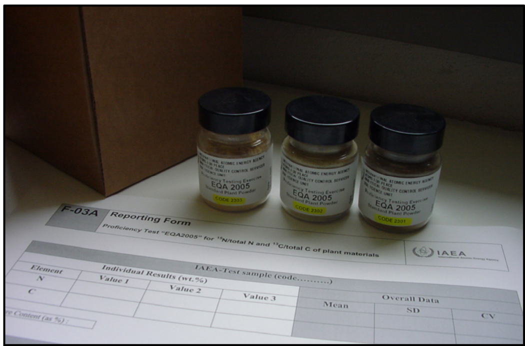
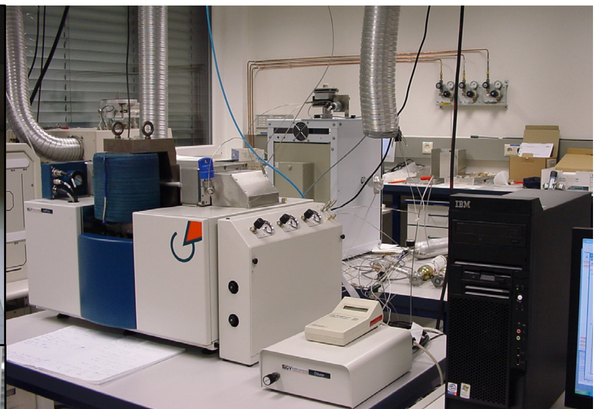
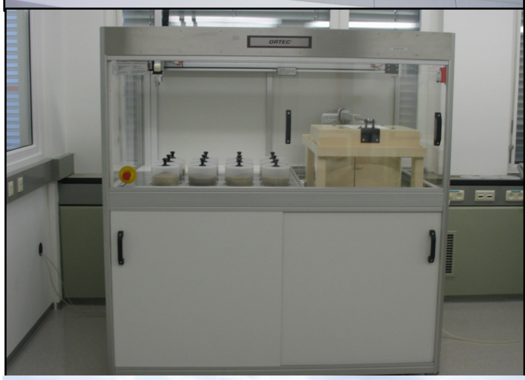
Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

# Annual Report 2005

## SOIL SCIENCE UNIT

**FAO/IAEA Agriculture & Biotechnology Laboratory**

**Agency's Laboratories, Seibersdorf, Austria**



# Executive Summary

The Soil Science Unit's main objective is to develop and apply nuclear-based techniques in improving the integrated management of soil, water, nutrient and cropping practices, with the aim of increasing agricultural productivity and sustainability in Member States. In this endeavour the Soil Science Unit and the Soil and Water Management & Crop Nutrition Section of the Joint FAO/IAEA Division continues to provide support to national institutes involved in agricultural production in developing Member States to use nuclear and related techniques to improve crop nutrition and water management of agricultural crops. The main emphasis of the Unit's research and development during 2005 was on the use of fallout radionuclides to measure soil erosion. Experiments were furthermore conducted on below ground nitrogen and the transfer of nitrogen fixed by leguminous crops to associated non-fixing crops as well as on abiotic stress, which will receive major emphasis in the future. The Unit implemented work in support of seven Coordinated Research Projects.

Research activities were conducted in the field of soil degradation/soil erosion, abiotic stress and below ground nitrogen transfer from legumes to non-legumes. Research projects using fallout radionuclides to quantify soil loss risks at the field and watershed scale in collaboration with the University of Natural Resources and Applied Life Sciences, Vienna (Austria) and Laval University (Canada) have been implemented. This work has included soil sampling and measurements in order to estimate the initial fallout of 137Cs.

In the future, the data obtained with Fallout RadioNuclides (FRN) methods will be compared to the conventional measurements of soil erosion (currently in process at the University of Natural Resources and Applied Life Sciences) at the watershed scale (modelling) and at the field scale (runoff measurements under different tillage systems and conservation practices).

The Unit trained 15 fellows from China, Ghana, Haiti, Iraq, Jamaica, Mongolia and Syria in the use of nuclear techniques for measuring crop nutrition and water management. A five-week Training Course was organised for eight fellows from Iraq with a CD-ROM produced with all lectures and presentations delivered during the course. All the training activities were implemented in support of Technical Cooperation Projects or Manpower Development in the mentioned countries.

The Soil Science Unit conducted 17 000 stable isotope measurements during 2005 for CRPs, TCPs and training and research activities of the Seibersdorf laboratory. The mass spectrometer room was renovated, furnished and all electrical and gas installations were renewed during the year. This was necessary because space for a new mass spectrometer and a preparation device had to be made available, and the mass spectrometer room with its 20-year-old installations and furniture was not suitable for that purpose.

The Unit implemented Proficiency Test "EQA2005" for the measurement of $^{15}$N- and $^{13}$C isotopic abundance and total nitrogen- and carbon concentration in plant materials**.** The principal aim of this Proficiency Test (PT) was the assessment of laboratory performance against established criteria, to assist participants in meeting the formal requirements, to monitor and demonstrate improvements in accuracy and precision in order to achieve international comparability of analytical data, and to demonstrate competence of the participating laboratory. The majority of the participating laboratories, i.e. 11 of 17 (65 %) showed proficiency in the analysis of plant materials for $^{15}$N abundance and 4 of 5 (80%) of the laboratories that have a mass spectrometer at their disposal and therefore the possibility to analyse $^{13}$C, showed proficiency in the analysis of plant materials for $^{13}$C abundance. Total nitrogen concentration was performed well by 13 of 17 laboratories (76 %) and total carbon element concentration by 4 of the 5 participants (80%).

Six publications were generated by the Unit during 2005 and the staff of the Unit received two awards for their publications;. Mr Lionel Mabit received the “Arnold-Drapeau Award” for the best scientific paper published in the journal “Vecteur Environnement”; and Mr Gudni Hardarson received the NA Departmental Award for the best Technical Report published in 2003. The Unit furthermore produced 4 fact sheets.

The Unit staff coordinated nine Technical Cooperation Projects in China, Kenya, Libya, Mongolia, Senegal, Sierra Leone, Slovenia, and Yemen.

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# 1. Introduction

## 1.1. Sub-Programme and Unit Objectives

The sub-programme involving the SSU and SWMCNS assists national institutions involved in agricultural production in developing countries to use nuclear and related techniques to develop integrated strategies and technologies for improving the efficiency of nutrient and water use by crops within selected cropping systems, while preserving the natural resource base (soil, water, biodiversity, etc.) and protecting the environment. The overall goal of the development and use of these novel technologies is a more profitable and sustainable agriculture, a secure food production and a healthier environment.

Currently the sub-programme is involved in:

- development of integrated plant nutrient and water management practices for increasing soil fertility and crop yields
- development of soil management and conservation practices for sustainable crop production and environmental protection
- identification and development of crop germplasm with superior resource use efficiency and nutritional value and adapted to harsh environments (jointly with the Plant Breeding and Genetics Section).

The Soil Science Unit of the FAO/IAEA Agriculture & Biotechnology Laboratory (ABL), Agency's Laboratories, Seibersdorf, assists in the development and transfer of nuclear techniques to Member States with the main objective of adopting these techniques for optimising soil, water and nutrient management practices in cropping systems, which support increased and sustainable crop production.

Nuclear techniques used in the field of Soil Fertility and Water Management complement conventional techniques, and provide unique information which other techniques cannot, e.g.

- Quantitative information on the flow and fate of fertiliser in soils and uptake of nutrients by plants to identify efficient fertiliser management practices
- Identification of sources of soil water and their availability to plants
- Identification of sources of soil carbon and estimation of the contribution of organic sources to crop nutrition
- Measurement of biological nitrogen fixation
- Measurement of soil erosion

The main roles of the Soil Science Unit are to:

- react to the priority needs of developing countries in terms of soil fertility, water management and soil conservation and develop research and training programmes for developing Member States,
- develop and validate nuclear methods for the use in Co-ordinated Research Programmes and Technical Co-operation Projects of the FAO/IAEA,
- train technical staff and scientists from Member States in the analyses of stable isotopes and the use of nuclear and related techniques,
- provide isotope analyses to projects where analytical facilities are not available,
- provide quality assurance services to Member States.

## 1.2. Staff of the Soil Science Unit and staff changes

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**Joint FAO/IAEA Programme of Nuclear Techniques in Food and Agriculture**

### FAO/IAEA Agriculture & Biotechnology Laboratory

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| Erik BUSCH-PETERSEN | Laboratory Head | e.busch-petersen@iaea.org | 28267 |

### Soil Science Unit

| Name | Title | E-mail | Extension |
|---|---|---|---|
| Gudni HARDARSON, Head of the Unit | Soil Microbiology, Plant Nutrition | g.hardarson@iaea.org | 28277 |
| Lee K. HENG | Soil Physics (contract completed in 2005) | | |
| Lionel MABIT | Soil Scientist (joined the Unit in March 2005) | l.mabit@iaea.org | 28271 |
| Martina AIGNER | Senior Laboratory Technician (50%) | m.aigner@iaea.org | 28212 |
| Leopold MAYR | Senior Laboratory Technician | l.mayr@iaea.org | 28305 |
| José Luis ARRILLAGA | Senior Laboratory Technician | j.l.arrillaga@iaea.org | 28306 |
| Maria HEILING | Senior Laboratory Technician (50%) | m.heiling@iaea.org | 28272 |
| Stefan BOROVITS | Laboratory Technician | s.borovits@iaea.org | 28304 |
| G4 position | Laboratory Technician (open) | | |
| Christine FICKER | Laboratory Attendant (retirement 2005) | | |
| Josef SEUFZENECKER | Temporary Assistant (6 months in 2005) | | |
| Elisabeth SWOBODA | Secretary | e.swoboda@iaea.org | 28281 |

**Mr. Lionel Mabit** joined the Soil Science Unit of the Agency's Laboratories Seibersdorf in March 2005 as a soil scientist directly linked to the FAO/IAEA project E.1.02 on "Development of soil management and conservation practices for sustainable crop production and environmental protection". Mr. Mabit will be particularly involved in research and training on soil erosion, in support to the soils subprogramme and the related activities. Mr. Mabit's background is in geology, hydrology and physical geography. He completed his Ph.D. at the Sorbonne University in Paris, France. The thesis was entitled "Assessment of soil erosion by the $^{137}$Cs methods. Application to the Vierzy (France) and Lennoxville (Canada) watersheds". Before joining the IAEA, Mr. Mabit worked as soil scientist in soil erosion at Laval University, in Canada. His main areas of research expertise include soil and water quality assessment, geostatistical analysis and soil mapping, soil fertility, soil erosion and sediment budget at a range of scales (plot, field, watershed) using various tools such as fallout radionuclides (e.g., $^{137}Cs$, $^{134}Cs$), rainfall simulator, models and GIS.

**Ms Lee Heng** has left the IAEA for FAO, in Rome, after more than 7 years with the Soil Science Unit. Lee joined the FAO/IAEA programme in May 1998. She brought with her an excellent background in soil physics and experience in irrigation, water management and modeling. Her work for the IAEA was in particular to perform research on the use of nuclear techniques in irrigation and water management and she coordinated several IAEA publications including the following: Water Balance and Fertigation for Crop Improvement in West Asia. IAEA-TECDOC-1266; Deficit Irrigation Practices, Water Reports 22; Comparison of Soil Water Measurement Using the Neutron Scattering, Time Domain Reflectometry and Capacitance Methods, IAEA-TECDOC-1137; Nutrient and Water Management Practices for Increasing Crop Production in Rainfed Arid/Semi-Arid Areas IAEA-TECDOC-1468. Lee trained 17 fellows at the Seiberdorf Laboratory and organised an inter-regional training course as technical officer for 18 participants on water management at the Laboratory in 2003 and training workshops in several Member States. Lee also coordinated national (Libyan Arab Jamahiriya, Sierra Leone, Yemen, Uzbekistan) and regional (West-Asia and Europe) TCs on water management. Some excellent results have been reported from these projects both in previous newsletters and in external publications. Lee will be working for the FAO for the next 6 months on water productivity, crop-water relations and modeling. We thank Lee for her excellent work for the FAO/IAEA and wish her all the best for the future.

**Ms Christine Ficker** retired after more than 30 years as a laboratory attendant for the Soil Science Unit (SSU). Christine performed excellent work in the maintenance of greenhouse and field experiments and sample preparation and assisted professional staff at the SSU with laboratory services for the training of IAEA fellows. We thank Christine for her contribution to FAO/IAEA projects and wish her all the best for the future.

## 1.3. SSU & Working Groups (WG)

With the changes occurring in the Soils sub-programme and the additional emphasis on water management, soil conservation and abiotic stress it was found necessary to form new working groups (WG) at the Soil Science Unit to be able to support these future activities. The staff has been allocated to the various groups with some of them serving in two groups.

WG 1) Working Group on Soil Conservation (Erosion)

Mr Lionel Mabit and G4 staff (open) will be working full time in this area using newly purchased gamma counter and working closely with the Chemistry Unit at the Laboratory.

WG 2) Working Group on Water Management and Modelling.

Ms Lee Heng, Mr Jose Luis Arrillaga and Ms Christine Ficker.

WG 3) Working Group on Abiotic Stress and Crop Nutrition

Ms Lee Heng, Mr Gudni Hardarson, Ms Maria Heiling (part time) and Ms Christine Ficker.

WG 4) Working Group on Isotope Analyses

Mr Leo Mayr, Mr Jose Luis Arrillaga, Mr Stefan Borovits and Mr Josef Seufzenecker.

WG 5) Working Group on Quality Assurance

Ms Martina Aigner (part time) and Mr. Leo Mayr.

