methods of estimating soil water status (the use of neutron moisture guages and other soil water measuring devices). 2. Integrated soil, water, and nutrient management using isotope and radiation techniques. These include (i) Field measurement using neutron probe and other relevant devices, (ii) Field quantification on the use of N15 and carbon-13 for nutrient dynamics and nitrogen and water use efficiencies. (iii) Field experiments on water and nutrient interaction. (iv) synthesizing current data on maize and bean from KARI. The training requested is related to the IAEA's TC project entitled: Assessing Nutrient and Moisture Use in Major Cropping Systems (KEN5030).	13 April to 13 July
Soumare Mahamadou (MLI08002)	Mali	On the use of soil moisture measuring techniques for better management for crop productivity in Mali. The training requested is related to the IAEA's TC project entitled: Sustainable Intensification and Diversification of Sorghum Production Systems in the Southern Zone of Mali, Phase-1(MLI5021).	14 April to 14 May
Collis Mukungurutse (ZIM08006)	Zimbabwe	(i) Safe handling of P-32 labelled materials and disposal of radioactive wastes; radiation protection and safety regulations. (ii) Basics training on the principles and practical applications of P-32 isotopic exchange kinetics technique to study soil P status, its changes with the use of P nutrient sources in glasshouse and control environment experiments. Training in techniques and methods of labelling plant material and the type of experiment required. Total P analyses and isotopic measurement of P-32 activities with a liquid scintillation counter in soil and plant samples; Application rates and mode of application of P-32 fertilizer. The training requested is related to the IAEA's TC project entitled: Combating Desertification in Agricultural Drylands (ZIM5011).	14 April to 14 July

7.2.Scientific Visitors

Name	Country	Period
Mr Nhantumbo, Alfredo	Mozambique	19-24 July 2009
Mr Hassan, Ahmad Ali	Bangladesh	10-14 August 2009
Mr Felix, Jean Fenel	Haiti	17-28 August 2009
Mr Abdul Razzaq, Ibrahim Bakry	Iraq	12-16 October 2009
Mr Razzaque, A.H.M.	Bangladesh	12-16 October 2009
Mr Toure, Sidi	Mali	2-6 November 2009
Mr Atawoo, Mohammad Alfaz	Mauritius	9-13 November 2009
Mr Chikwari, Emmanuel	Zimbabwe	10-20 November 2009

Figure 40 Soil samples collection and samples pretreatment performed by Instrumentation Unit (IU) fellows and SSU staff member in the frame of an IU and SSU collaborative trainnig

8. ABBREVIATIONS

CNESTEN = Centre national de l'énergie, des sciences et des techniques nucléaires (Morocco)

CP = Counterpart

CRP = Coordinated Research Project

CU = Chemistry Unit

CV = Coefficient of Variation

FRN = Fallout radionuclides

FSIC = Fine Soil Increment Collector

IITA = International Institute of Tropical Agriculture

MBM 2 = Mass Balance Model 2

MDA = Minimum Detectable Activity

PMO = Programme Management Officer

PT = Proficiency Test

RCM = Research Coordination Meeting

SD = Standard Deviation

SV = Scientific Visitor

SSU = Soil Science Unit

SWMCN = Soil Water Management and Crop Nutrition section

TCP = Technical Cooperation Project

TO = Technical Officer

Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

International Atomic Energy Agency
Wagramerstrasse 5
P.O. Box 100
A-1400 Vienna, Austria

Food and Agriculture Organization of the United Nations
Vial delle Terme di Caracalla
I-00100 Rome, Italy

http://www-naweb.iaea.org/nafa/index.html