# 2. Research and development

## 2.1. Study of erosion processes using radioisotopes

Because of the scarcity of arable land and continuously degrading quality of water, conservation of soil and water resources is a major concern in the context of sustainable agriculture and environment. Runoff and associated water erosion is a major vector of non-point source pollution and constitutes the principal way of conveying sediments and agricultural nutriments towards hydrosystems and thus contribute to water quality degradation.

Erosion is the end-result of a combination of several processes and before new management practices are proposed to land owners to solve their problem, the latter must be well documented in terms of extension: field, farm or watershed. Water erosion studies which began during the first half of the twentieth century, have commonly involved conventional sediment loading measurement at spatial scales ranging from micro-plots to large-sized plots (under simulated or natural rainfall) and more recently at watershed scale. Assessing the severity and spatial extent of soil erosion over large areas is no easy task. Soil movement mapping, at scales exceeding fields, is complex. If rills and gullies can be easily located, and their volumes estimated, more diffuse processes, like sheet erosion, are difficult to assess. The monitoring has to be repeated regularly, and thus, the results are representative of the record period only. Rills can also be erased by tillage operations. Investigations on the relationships between agrosystems and hydrosystems raise many methodological problems. Besides, traditional monitoring techniques, water levels and quality measurements in small watersheds, require many years of measurements to integrate the inter-annual variability of precipitation erosivity, soil erodibility and effect of cropping practices. These measurements generate sediment production figures, but give no information on the spatial origin of these sediments or on the processes at the origin of the solid loads. More recently, Caesium-137 was shown as an effective means of quantification and spatialization of erosion. $^{137}$Cs (half-life : 30.12 years) is a radioisotope that was artificially introduced in the environment through the extensive high-atmosphere bomb tests that took place in the 1950s and 1960s. Due to its environmental behaviour in soils, this isotope is a particularly interesting soil movement indicator. Its spatial redistribution reveals global soil movements that were initiated some 40 years ago.

The rates and spatial extent of soil loss and deposition areas can be established, and soil movement budgets are easily estimated, at scales ranging from small plots to watersheds. Generally, soil movements are estimated by comparing the activity of $^{137}$Cs of cultivated soils to that of so-called reference sites assumed to be uneroded. This technique is useful to quantify, spatialize and map net soil movements.

In order to support the CRP D1.50.08 "Assess the effectiveness of soil conservation measures for sustainable watershed management using fallout radionuclides" studies using $^{137}$Cs to quantify soil loss risks at the watershed scale have been initiated with institutes in Member States and are being developed in collaboration with the University of Natural Resources and Applied Life Sciences, Department of Water, Atmosphere and Environment, Institute of Hydraulics and Rural Water Management, Vienna, Austria).

## 2.2 Assessment of erosion using $^{137}$Cs and a GIS oriented sampling strategy

Due to the scarcity of good quality arable land and the poor quality of water in rural areas in Quebec, conservation of soil and water resources is a major concern, in a context of sustainable agriculture and environment. The selected area for the present study, the Boyer River watershed, covers 217 $km^2$ and a part of it is under intensive agriculture. The spawning of Rainbow Smelt (*Osmerus mordax*) in the last two km of the river gradually declined and completely disappeared at the beginning of the 1980's. Eutrophication linked to increasing concentrations of nutrients and transport of fine sediments from the basin, is directly associated with this disappearance. Runoff, and then water erosion, is the principal vector of non-point source pollution and constitute the main way of conveying sediments and agricultural nutrients towards hydrosystems, leading to water quality degradation.

The study's objectives were to quantify and map the magnitude of erosion risks in the Boyer River watershed, using an approach based on $^{137}Cs$ measurements.. It was also planned to estimate the origin and magnitude of sediment production in the river system, so that appropriate conservation practices could be targeted.

**Study area and watershed sampling strategy**

The Boyer River drains a 217 km2 territory located on the right bank of the St. Lawrence River, approximately 30 km to the east of Quebec City (Figure 1). A river system density of 1.5 km/km² and a mean annual water flow at the outlet of 4 m3 s-1 have been measured. The basin is subdivided in four sub-basins: Boyer (74 km2), Portage (21 km2), North-Boyer (55 km2), South-Boyer (67 km2) (Figure 1).The climate is humid continental (cool summers and cold snowy winters) with an average annual precipitation of 1100 mm and a growing season between 120-150 days. The topography is complex. The total relief is 300 m. Soil textures range from clay loams to sandy loams, argillaceous on the edges of the river and its tributaries and rather sandy in the upstream part of the basin.

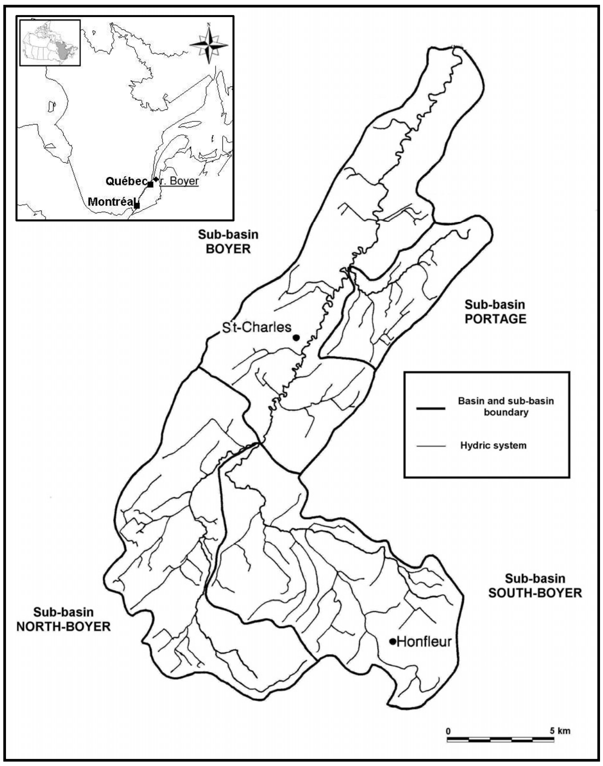


**Fig.1. Location of the Boyer River**

There are some 275 farm operations in the watershed, for 23 055 animal units. Pig farming dominates with 55% of animal units. Dairy farming follows, with 38% of the animal production. Land use is mainly arable and forest covers the remaining 44% of the area (50% maple bush, 35% mixed forest and 15% coniferous). Dairy farming, characterized by pasture and hay production, dominates the downstream half of the basin. The upstream (Northern and Southern Boyer) is characterized by a more intensive agriculture with a larger proportion of annual crops.

Using the Geographical Information System IDRISI (Eastman, 1993)[1], the Boyer River watershed was divided into isosectors according to topography and soil texture, based on topographic and pedological maps and compilation of background information and field reconnaissance.

Three soil texture classes are found in the watershed: loam, sandy loam and sandy clay loam. Two slope classes were defined following the terminology of the Canadian System of Soil Classification (1998)[2].

1 Eastman, J.R., 1993. IDRISI Version 4.1 Update Manual. Worcester, MA: Clark University Graduate School of Geography. 211 pp.

Six different isosectors were thus defined (Figure 2), i.e. five sectors with a soil-slope combination and forest cover. Forests were considered as an isosector since they cover 44% of the watershed area and the fact that their sedimentary budget was considered as: ± 0 t $ha^{-1}$ $yr^{-1}$. The respective area of each isosector was calculated for each sub-basin with the GIS. Sandy loams with a slope > 2% cover 4.6% of the surface, loams with a slope > 2%, 15.7%, loams with a slope < 2%, 3.2%, sandy loams with a slope < 2%, 20.5% and sandy clay loams with a slope < 2%, 12%.

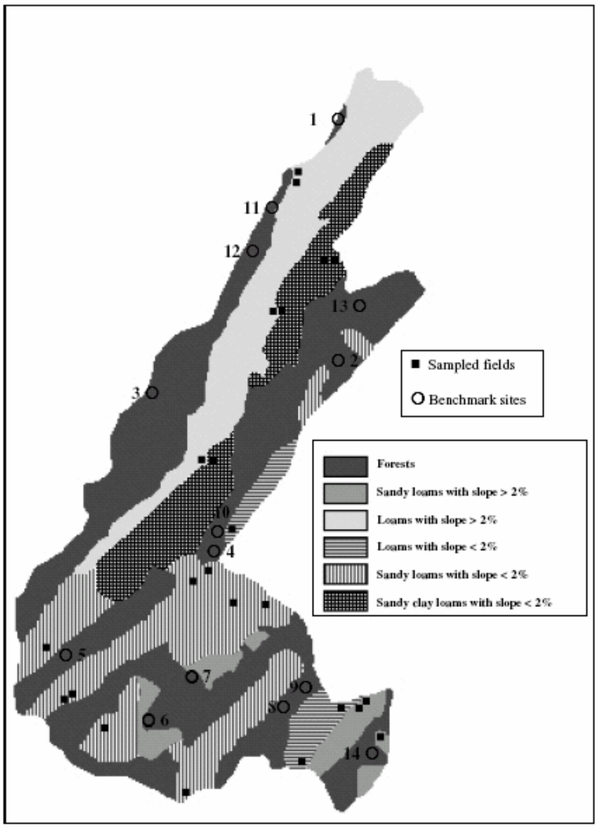


**Fig. 2. Fields and reference sampled sites according to the isosectors**

A minimum of three representative agricultural fields was sampled for $^{137}Cs$ in each isosector (except forest), on a variable grid basis. Sediment budgets (gross and net soil loss, deposition) were calculated for each field, based on the $^{137}Cs$ results. A net sediment production value was calculated for each isosector on the basis of the sampled fields results. A total sedimentary assessment for the watershed was established by taking into account the six isosectors, including the forest area.

Overall, twenty-four agricultural fields (24) were sampled to evaluate the soil movement magnitude as well as 14 undisturbed forest sites, to evaluate the initial fallout of radiocaesium (Figure 2).

A total of 412 points were sampled in the 24 cultivated fields that were investigated, for a total of 1236 cores. $^{137}Cs$ was determined using the procedure of de Jong et al. 1982[3]. Net soil displacements, either loss or deposition, were estimated with the Simplified Mass Balance Model (SMBM) (Mabit et al., 2002)[4]. For each field, a sediment budget (eroded, stable and deposition areas) was produced using the SURFER 8 package (Golden software, 2002)[5].

**Statistic and base level $^{137}$Cs activity**

The $^{137}Cs$ activity of the fourteen (14) forested sites ranged from 1622 to 3697 Bq $m^{-2}$. The average value reached 2780 ± 300 Bq $m^{-2}$, (mean ± 95% confidence interval) with a coefficient of variation (CV) of 21 %. The results of the vertical distribution of the $^{137}Cs$ show an exponential decrease of the $^{137}Cs$ activity with depth, with an average concentration of 9.0 Bq $kg^{-1}$ in the 0-20 cm layer.

The 412 composite samples were classified into six classes of soil movement. Soil movements ranged from – 39 t $ha^{-1}$ $yr^{-1}$ to + 21 t $ha^{-1}$ $yr^{-1}$ with an average of – 4.9 t $ha^{-1}$ $yr^{-1}$. Of the 412 samples,

2 Canadian System of Soil Classification (third edition), 1998. Soil Classification Working Group. Agriculture and Agri-Food Canada Publication 1646, 187 pp.

3 de Jong, E., Villard, H. and Bettany, J.R., 1982. Preliminary investigations on the use of 137Cs to estimate erosion in Saskatchewan. Can. J. Soil Sci. 62:673–683.

4 Mabit, L., Bernard, C. and Laverdière, M.R., 2002. Quantification of soil redistribution and sediment budget in a Canadian watershed from fallout caesium-137 (137Cs) data. Can. J. Soil Sci. 82(4):423–431.

5 Golden Software., 2002. Surfer 8. Contouring and 3D Surface Mapping for scientists and Engineers. User's guide. Golden Software, Inc. 640 pp.

302 indicated an average soil loss of 9 t $ha^{-1}$ $yr^{-1}$. The other 110 samples were considered as having experienced soil accumulation with an average of 6.4 t $ha^{-1}$ $yr^{-1}$. It appears that under short rotations, erosion situations are more frequent and with higher loss rates. Long rotations also involve losses, which are however compensated by higher frequencies and rates of material deposition. This translates into an average loss of 5.4 t $ha^{-1}$ $yr^{-1}$for short rotations. For long rotations, the average loss is 40% lower, with a rate of 3.3 t $ha^{-1}$ $yr^{-1}$.

**Agricultural fields results by isosectors and sub-basins**

The net sediment production for the 24 individual fields that were sampled for $^{137}Cs$ ranged from a minimum of 0,1 t $ha^{-1}$ $yr^{-1}$ to a maximum of 12.9 t $ha^{-1}$ $yr^{-1}$. The average production was 5.2 t $ha^{-1}$ $yr^{-1}$ with a standard deviation of 3.7 t $ha^{-1}$ $yr^{-1}$.

These results are consistent with those obtained for fields from dairy and horticultural farm on Orleans Island, in Quebec, from $^{137}Cs$ data (Bernard and Laverdière, 1992)[6]. The 63 sampled fields in that study showed an average net soil loss of 11 t $ha^{-1}$ $yr^{-1}$ under annual crops and 3 t $ha^{-1}$ $yr^{-1}$ on dairy farms with long rotations including hay production for 3 to 5 years. Still in Quebec, annual erosion rates lower than 0.5 t $ha^{-1}$ $yr^{-1}$ under a permanent forage cover, from 0.5 to 17 t $ha^{-1}$ $yr^{-1}$ under cereals or corn and between 6 and 13 t $ha^{-1}$ $yr^{-1}$ for potato were measured on conventional erosion plots (Pesant et al., 1987)[7]. The results of the five isosectors (texture-slope combination) were used to estimate a sediment production at the watershed scale. This was done by multiplying the average sediment production rate for each isosector by the area covered by this isosector in the watershed. The results are presented in Table 1.

**Table 1. Sediment budget for the different Boyer River isosectors.**

| Soil texture | Slope | Area of sampled fields | Area of isosector | Net sediment production from sampled fields | Net sediment production for each isosectors | Fraction of sediment production |
|---|---|---|---|---|---|---|
| | (%) | ha | ha | t $ha^{-1}$ $yr^{-1}$ | t $yr^{-1}$ | % |
| Sandy loam | > 2 | 33.5 | 1070 | 5.5 | 5 489 | 9.0 |
| Sandy loam | < 2 | 45.6 | 4610 | 5.0 | 22 245 | 36.6 |
| Loam | > 2 | 9.6 | 3310 | 6.9 | 23 508 | 38.7 |
| Loam | < 2 | 15.5 | 700 | 3.6 | 2 498 | 4.1 |
| Sandy clay loams | < 2 | 14.9 | 2580 | 2.7 | 7 031 | 11.6 |
| Total | | 200.9 | 12270 | | 60771 | 100 |

Loam soils with a slope higher than 2% generate the highest sediment rate (6.9 t $ha^{-1}$ $yr^{-1}$) and nearly 40% of the global sediment production. Sandy loams with slopes lower than 2% exhibit a sediment production rate of 5 t $ha^{-1}$ $yr^{-1}$ and the second largest sediment contribution, with 36.6% of the total. Sandy loams with slopes higher than 2% show a similar rate of sediment production. However, the small area they cover translate into a low contribution to the overall sediment

6 Bernard, C. and Laverdière, M.R., 1992. Spatial redistribution of Cs-137 and soil erosion on Orléans Island, Québec. Can. J. Soil Sci. 72:543–554

7 Pesant, A.R., Dionne, J.L. and Genest, J., 1987. Soil and nutrient losses in surface runoff from conventional and no-till corn systems. Can. J. Soil Sci. 6:835–843.

production (9%). The sediment production could also be calculated on a sub-basin basis, by calculating, with the GIS, the area of the five isosectors included in each of the four sub-basins. The average sediment production rate of each isosector was multiplied by the area of this isosector in each sub-basin. For each sub-basin, the sediment production was summed over the five isosectors to generate a total sediment production by sub-basin. This value was divided by the area of the sub-basin, to produce an average sediment production rate for the whole sub-basin. The results are presented in Table 2. The Boyer sub-basin has the highest rate, with 3.6 t $ha^{-1}$ $yr^{-1}$. The Portage sub-basin has the lowest, with less than 1 t $ha^{-1}$ $yr^{-1}$. A soil vulnerability index, reflecting the relative importance of erosive crops, was calculated for each sub-basin. Table 2 shows that the average sediment production rate of each sub-basin is related to the magnitude of its soil vulnerability index.

**Table 2. Net sub-basins sediment production.**

| | Sub-basins | | | |
|---|---|---|---|---|
| | Boyer | Portage | Northern Boyer | Southern Boyer |
| Forest (ha) | 2490 | 1680 | 2660 | 2610 |
| Sandy loam, Slope > 2% (ha) | 0 | 0 | 180 | 890 |
| Sandy loam, Slope < 2% (ha) | 0 | 250 | 1990 | 2370 |
| Loam, Slope > 2% (ha) | 3060 | 0 | 250 | 0 |
| Loam, Slope < 2% (ha) | 210 | 0 | 0 | 490 |
| Sandy clay loams, Slope < 2% (ha) | 1640 | 170 | 430 | 340 |
| Net sediment production (t $ha^{-1}$ $yr^{-1}$) | 3.6 | 0.8 | 2.3 | 2.2 |
| Soil Vulnerability Index † | 0.20 | 0.03 | 0.15 | 0.19 |

*† SVI = % Erosive crops / (% Forage + % Forest).*

**Sediment budget for the Boyer River watershed**

A total sediment assessment was established by taking into account the various isosectors, including forest surfaces. The net sediment production for the Boyer River is estimated at 2.8 t $ha^{-1}$ $yr^{-1}$. This represents an annual export of 60 771 t of material from the watershed towards the St. Lawrence River. Globally, 28% of the cultivated lands of the Boyer River watershed experienced erosion rates higher than 6 t $ha^{-1}$ $yr^{-1}$, the suggested soil loss tolerance level for most Canadian soils. Another 45% of the cultivated area is near this limit. The isosectors loams with slopes higher than 2% and sandy loams with slopes lower or higher than 2% are the most vulnerable ones. The erosion rates and net sediment output, as estimated in this study using a GIS and $^{137}Cs$ data, are similar to the results from Landry (1998)[8] who estimated a net sediment production of 3 t $ha^{-1}$ $yr^{-1}$ using the USLE.

Using a "fingerprinting" technique based on sediment and sources material properties measurements, it was then estimated that 75% of the bottom sediments would originate from the cultivated fields and that the banks would produce the other 25%. Therefore, it seems that the sediments come essentially from the cultivated areas, so it is important to control soil erosion at the field level to reduce sediment losses and eutrophication problems at the watershed level.

**Conclusion**

The quantitative and qualitative degradation of the soil and water resources of the Boyer River watershed are directly linked with intensive and specialized agricultural developments. This study shows that it is possible, through a sampling strategy prepared under a GIS oriented sampling strategy, to use $^{137}Cs$ measurements to estimate sediment budget at the scale of a 217 $km^2$ watershed. For the Boyer River watershed, the net sediment output was estimated at 2.8 t $ha^{-1}yr^{-1}$.

8 Landry, I., 1998. Analyse par géomatique des bilans et des flux d'azote et de phosphore dans un bassin versant agricole: le cas de la rivière Boyer. Rapport de Maîtrise. Université du Québec, INRS-Eau. 139 pp.

The study also highlights sediment budget assessment for isosectors and sub-basins. Approximately 50% of the agricultural basin surface is affected by erosion rates approaching or exceeding the tolerable level of 6 t $ha^{-1}yr^{-1}$. In addition to soil/slope combinations, land use plays a major role. Data from the 24 sampled fields revealed that net sediment output of fields under short crop rotation is almost three times higher than that of fields under long crop rotation.

Data obtained at the field and watershed level are useful in determining the appropriate management technologies of land and water resources at different scales. For the Boyer River basin, soil erosion control, in combination with limitations of the phosphorus inputs on crops, must ensure the durability of soil and water resources. Reduced disturbances of aquatic systems, through prevention of nonpoint pollution upstream, will support the sustainability of soil and water resources. In the case of the Boyer River, water quality improvement is certainly a first step towards the rehabilitation of the Rainbow Smelt habitat in the Boyer River.

This study was initiated under the joint CRP on *Assessment of soil erosion through the use of $^{137}$Cs and related techniques as a basis for soil conservation, sustainable agricultural production and environmental protection* and on *Sediment assessment studies by environmental radionuclides and their application to soil conservation measures,* and finalised in support of the E1.02 project on *Development of soil management and conservation practices for sustainable crop production and environmental protection* of the Joint FAO/IAEA Programme of Nuclear Techniques in Food and Agriculture. This study has been submitted in full form to CATENA.

## 2.3 Preliminary test of $^{134}$Cs as soil erosion tracer under rainfall simulation

Soil erosion processes may be estimated from $^{137}$Cs spatial redistribution data. Relationships between radioisotope distribution and soil losses have been validated and used in many locations around the world. However, estimations of soil movement from residual $^{137}$Cs may overestimate net loss and underestimate net deposition if the selectivity of erosion is not taken into consideration. In order to investigate this aspect, experimental erosion tests were conducted under controlled conditions in a greenhouse with $^{134}$Cs-labelled soil and using rainfall simulator.

Twenty 0.35 $m^2$ boxes were filled with a loamy soil and placed on a 5 % slope. The soil of the boxes was labelled by a surface application of $^{134}$Cs. This isotope was selected because it shows the same physical and chemical behaviour in soils as $^{137}$Cs. Once applied, the radiocaesium was incorporated in the first 5 cm of soil. Ten boxes received 7100 Bq (20285 Bq $m^{-2}$) of $^{134}$Cs and the other ten, twice this amount. At the downslope and of each experimental plot, a S-shaped stainless steel ramp was placed in such a way to force deposition of some part of the suspended load leaving the plots. Eroded sediments leaving the plots, those deposited on the ramp and those leaving the ramp could thus be sampled, analysed and compared to the source material they originated from. A GRS-II type rainfall simulator was used to generate runoff and erosion from the plots. Three successive 80 mm $hr^{-1}$ were applied with a delay of 24 hours between each event. The first rain was for 30 minutes, the two other lasted 20 minutes. Radiocaesium measurements on soil and sediment samples were performed using a high purity coaxial germanium detector with a relative efficiency of 26 % and resolution of FWHM of 1.8 keV at 1.3 MeV. Counting times ranged between 7 000 and 50 000 seconds, to produce an error smaller than 10 % at the 0.05 significance level. All the values were adjusted to a common date of 30 January 2002. Some 200 samples were thus counted, 180 sediment samples and 20 soil samples.

For the twenty experimental plots, individual runoff coefficients ranged between 75 and 83 % and soil losses varied from 0.94 to 1.24 Mg $ha^{-1}$. The $^{134}$Cs concentration of the plot soils, in the first 5 cm, varied from 90 to 345 Bq $kg^{-1}$.

For each simulated rainfall, the results indicate that the quantities of $^{134}Cs$ exported represent approximately 1 % of the initial inputs. Moreover, for the same soil loss, the loss of $^{134}Cs$ was directly proportional to the initial soil activity. Losses from plots having received 14200 Bq of radiocaesium produced sediments that showed a $^{134}Cs$ concentration 2 to 2.8 times that of the plots receiving 7100 Bq.

On the sediments eroded from the plots, the concentration was between 590 and 7550 Bq $kg^{-1}$. This translate into an average enrichment ratio (concentration on sediments divided by that on plot soils) of 16. The sediments that deposited on the flat section of the ramp showed a higher content in large particles, when compared to sediments eroded from the plots. This translated into lower radiocaesium concentrations and lower enrichment ratios. At the opposite, the sediments leaving the downslope portion of the ramp were strongly enriched in fine particles. This was reflected by $^{134}Cs$ concentration that were, on the average, 23 times higher than on plot soils.

These preliminary results indicate that $^{134}Cs$ can be used for erosion studies. They also show that enrichment ratios of eroded sediments can be quite high and that this enrichment effect must be considered when comparing eroded material to the soil it originates from.

*NB: This study was initiated in collaboration with Laval University (Canada)*

## 2.4 Transfer of nitrogen from alfalfa to ryegrass in a mixed sward

Pastures occupy more than 2000 million ha in developing countries. In most cases no fertilizer is applied and therefore nitrogen fixation by legumes, animal manure and atmospheric deposition are the only nitrogen sources. Losses may occur through grazing, leaching of nitrate, runoff, denitrification and volatilization.

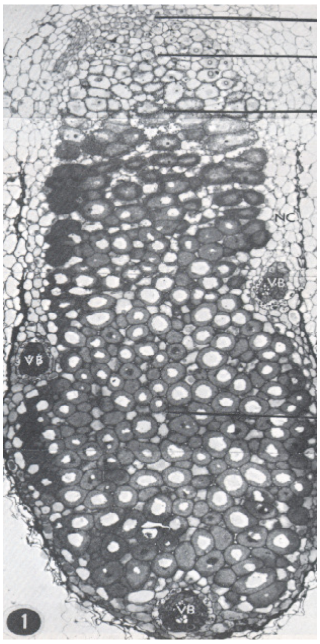

**Fig. 1. Section of an effective alfalfa nodule. (Vance, Johnson and Hardarson, 1980[9])**

Pasture legumes are known for its effectiveness, shown by the nodules which are packed with rhizobia (Figure 1) and as measured in several FAO/IAEA projects (Figure 2). Pasture legumes furthermore provide the basis for developing sustainable farming systems.

To quantify the benefit in pasture and to understand the transfer of nitrogen from fixing to non-fixing plants the indirect labeling technique was used in the past at the Agency's Laboratories, Seibersdorf (Hardarson et. al 1988)[10]. This report showed a possible transfer from alfalfa to ryegrass. The largest proportion or amount of ryegrass N that could have been transferred from alfalfa in this study was 16% or 4 kg N $ha^{-1}$.

It was concluded that the transfer from the alfalfa to the associated ryegrass crop occurred mainly after the senescence of roots and nodules.

The objective of the present study was to measure the below ground transfer of N from nitrogen fixing alfalfa to the associated ryegrass crop using the direct $^{15}N$ labeling method. A mixed sward of alfalfa and ryegrass was grown under greenhouse conditions on two different soil types. Both soils (Mauerbach, 0.077% N and Seibersdorf, 0.21% N) were mixed with sand in a ratio of 2:1. Each large pot was filled with aliquots of 45 kg of each mixture. The pots were without holes to avoid any leaching. A mixture of alfalfa and ryegrass was planted to six replicated pots, i.e. 0.27g alfalfa seeds and 0.13 g ryegrass seeds / pot. The pots were watered to 75% of field capacity. For optimal watering, TDRs were used to monitor water content. All legumes were inoculated with *Rhizobium meliloti* strains 59-102F51

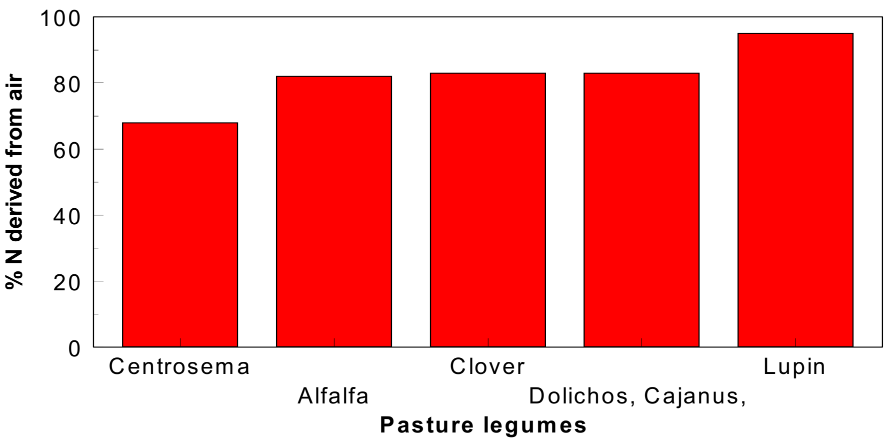


**Fig. 2. Nitrogen fixation in several pasture legumes as measured by field evaluations in several developing countries using N-15 methodology (Hardarson and Atkins, 2003[11])**

9 Vance, Johnson and Hardarson, 1980 Histological comparison of plant and Rhizobium induced ineffective nodules in alfalfa. Physiological Plant Pathology. 17, 167-173

10 Hardarson G., Danso S.K.A. and Zapata F. (1988) Dinitrogen fixation measurements in alfalfa-ryegrass swards using nitrogen-15 and influence of the reference crop. Crop Science, Vol. 28:101-105.

11 Atkins C and Hardarson G (2003) Optimising biological N2 fixation by legumes in farming systems. Plant and Soil 252, 41-54.

and 235-L34, applied in liquid form.

To quantify biological nitrogen fixation (BNF), two replicates per soil type were labelled with ammonium sulphate solution (10.12% $^{15}N$ atom excess, containing 5mg N $kg^{-1}$) after the second cut. In the remaining pots three alfalfa plants per pot were stem labelled using 94.4% $^{15}N$ atom excess enriched urea with a concentration of 0.075M to observe transfer below ground to the adjacent unlabelled plants.

Two months after stem labelling the crops were harvested, i.e. the labelled plants as well at the alfalfa and ryegrass in 3cm and 6cm distance from the labelled plant. The alfalfa and ryegrass were separated, dried at 70 °C. The atom % $^{15}N$ and total nitrogen were determined using the Isotope Ratio Mass Spectrometer, coupled to an elemental analyzer.

As the yield of the alfalfa was much larger than the yield of the ryegrass, the amount of $^{15}N$ was proportionally higher in the alfalfa. To compensate the area of the two harvested rings, the amount of $^{15}N$ per $cm^2$ was calculated (Table 1). Most of the applied $^{15}N$ was transferred to the alfalfa located close to the labelled plant. This was observed in both soil types. The transfer to ryegrass was higher in the nitrogen limited Mauerbach soil, were the yield of both pasture plants varied less than in the Seibersdorf soil.

**Table 1: $^{15}$N and total nitrogen recovery by alfalfa and ryegrass grown adjacent to a stem labelled alfalfa plant. The experiment was done in two different soil types.**

Seibersdorf soil

| Crop and distance from labelled plant | %$^{15}$N exc. | yield [g] | µg $^{15}$N | proportion % | µg N15/cm$^2$ | proportion % | proportion without labelled alfalfa % |
|---|---|---|---|---|---|---|---|
| Alfalfa 0-3cm | 0.16 | 4.19 | 174.01 | 6.75 | 6.15 | 0.2731 | 95.17 |
| Alfalfa 3-6cm | 0.02 | 3.09 | 11.93 | 0.46 | 0.14 | 0.0062 | 2.17 |
| Ryegrass 0-3cm | 0.10 | 0.17 | 2.91 | 0.12 | 0.10 | 0.0046 | 1.59 |
| Ryegrass 3-6cm | 0.05 | 0.81 | 5.83 | 0.24 | 0.07 | 0.0030 | 1.06 |
| Labelled alfalfa | 3.22 | 2.49 | 2246.79 | 92.44 | 2246.79 | 99.7130 | |

Mauerbach soil

| Crop and distance from labelled plant | %$^{15}$N exc. | yield [g] | µg $^{15}$N | proportion % | µg N15/cm$^2$ | proportion % | proportion without labelled alfalfa % |
|---|---|---|---|---|---|---|---|
| Alfalfa 0-3cm | 1.07 | 1.12 | 5.51 | 14.76 | 5.51 | 0.5334 | 84.58 |
| Alfalfa 3-6cm | 0.03 | 1.49 | 0.10 | 0.71 | 0.10 | 0.0093 | 1.48 |
| Ryegrass 0-3cm | 0.27 | 0.61 | 0.53 | 1.14 | 0.53 | 0.0513 | 8.13 |
| Ryegrass 3-6cm | 0.22 | 1.01 | 0.38 | 2.56 | 0.38 | 0.0366 | 5.81 |
| Labelled alfalfa | 8.58 | 0.94 | 1026.62 | 80.83 | 1026.62 | 99.3694 | |

Most of the $^{15}N$ tracer remained in the stem labelled plant, i.e. 92 and 81 % in the ones grown in Seibersdorf and Mauerbach soils, respectively. Nitrogen was mostly transferred to the alfalfa growing close to the labelled plant with 7 and 15% of the tracer found in alfalfa grown at 0 to 3 cm distance from the labelled alfalfa. Ryegrass grown at 0 to 3 cm distance from the labelled alfalfa received only a very small proportion of the tracer also due to the much lower yield of that crop. Some measurable amounts of the $^{15}N$ was transferred to alfalfa or ryegrass grown 3 to 6 cm from the labelled alfalfa but this was again much lower than to the crops grown closer to the labelled plant.

In the nitrogen deficient Mauerbach soil more of the $^{15}N$ label was recovered in ryegrass (8.13% in 0-3 cm distance, 5.81% in 3-6cm distance) as compared to the Seibersdorf soil. In Seibersdorf soil a higher transfer to the further alfalfa (2.17% in 3-6cm) was observed, compared to the ryegrass (1.59% in 0-3cm and 1.06% in 3-6cm).

The results clearly illustrate direct transfer of N from fixing to both adjacent fixing and non-fixing crops, a characteristic which can be of major importance in pasture management.

## 2.5. The relationships between transpiration, transpiration efficiency, fraction transpirable soil water (FTSW) and carbon isotope discrimination

Water scarcity results in huge reductions in crop yield and is one of the greatest limitations to crop productivity. Understanding the mechanisms behind drought resistance and their responses to water deficits is fundamental for improving crop genotypes for drought-prone areas. Studies have suggested that transpiration efficiency (TE) is an important plant trait of water use efficiency (WUE) and a major source of yield variation under drought stress Studies also shown that leaf expansion and gas exchange (transpiration and photosynthesis) have similar response curves under water-deficits, when expressed as a function of the fraction of transpirable soil water (FTSW) in the root zone. Several empirical models have been developed, based on these curves, to describe the relationships between leaf expansion, stomatal conductance, photosynthesis, $N_2$-fixation, transpiration, and available soil water, for a variety of crop species and growing conditions. The response of transpiration to FTSW can be generally described as the sequence of three successive stages of soil dehydration: stage I where water is not limiting and stomata are fully open, stage II where stomata adjust transpiration to a declining rate of water uptake, and stage III where stomatal conductance is at a minimum and major processes contributing to crop yield are fully inhibited (Serraj et al., 1999)[12].

Under well-watered conditions, stomata respond largely to changes in atmospheric vapour pressure deficit (VPD), with a response more pronounced in intermediate leaves, suggesting an effect of leaf stage on stomatal sensitivity to VPD. The stomatal sensitivity to VPD is reduced or even absent in plants under dry soil conditions although the reduction in transpiring leaf area can partially restore stomatal sensitivity to VPD. Although stomatal closure under drought means an economy of water under progressive drying, it implies a penalty in carbon assimilation. Whether TE, i.e. the amount of biomass produced per unit of water transpired, under drought varies is still a matter of conflicting debate, in particular because the assessment of genetic variation in TE has often been based on instantaneous measurements of $CO_2$ fixation and transpiration from single leaf. Both of these processes vary markedly during the day and across leaves and plant age, with resulting high coefficient of variation. Thus, these instantaneous measurements do not integrate performance through out the life of the plant; in particular the morphological and physiological adaptations to drought that may influence season long TE (Tanner and Sinclair, 1983)[13]. There is a need to investigate the genotypic differences in stomatal and TE responses to drought stress, and the use of surrogate trait such as carbon discrimination ($\Delta\ ^{13}C$) for the selection criteria of WUE.

The objective of this study is to investigate the relationships between transpiration, transpiration efficiency, fraction of transpirable soil water and carbon isotope discrimination in a dry-down experiments on wheat genotypes.

12 Serraj R, Allen LH, Sinclair TR. 1999. Soybean leaf growth and gas exchange response to drought under carbon dioxide enrichment. Global Change Biol. 5, 283-291.

13 Tanner CB, Sinclair TR. 1983. Efficienct water use in crop production; Research or re-search. In: Taylor HM, Jordan WR, Sinclair TR, eds. Limitations to efficient water use in crop production. Madison, WI: American Society of Agronomy, 1-27.

## MATERIAL & METHODS

A preliminary glasshouse pot experiment involving nine wheat genotypes, known to possess various combinations of transpiration, TE from Centro International de Mejoramiento de Maiz y Trigo (CIMMYT) were subjected to a dry down experiment. Twenty-five cm pots were filled with a soil-sand mixture at 2:1 ratio. Four seeds were planted per pot; they were thinned to one plant per pot two weeks after sowing. In each experiment, pots were divided into the following 3 subsets, with 5 replicated plants per subset, per genotype:

- One subset was harvested before submitting plants to drought (pre-treatment harvest).
- One subset of plants was maintained under well-watered conditions and used as control.
- The third subset was used as stress treatment pots for the drought treatments.

The plants were grown in glasshouse subjected to natural solar radiation with day and night time air temperature ranging from 20-30$^{\circ}$C. Plants were grown under well-watered conditions up to 3-4 weeks following emergence. At that time, one subset of plants was submitted to progressive drought, and another set harvested the day the irrigation was withheld in the drought-treated pots. Pots were fully watered (saturation) the afternoon before imposing drought. After draining overnight, they were enclosed in white plastic bags, around the stem to prevent direct soil-evaporation. A small tube was then inserted in the plastic bags for re-watering pots. The pots were weighed after enclosing in plastic bags and this value was recorded as the initial target pot weight. Thereafter, the pots were weighed every morning around 9 am. Daily transpiration was calculated as the difference in weight on successive days.

To avoid too rapid imposition of stress and to homogenize the development of drought stress across replicated plants, the decrease in soil moisture was limited to a net loss of 70 g per day, controlled by partial re-watering of the stressed pots. In all experiments, well-watered control plants of each genotype were maintained at initial target weight by adding the daily water loss back to the pot.

The experiment was terminated when all the soil water in drought-stressed pots had decreased to a level where there was no longer soil water available to support transpiration. This endpoint, was identified when the daily transpiration rate of drought-stressed plant had decreased to less than 10% of the well-watered plants.

The transpiration data were analyzed by the procedure previously described by Sinclair and Ludlow (1986)[14] and Ray and Sinclair (1997)[15]. To minimize the influence of large variations in daily transpiration across days, the daily transpiration rates of the drought-stressed pots were normalized against the transpiration rates (TR) measured for the well-watered plants on each day. This daily normalization was achieved by dividing daily transpiration of each individual plant in the drought-stressed regime by the daily mean transpiration of the well-watered control plants for each genotype.

$$TR = \frac{\text{Transpiration of stressed plant}}{\text{Average transpiration of control plants}} \qquad (1)$$

14 Sinclair TR, Ludlow MM. 1986. Influence of soil water supply on the plant water balance of four tropical; grain legumes. Aust. J. Plant Physiol. 13, 329-341.

15 Ray JD, Sinclair TR. 1997. Stomatal closure of maize hybrids in response to drying soil. Crop Sci. 37, 803-807.

The values of TR vary among individual plants because of plant size and differences between replicates. To facilitate comparisons between plants, a second normalization was carried out in each individual plant to adjust TR to the initial TR when the soil water content in each pot was high. To do so, a mean TR was calculated for each plant for the first 3 days of the experiment. Then, the daily-normalized transpiration ratio (NTR) is the ratio of daily TR of each plant divided by the mean TR of that same plant in the first 3 days of the experiment.

The transpirable soil water available to the plant in each pot was calculated as the difference between the initial and final pot weight. The use of transpirable soil water as the basis of comparing plant response to soil drying under a range of conditions has been effectively used in a number of studies (Ray and Sinclair, 1997[16]; Serraj et al. 1999[17]). The comparison among the genotypes was further facilitated by expressing the available soil water as the fraction of transpirable soil water (FTSW) for each pot in the drought-stressed treatment on each day.

$$\mathrm{FTSW} = \frac{\text{Daily pot weight - final pot weight}}{\text{Initial pot weight - final pot weight}} \qquad (2)$$

The relationship of FTSW and transpiration for each genotype was calculated using non-linear regression procedures.

$$NTR = \frac{1}{[1 + A * \exp(B * FTSW)]} \qquad (3)$$

Comparisons of the curve generated by equation (3) for each genotype were based on 95% confidence intervals of coefficients A and B. To determine the specific FTSW (threshold) value at which transpiration began to decline, the plateau regression procedure is employed.
Meanwhile, leaves were sampled at the end of the dry down experiment and analysed for $\delta^{13}C$ using a mass spectrometer (IRMS Optima Micromass system, Micromass UK, Wythenshaw), at the IAEA's laboratory in Seibersdorf, Austria.
The carbon isotope ratio was expressed in delta notation as $\delta^{13}C$ (‰), which is a measure of the $^{13}C/^{12}C$ ratio in a sample relative to that of a standard:

$$\delta^{13}C_{sample}(‰) = (\frac{R_{sample}}{R_{standard}} - 1) \text{ x } 1000,$$

where $\delta^{13}C_{sample}$ is the isotope ratio in parts per mil (‰), $R_{\text{sample}}$ and $R_{\text{standard}}$ are the $^{13}C/^{12}C$ molar abundance ratios of the plant material and the Pee Dee Belemnite (PDB) standard, respectively. Carbon isotope composition provides a means of relating samples of diverse origin for carbon isotope content.

16 Ray JD, Sinclair TR. 1997. Stomatal closure of maize hybrids in response to drying soil. Crop Sci. 37, 803-807.
17 Serraj R, Allen LH, Sinclair TR. 1999. Soybean leaf growth and gas exchange response to drought under carbon dioxide enrichment. Global Change Biol. 5, 283-291.

The values were re-expressed as carbon isotope discrimination (Δ), which is a measure of the $^{13}C/^{12}C$ ratio in plant material relative to that in the air (Farquhar and Richards 1984)[18].

$$\Delta(‰) = \frac{\delta^{13}C_{air} - \delta^{13}C_{sample}}{1 + \delta^{13}C_{sample}}$$

where $\delta^{13}C_{air}$ is often assumed to be -8‰ relative to PDB, a value which is widely used for free atmospheric $CO_2$.

## RESULTS AND DISCUSSION

The relationship between normalized transpiration ratio (NTR) and the fraction of transpirable soil water (FTSW) for all nine genotypes is given in Fig. 1. It can be seen that there was a significant variation of the different wheat genotypes in their response to soil water deficit. There were also differences among the genotypes in their transpiration efficiency (TE), with a range of 2.0-4.3 g $kg^{-1}$ (Fig. 2). The soil water content where transpiration begins to decline relative to control, as expressed using the fraction of transpirable soil water (FTSW) threshold, varied from one genotype to the other and these threshold values were negatively related to TE (Fig. 2).

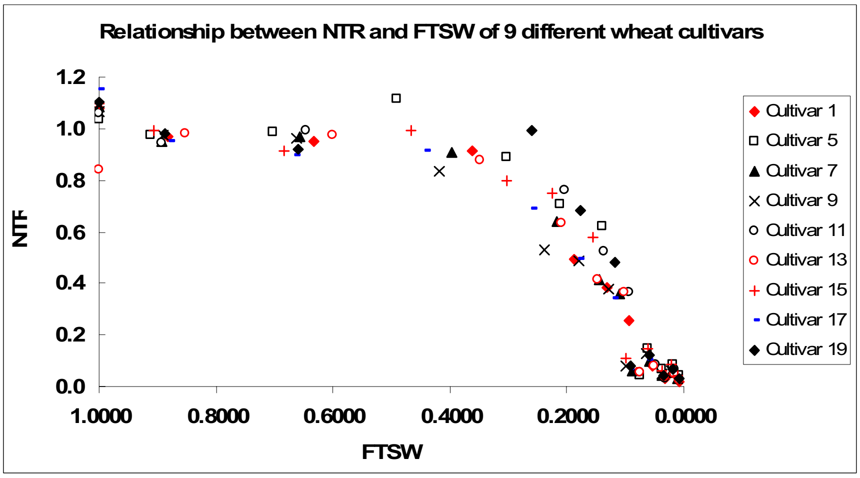


**Fig. 1. Plot of normalized leaf transpiration (NTR) against the fraction of transpirable soil water (FTSW) for nine wheat varieties.**

[18] Farquhar GD, Richards RA (1984) Isotopic composition of plant carbon correlates with water-use efficiency of wheat genotypes. Australian Journal of Plant Physiology 11, 539-552.

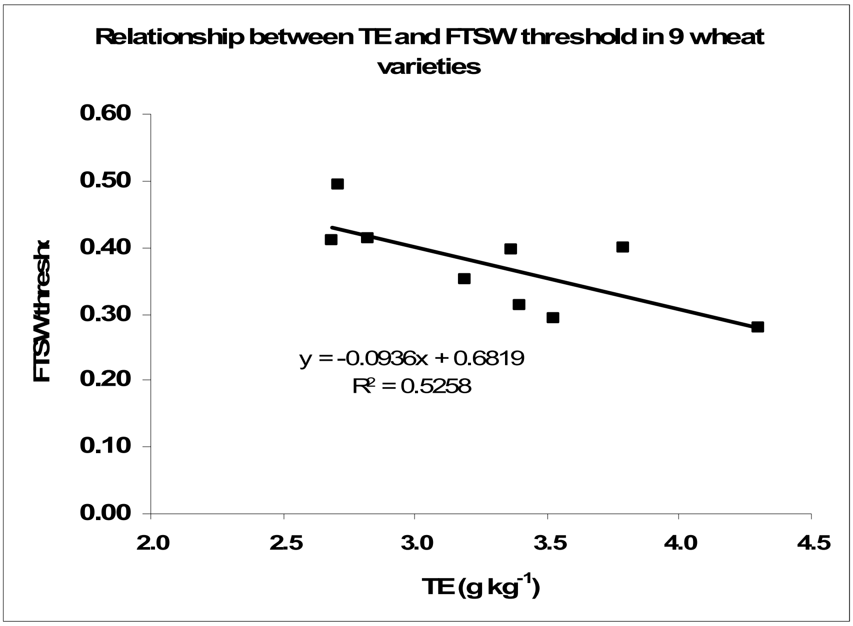


**Fig. 2. The relationship between transpiration efficiency (g kg$^{-1}$) and the fraction of available soil water (FTSW) threshold (at which stomatal control starts limiting transpiration) in nine wheat genotypes.**

The relationship between carbon discrimination (Δ) and the fraction of available soil water (FTSW) for the nine wheat varieties is given in Fig. 3. There was a positive relationship between the two variables, however, the relationship was not significant. The experiment is currently being repeated and results will be reported in the next report.

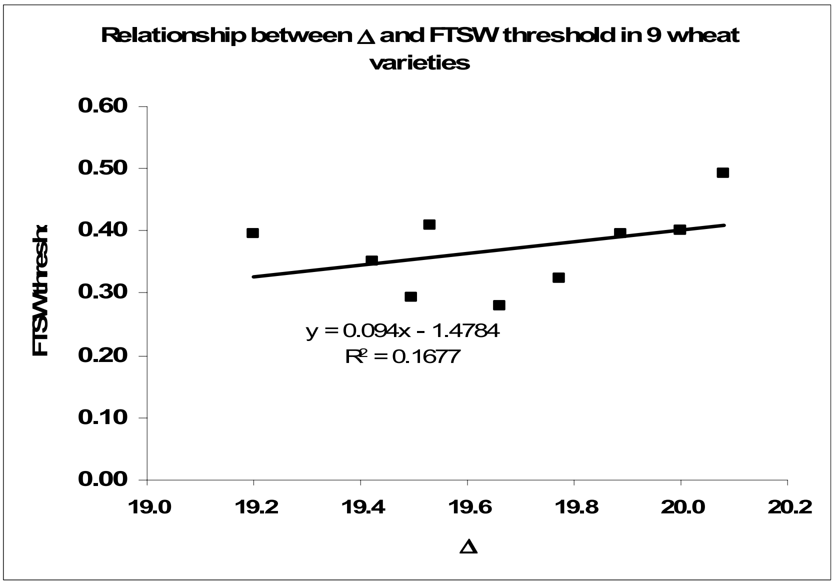


**Fig. 3. Relationship between carbon discrimination (Δ) and the fraction of available soil water (FTSW) for the nine wheat varieties.**

## 2.6. Optimizing wheat productivity in two rain-fed arid and semi-arid environments of West Asia - North Africa using a simulation model

In many arid and semi-arid regions of the world, such as the West Asia and North Africa (WANA) region, water shortage is a major constraint to agricultural production. Cereal production is generally low at 0.6 to 1.5 t/ha. Applying nitrogen (N) and phosphorus (P) fertilizers and other management practices can have either positive and negative effects on yield depending if water is severely limiting, making it difficult to determine the level and timing of fertilizer needed to attain optimum yields. In this region, grain yields and water productivity have been shown to increase by applying relatively small quantities of supplementary irrigation (SI) in conjunction with rainfall. SI is defined as the application of a limited amount of water to crops when precipitation fails to provide the essential moisture for normal plant growth (Oweis et al., 1998)[19]. This practice has a tremendous potential in alleviating the adverse effects of low rainfall, improving and stabilizing crop yields.

To develop appropriate crop production strategies to increase yields, and understanding the links between climate variability, water availability and agricultural management and their interactive effects on yield would require long and expensive field experiments. Using a simulation model, one can study the outcomes over many seasons in parallel with minimal computing time; overcoming the limitations of field experiments, which are normally limited by time, location, soil type, management options and varying initial conditions. Information from long-term simulation experiments can also be extrapolated to similar agro-ecological zones to explore potential implications of the various improved cropping systems in farmers' fields.

The objective of this study was to evaluate the performance of Agricultural Production Systems Simulator Model (APSIM-Nwheat), using field experimental data collected at several experiments in Morocco and Jordan, and to analyze the effect of N fertilizer, management practices in increasing wheat production in WANA, using a 20-year historical weather record.

### MATERIAL AND METHODS

The studies were conducted between 1998-2002 in Jemaa Riah (Morocco JR) at the Agricultural National Research Institute (INRA) experimental station, located 60 km south of Casablanca in the Chaouia region in Morocco (M). The annual average rainfall is about 270 mm. The experiment was to investigate the role of wheat crop residues and levels of N fertilizer on the subsequent wheat crop in three crop rotations. Fertilizer N as urea was applied at 0 and 40 kg N/ha at sowing and at tillering. A bread wheat cultivar Achtar was planted on 5 November at a rate of 120 kg seeds/ha corresponding to about 300 plants/$m^2$. Harvest was carried out in May/June the following year. Grain yield data from 2001/02 from a nearby field experiment at Jemaa Shaim (Morocco JS) with a similar experimental design as Jemaa Riah with similar rainfall in this year were also used for model-experiment comparison (El Mejahed and Aouragh, 2005)[20].

Another field experiment was carried out in 1998/99 at Maru Agricultural Research Station, 100 km north of Amman, Jordan (J). The area has a mean annual rainfall of about 350 mm. The experiment was to investigate the role of wheat crop residues and levels of N fertilizer on the subsequent wheat crop in crop rotations (Rusan et al., 2005)[21]. An early flowering wheat cultivar Horani 27 was used

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19 Oweis, T., Pala, M. and Ryan, J., 1998. Stabilizing rainfed wheat yields with supplemental irrigation and nitrogen in a Mediterranean climate. Agron. J. 90, 672–681.

20 El Mejahed, K., and Aouragh, L., 2005. Green manure and n fertilizer in soil quality and profitability of wheat based system in semiarid morocco using nuclear techniques. In: 'Management of Nutrients and Water in Rainfed Arid and Semi-arid Areas for Increasing Crop Production'. IAEA-TECDOC-1468, pp. 89–106.

21 Rusan, Munir Mohammad, Battikhi, A. and Zuraiqi, S., 2005. Enhancement of nitrogen and water use efficiency by optimizing the combination of soil, crop and nitrogen management. In: 'Management of Nutrients and Water in Rainfed Arid and Semi-arid Areas for Increasing Crop Production'. IAEA-TECDOC-1468, pp. 155–177.

in the Jordanian study. Seeds were sown at a density of 150 kg seeds/ha, urea N fertilizer applied at 0, 40, 80 kg N/ha in March.
APSIM was used to evaluate the field experimental data collected in these two studies. The simulation was run from 1999-2002 for Morocco and 1998/99 season for Jordan.

In order to examine the effect of management practices (amount and timing of N fertilizer, initial stored soil water, sowing date and density, soil types and supplemental irrigation) and crop genotype (early versus late flowering cultivar) on the probability distribution of grain yield potential, the model was also run with a 20-year historical weather record from Morocco.
Sowing was assumed to occur within a sowing window (November and January of each year, when ≥ 10 mm of rain fell within 10 days and soil water in the 5-10 cm depth had > 50% of the available soil water holding capacity) or fixed on 5 November (as used in the Moroccan field experiment) and one month later on 5 December.

To optimize the amount and timing of N fertilizer applications, a range of fertilizer combinations were simulated (0, 40, 80 and 120 kg N/ha, split at three growth stages: sowing, tillering and stem elongation) for both soil types. Two initial pre-sown plant available water (PAW) treatments (zero initial water and 30 mm initial stored soil moisture below 30 cm depth) were also simulated. The latter represents management practices for summer water conservation through mulching, crop rotation and water harvesting. Other comparisons were made between early and late flowering cultivar; planting density (150 plants/m$^2$ and 300 plants/m$^2$ which corresponds to approximately 120 and 60 kg/ha of seeds, respectively), and 40 mm of supplemental irrigation (SI) at sowing compared with 5 times 60 mm applied at the beginning of each month during the growing season (December to April).

## RESULTS

The cumulative growing season rainfall between October and April at the Morocco and Jordan sites and the sowing dates are shown in Figure 1. The first two years at the Morocco site were very dry. The highest rainfall was received during the 2001/02 cropping season with 270 mm. Rainfall at the Jordan site for 1998/99 growing season started late in December 1998. The late start of rainfall resulted in delayed emergence and poor wheat establishment.

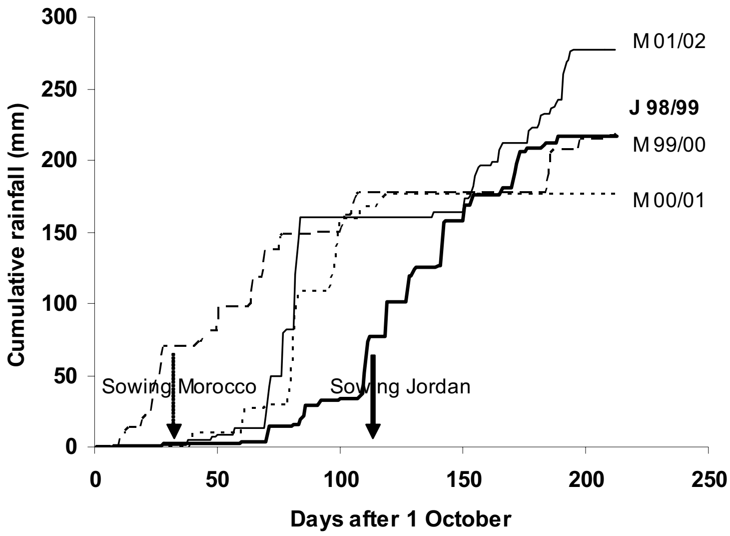



**Fig. 1. Cumulative rainfall during the growing season between October to April for Morocco (M) (1999/00, 2000/01, 2001/02) and the Jordan (J) site (1998/99)**
**The sowing dates are indicated by vertical arrows.**

The measured and simulated grain yields for Morocco and Jordan plotted against cumulative rainfall from October to April are shown in Figure 2. The measured grain yields were very low at both sites. Applications of N fertiliser either reduced or had no effect on yield. The model simulated yield reasonably well in most seasons except for the high rainfall season in 2001/02 at JR, Morocco. In this year, the simulated yields were about 3 t/ha while the measured yields were only 0.5 t/ha. The reasons for these low measured yields were unknown but probably due to soil born root or foliar diseases. However, a similar experiment carried out in a nearby location at Jemaa Shaim (JS), with similar experimental design and rainfall amount, showed measured grain yields close to model simulation for this season (Fig. 2).

This indicates some deficiency in the field experiment not explained by the model, which are not related to water and N supply.

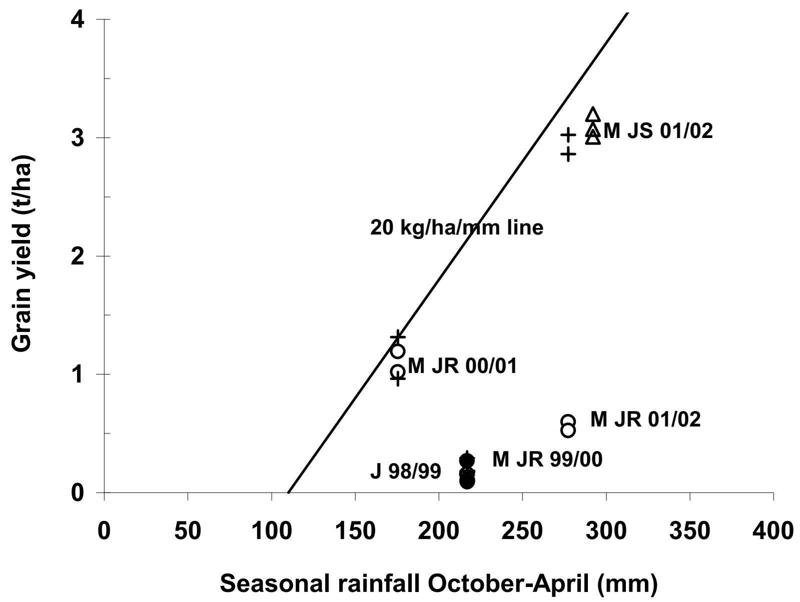



**Fig. 2. Measured wheat grain yields versus cumulative seasonal October to April rainfall for Morocco JR (open cycles), Morocco JS (open triangle) and Jordan (filled cycle), and their corresponding simulated grain yields (+).**
**Also shown is the potential yield line of 20 kg grain yield/ha/mm, assuming 110 mm soil evaporation.**

The Moroccan 20-year rainfall during the growing season (October to April) between 1982 and 2001, varied markedly between and within seasons. Of the 20 seasons, 9 were very dry with <250 mm rainfall, 5 seasons were >350 mm rainfall, and the other seasons received about 270-320 mm. In the low rainfall seasons, grain yields were also very low irrespective of N treatment, ranging between 0 to 1.2 t/ha (Fig. 3).

In some seasons, simulated grain yields decreases with N application. Near zero yields were simulated for 1991/92, 1992/93 and no yield in 1994/95 seasons due to lack of rainfall. In average and above rainfall years, simulated grain yields reached >3.0 t/ha (Fig. 3).

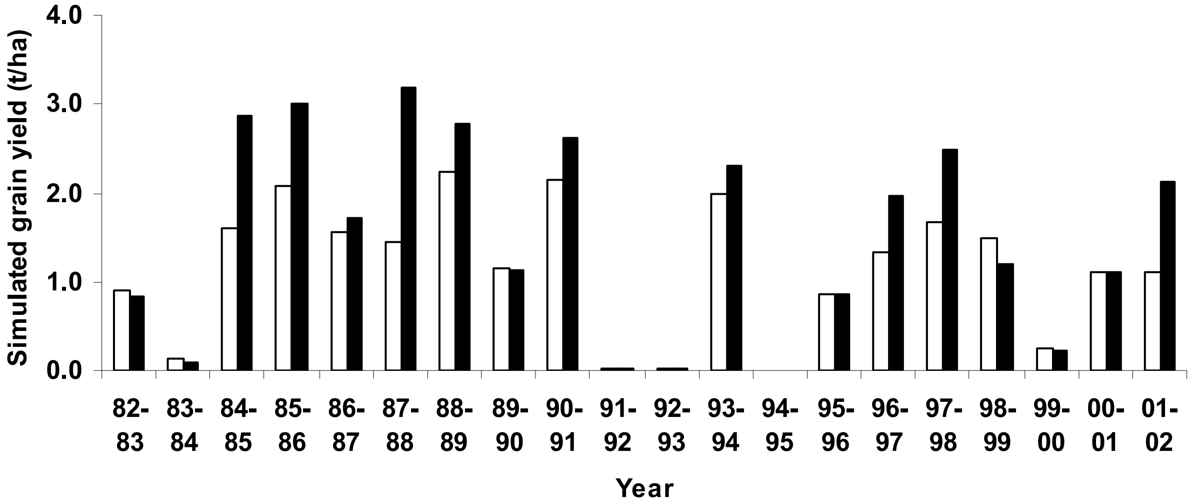



**Fig. 3. Simulated wheat grain yields from 1982-2001 for fixed early sowing on 5 November for zero N (open bar) and 40 kg N/ha applied at sowing (full bar) for the Morocco site.**

The effects of soil types (Morocco versus Jordan soil, with 70 and 95 mm PAW, respectively), pre-sown soil profile PAW (zero Dry versus 30 mm PAW below 30 cm depth Wet), sowing dates (early versus late sowing), and planting density (PD) (low 150 plants/m$^2$ versus high 300 plants/m$^2$) were given in Fig 4. Higher yields were simulated on the higher water-holding capacity soil in Jordan, especially when crops were sown early (Fig. 4a). The simulations indicated that 30 mm pre-sown pant-available stored soil moisture below 30 cm soil depth slightly improved grain yields and reduced yield variability, especially when N fertilizer was applied (Fig. 4b). Early sowing crops increased grain yields in average by more than 25% compared to late sown crop when N was applied (Fig. 4c). The study also observed rainfall-defined sowing using a sowing rule often resulted in similar grain yield as late sowing treatment (data not shown). Increasing plant density from 150 to 300 plants/m$^2$ had little effect on grain yield (Fig. 4d).

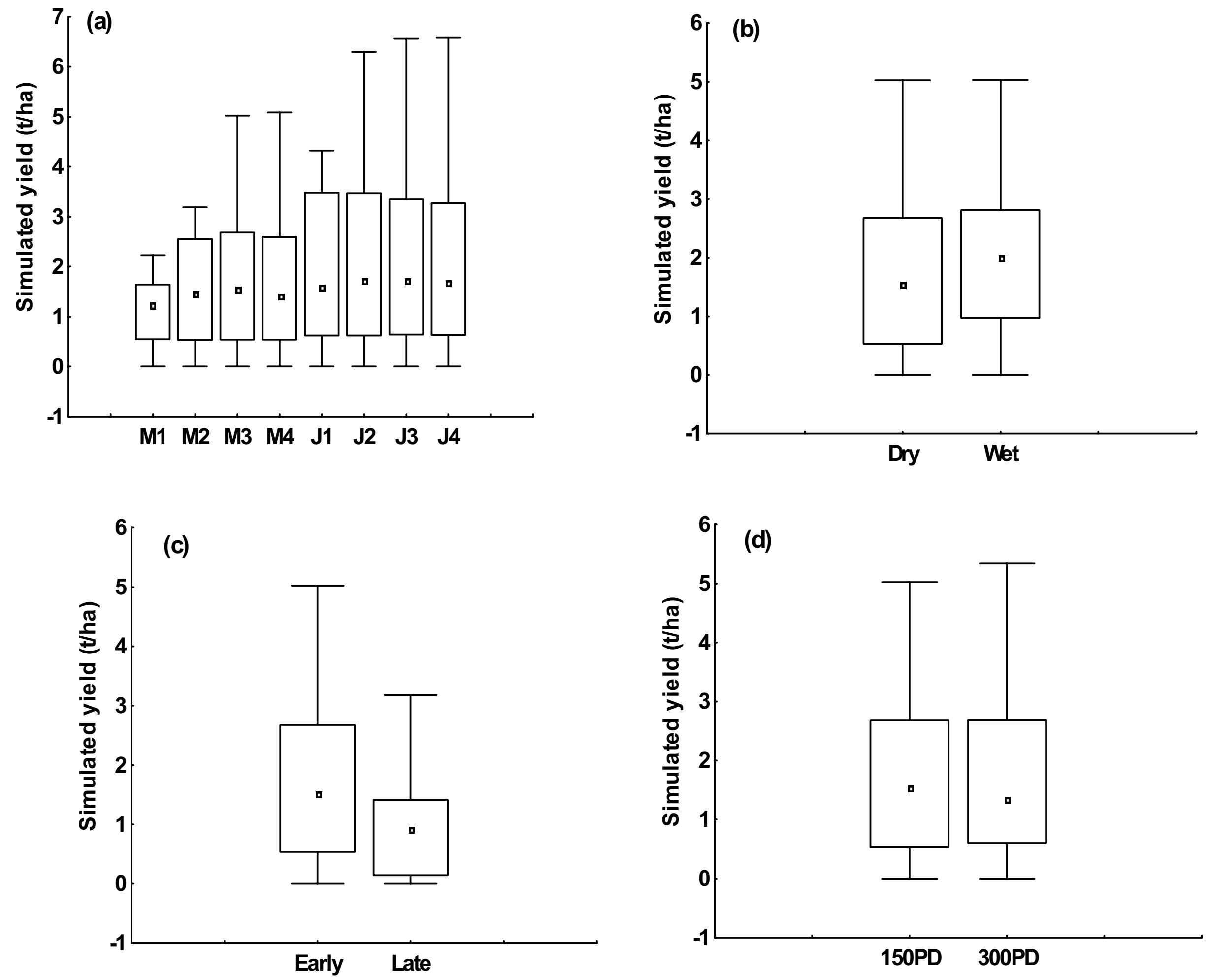



**Fig. 4. Simulated wheat grain yields from 1982-2001 for (a) 00-00-00, 40-00-00, 40-80-00 and 120-40-00 kg N/ha (1, 2, 3, 4) for Morocco (M, 70 mm PAW) and Jordan (J, 95 mm PAW), (b) zero pre-sown soil profile (Dry) and with 30 mm below 30 cm depth (Wet), (c) early and late sowing dates, (d) low (150 plants/m$^2$) and high (300 plants/m$^2$) planting density (PD). The boxes show 75% (top edge) and 25% (lower edge) percentiles, small square within box represents the median (50% percentile); error bars indicate 90% (top) and 10% (lower) percentiles simulated yield.**

Supplemental irrigation (SI) of 40 mm at sowing had little effect on grain yield when N fertilizer was not applied (not shown), however, SI together with 40 kg N/ha fertilizer significantly ($P < 0.05$) improved grain yields due to early crop establishment with the avoidance of terminal drought and the additional water supply (Fig. 5). Higher sowing density (300 plants/m$^2$) together with 40 mm SI did not increase grain yields, irrespective of N rates (data not shown). When applying five monthly rates of 60 mm SI, grain yields increased statistically significantly ($P < 0.05$) when combined with high N applications and high sowing density of 300 plants/m$^2$ (Fig. 5). More than 300 mm SI had not further effect on increasing grain yields (data not shown).

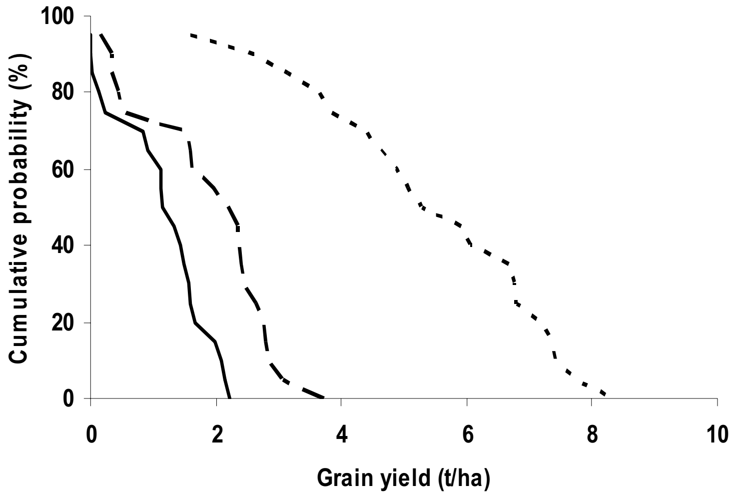



**Fig. 5. Simulated probability distribution for wheat grain yield from 1982-2001 for zero kg N/ha with an initial dry soil profile and early sowing at 5 November (solid line); with 40 mm supplemental irrigation (SI) and 40 kg N/ha at sowing (dashed line) and with 5 x 60 mm irrigation in monthly intervals and with 120 kg N/ha (dotted line).**

## CONCLUSIONS

Increasing crop productivity in semi-arid areas is a difficult and challenging task due to low and erratic rainfall. Grain yields in the rain-fed environments of WANA depend and are sensitive to the amount and timing of rainfall during the growing season, as well as the availability of N supply. The analysis showed that there is potential for an increase of wheat yields with higher N inputs in this region by at least 20 per cent, in particular when pre-sown stored soil water is available, an early sowing opportunity occurred or small amounts of SI are available to enable early crop establishment. Better management of natural resources in combination with N fertilizer, early sowing, a low plant density, and the practice of soil water conservation techniques such as water harvesting, improved on-farm water and irrigation management techniques can save resources, increase yields and decrease yield variability in this region. The APSIM model was able to integrate all these factors in a simulation analysis and identified the potential for better N and water management practices to increase crop production in the rain-fed semi-arid areas of WANA.

# 3. Training Activities

Training is provided by the Soil Science Unit in the form of training courses, workshops, fellowships and scientific visits. The subjects of training are predominantly the use of nuclear technology in soil science, soil and water management and erosion, crop nutrition and isotope analyses.

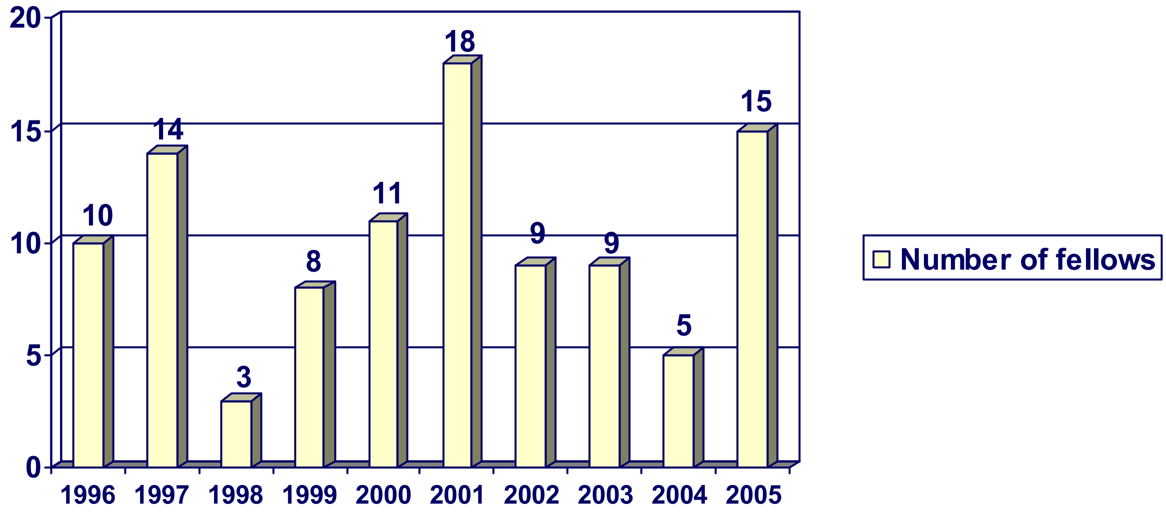
## 3.1. Fellowships

The SSU trains approximately 10–15 fellows annually. The training periods vary from 1 to 6 months. There are two categories of fellows, i.e. analytical fellows, who are accepted for short periods of 2 to 3 month to learn isotope analytical techniques used in plant nutrition. This form of training includes technical tutoring and hands-on practical sessions. Particular emphasis is given to specific techniques relevant to research conducted under technical cooperation projects, i.e. total N and $^{15}N$ isotope-ratio analyses by emission spectrometry or isotope analyses by mass spectrometry.

Whenever possible, group training of three to five fellows is organized. Research fellows are accepted for periods between four and six months to work on problems or techniques related to the Unit's research programme. The fellows receive guidance on experimental strategies and the use of isotopes and related techniques relevant to a particular area of research, which the fellow will pursue upon return to his or her home country. The fellow is expected to complete and write up a report of the research conducted.

**Evolution of number of fellows at the Soil Science Unit**

**(1996-2005)**



**The Soil Science Unit has trained fifteen fellows during 2005 as individual fellows or participants in a Training Course:**

| Name | Country of origin | Duration of stay | Training received |
|---|---|---|---|
| Mr. J. Louissaint | HAI | 1 month | Biological Nitrogen Fixation |
| Mr. F. Al Ain | SYR | 1 month | Modelling |
| Ms. M. Walker | JAM | 3 months | Crop nutrition |
| Mr. D. Asare | GHA | 3 months | Crop nutrition |
| Ms. J. Altangerel | MON | 4 months | Crop nutrition and water management |
| Ms. L. Li | CPR | 3 months | Soil erosion |
| Ms. L. Bai | CPR | 3 months | Soil erosion |

**Field sampling in Mistelbach (Austria)**

## 3.2. Training Course

*FAO/IAEA Training Session on the Use of Nuclear and Related Techniques in Studies of Soil/Plant Relationships with Emphasis on Soil Water Management*

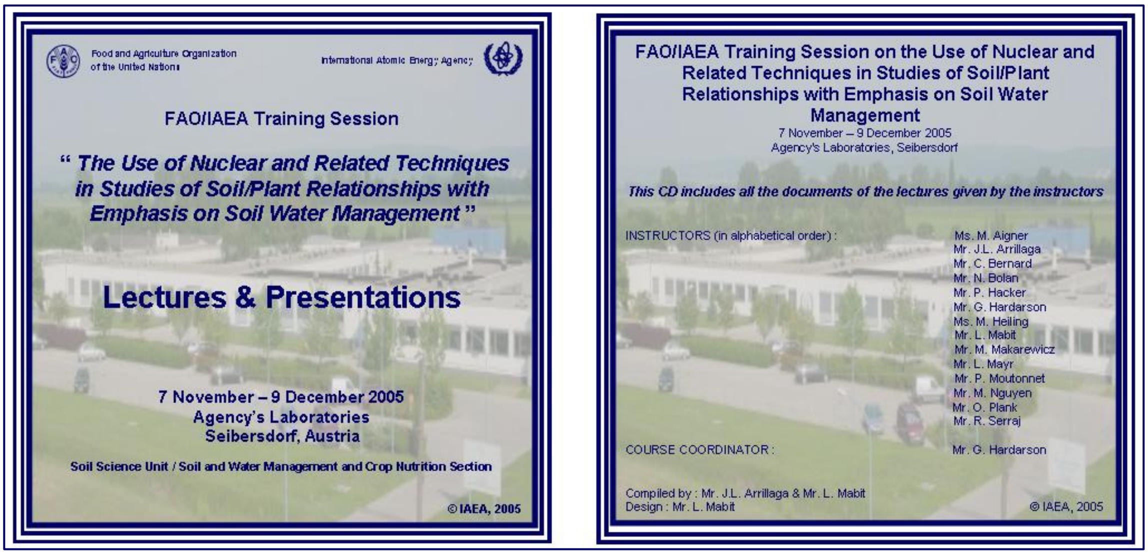
A training course was implemented by the Soil Science Unit from 7 November–9 December, 2005 with the following eight fellows from Iraq:

| Name | Fellowship Code |
|---|---|
| Mr. J. ABDUL-RIDHA | IRQ/05027 |
| Ms. B.H.A. AL-AMERI | IRQ/05028 |
| Mr. K.H.S. AL-JUBOURI | IRQ/05031 |
| Mr. H. AL-SAADI | IRQ/05032 |
| Mr. A.S. FALIH | IRQ/05025 |
| Mr. T. RASHEED | IRQ/05030 |
| Mr. S. SALIM | IRQ/05024 |
| Mr. M.M. SHAKER | IRQ/05029 |

The course covered crop nutrition, water management and soil erosion and conservation. Lectures and practical demonstrations were given by staff members from both the SSU and SWMCN with two external lecturers assisting with the implementation. Dr Pierre Moutonnet (France), gave lectures and practical exercises on the use of nuclear techniques in irrigation and water management and Dr Nanthi Bolan (Massey University, New Zealand) covered the field of fertilizer use efficiency and crop nutrition.

**Trainees from Iraq**

**CD ROM with the lectures and presentations published at the end of the Training Course**




## 3.3. Scientific Visits

Several scientific visitors have also been at the Soil Science Unit for a one week visit:

| Name | Fellowship Code |
|---|---|
| Mr. J.S. ANTOINE | HAI/05002 |
| Mr. H.N. KHAN | PAK/04040 |
| Mr. M.B. HALITLIGIL | TUR/05018 |
| Mr. B. SONMEZ | TUR/05011 |
| Mr. A.A. FAHAD | IRQ/05022 |
| Mr. Z. GNANKAMBARY | BKF/05003 |

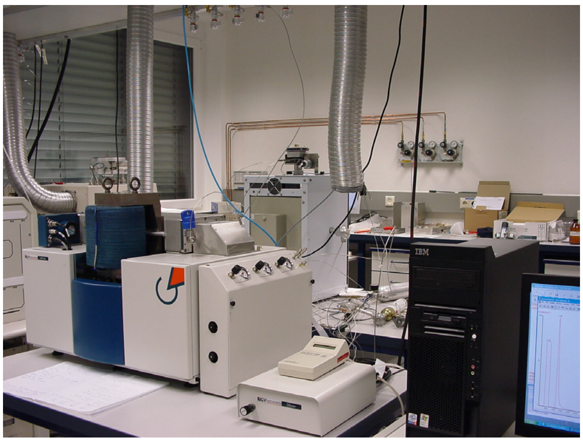
# 4. Analytical Services

In the first half of the year 2005 the Soil Science Unit received 4816 samples from CRPs, TCPs and training and research activities of the SSU. Together with blanks, calibration, test samples and the backlog of samples from 2004, a total of over 17 000 measurements were performed.

| **Samples received:** | **No.** | **% of Total** |
|---|---|---|
| CRP | 3016 | 62.6% |
| TC | 347 | 7.2% |
| Seibersdorf | 1453 | 30.2% |
| Total | 4816 | 100.0% |

| **Requested analysis:** | **No.** | **% of Total** |
|---|---|---|
| $^{15}N$ enriched level | 2878 | 45.1% |
| $^{15}N$ nat. ab. | 180 | 2.8% |
| $^{13}C$ nat. ab. | 2364 | 37.1% |
| $^{18}O$ nat. ab. | 958 | 15.0% |
| Total | 6380 | 100.0% |

| **Measurements carried out:** | **No.** | **% of Total** |
|---|---|---|
| $^{15}N$ enriched level | 7134 | 41.1% |
| $^{15}N$ nat. ab. | 1077 | 6.2% |
| $^{13}C$ nat. ab. | 5267 | 30.3% |
| $^{18}O$ nat. ab. | 3881 | 22.4% |
| Total | 17359 | 100.0% |

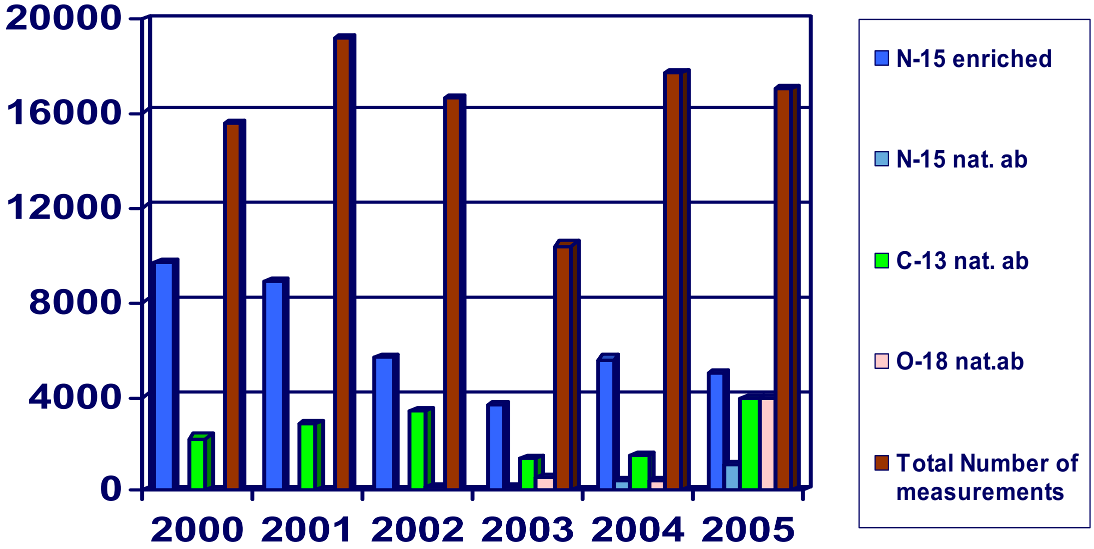


**The new Isoprime mass-spectrometer at the Soil Science Unit, Seibersdorf**

**Evolution of the number of stable isotope measurements**

**done by the Soil Science Unit**

**(2000 -2005)**





From the middle of May to the end of July 2005 the mass spectrometer room was renovated, newly furnished and all electrical and gas installations were renewed.

This was necessary because place for a new mass spectrometer and a preparation device, which was ordered last year, had to be made available and the mass spectrometer room with its 20-year-old installations and furniture was not suitable for that purpose. During that period of renovation, the analytical service was reduced to a minimum because only one of the four mass spectrometers of the Soil Science Unit was set-up at a different place and could be used to measure $^{15}N/^{14}N$ ratios.

The new mass spectrometer is an Isoprime IRMS (GV Instruments, GB) with continuous-flow inlet. The preparation device is a high-temperature conversion unit with a glossy carbon tube from HEKAtech, Germany. With this setup $^{2}H$ and 18O/$^{16}O$ ratios of solids (plant material) and as little as 1 µL of water can be determined. The installation of the new instruments was carried out in October 2005. It is expected that at the beginning of 2006 this analytical service is in full operation.

The stable isotope laboratory of the Soil Science Unit is now equipped with 4 mass spectrometers and can perform the following analyses upon requests from Member States:

| Mass-spectrometer | Preparation device | Isotope analyses |
|---|---|---|
| Isoprime (GV-Instruments, GB), continuous flow interface | High-temperature conversion system (HEKAtech, Germany) | D/H and $^{18}O/^{16}O$ in plant material<br><br>D/H and $^{18}O/^{16}O$ in 1µl water |
| OPTIMA (Micromass, GB), continuous flow and dual inlet interface | NA1500 combustion unit (Carlo Erba, Italy) | $^{15}N/^{14}N$ in plant and soil at natural abundance and enriched levels<br><br>$^{13}C/^{12}C$ in plant and soil samples |
| 20-20 (Europe Scientific, GB), continuous flow interface | ANCA combustion unit (Europe Scientific, GB) | $^{15}N/^{14}N$ and $^{13}C/^{12}C$ in plant and soil samples |
| | Equilibration line (Europa Scientific, GB) | $^{18}O/^{16}O$ in water (sample size 0.5ml minimum) |
| Integra-N (Europe Scientific, GB), continuous flow interface | Combustion unit integrated into the mass-spectrometer | $^{15}N/^{14}N$ enriched level in plant and soil samples |

## 5. Proficiency Test “EQA2005”

### Proficiency Test “EQA2005” for the measurement of $^{15}$N- and $^{13}$C isotopic abundance and total nitrogen- and carbon concentration in plant materials

The principal aim of this Proficiency Test (PT) was the assessment of laboratory performance against established criteria, to assist participants in meeting the formal requirements, to monitor and demonstrate improvements in accuracy and precision in order to achieve international comparability of analytical data and to demonstrate competence of the participating laboratory.

The annual Proficiency Test (PT) “EQA2005” was conducted free of charge for all participants, to evaluate the capability of the participating laboratories to determine the isotopic abundance of two stable isotopes, $^{15}$N at enriched levels and $^{13}$C at natural abundance level, as well as the total element concentration of nitrogen and carbon in three unknown plant materials. The test included a questionnaire on the applied quality control measures and the current status of quality system implementation in the laboratory.

**Participation in the Proficiency Tests (1995 – 2005) – *(Figures 1a, 1b and 1c)***
Nine rounds of Proficiency Tests (PT) on $^{15}$N isotopic abundance determination and total N content analysis in plant materials have been organized by the Soil Science Unit since 1995. Since 2004 additionally $^{13}$C and total C-content of the same test materials can optionally be analyzed by the participants in the frame of each PT exercise.

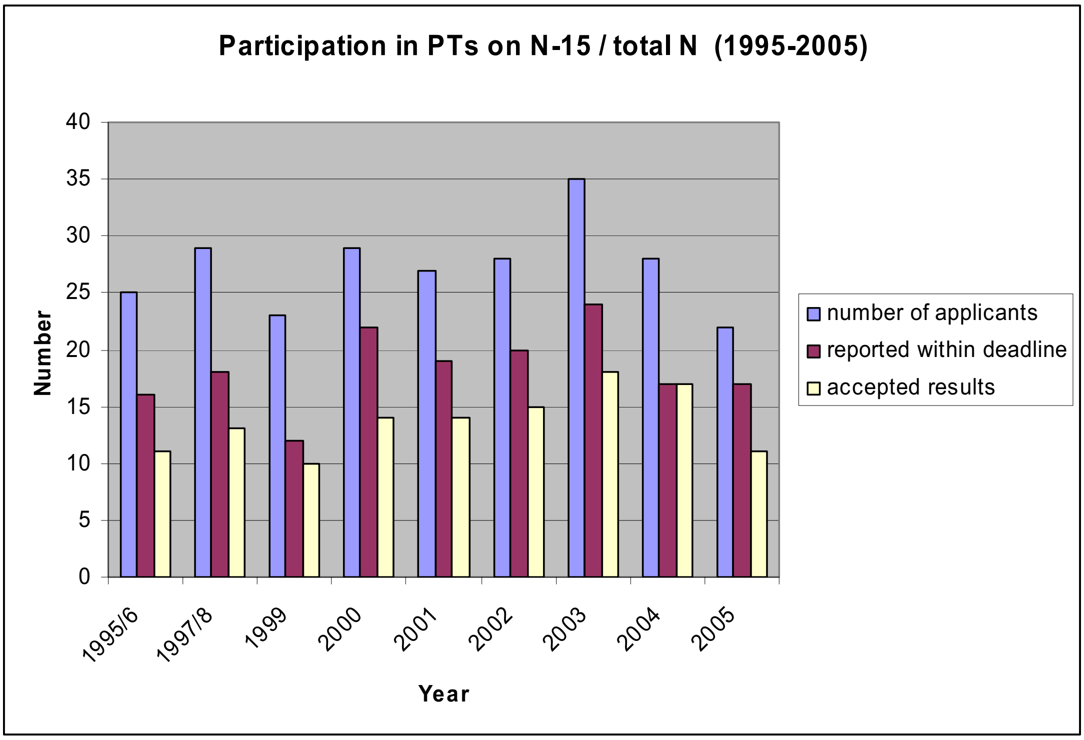



**Fig. 1a. Number of laboratories participating in the PT on $^{15}N$ and total N-determination from the year 1995 to 2005**

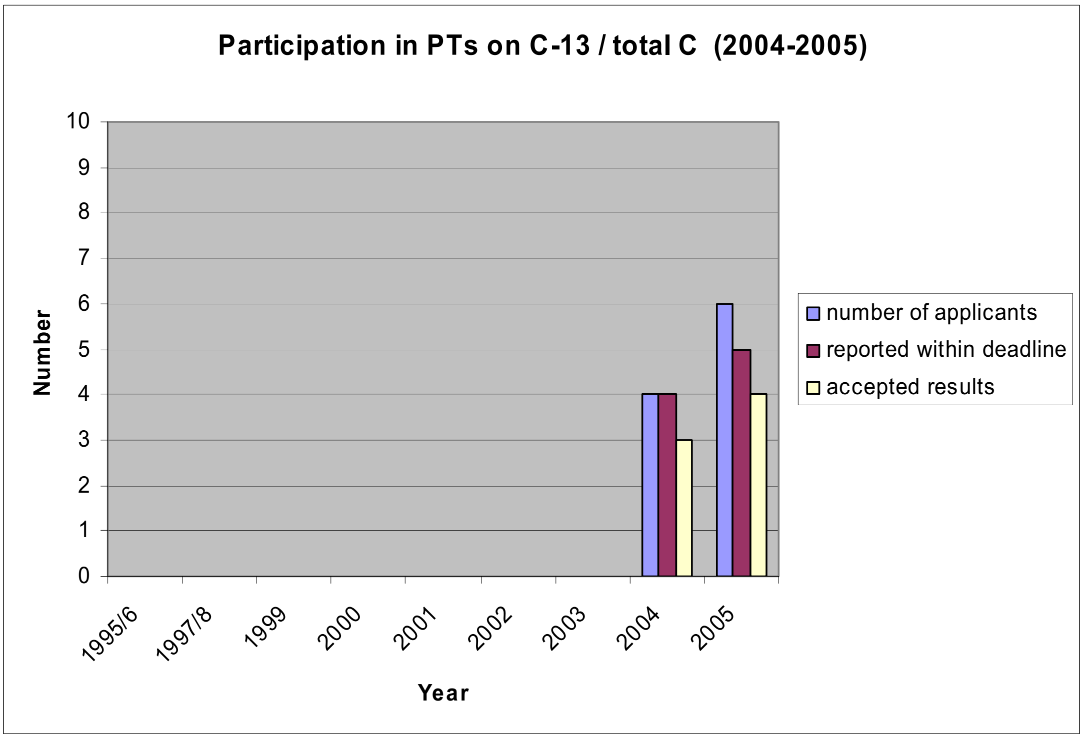



**Fig. 1b. Number of laboratories participating in the PT on $^{13}C$ and total C-determination from the year 2004 to 2005** ***(NB: 1995-2003 PT on $^{13}C$ not offered)***

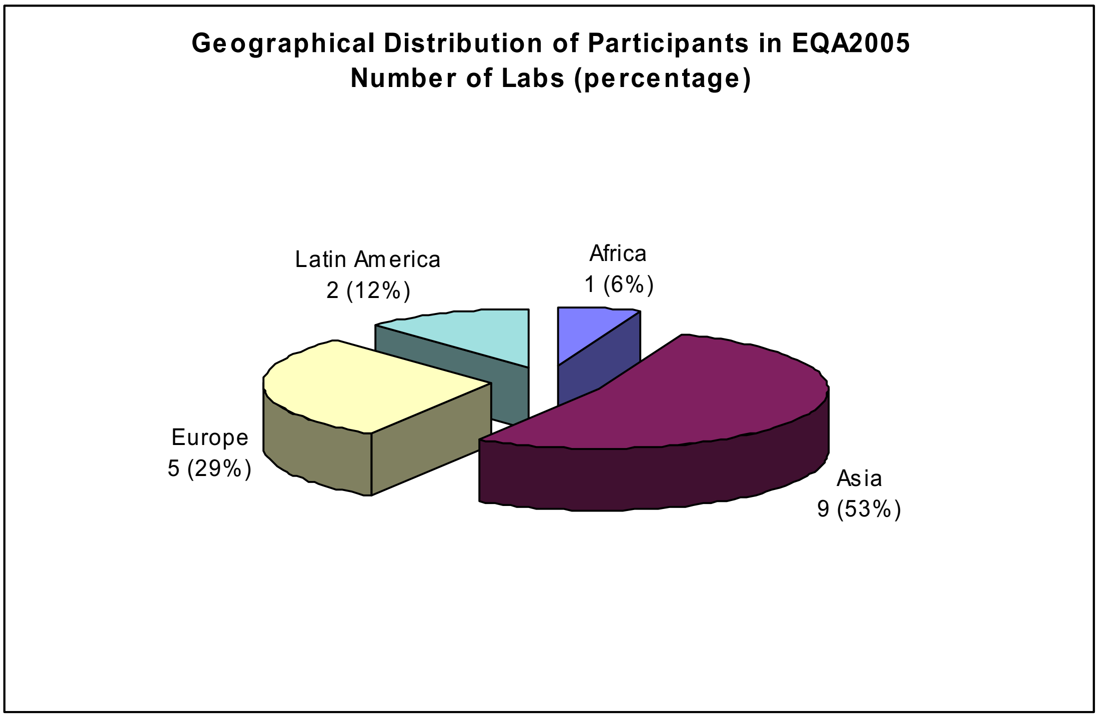



**Fig. 1c. Geographical distribution of the laboratories in EQA 2005 reporting analytical results.**

## SUMMARY OF ACTIVITIES AND OUTCOME

Laboratories in four regions known to be working on stable isotope analysis received the invitation letter in the end of January 2005 and after collection of the application forms the test panel were shipped in the middle of April 2005. Deadline for reporting was end of August 2005, i.e. 18 weeks were given for the analysis and filling the questionnaire. Individual evaluation letters were provided to each participant in December 2005. The certificates and a more detailed report will be sent out in the beginning of 2006.

In this year's round 22 laboratories from 21 countries in four regions agreed to participate. Eighteen weeks were given for the analysis and filling in the questionnaire. Seventeen laboratories submitted a complete set of analytical results within the deadline. The choice of the applied analytical method was up to the participant and depended mainly on the available instrumentation. A summary of the applied method combinations and types of analyses performed by the participating laboratories are shown below.

**Table 1. Summary of applied methods and instrumentation listed per region (OES = optical emission spectrometry, MS = mass spectrometry).**

| | | Applied methods: OES / Kjeldahl | Applied methods: MS / dry combustion | |
|---|---|---|---|---|
| Region | Number of participants | $^{15}N$ / total N | $^{15}N$ / total N | $^{13}C$ / total C |
| Africa | 1 | - | - | 1 |
| Asia | 9 | 6 | 1 | 2 |
| Europe | 5 | 3 | 1 | 1 |
| Latin America | 2 | 1 | - | 1 |
| TOTAL | 17 | 10 | 2 | 5 |

The results were evaluated by statistical methods for assessing laboratory analytical performance (accuracy and precision) by the “z-score test”. The standard deviation for proficiency assessment was set at a value that corresponds to the level of performance that the organizer wishes the laboratories to be able to achieve.

The majority of the participating laboratories, i.e. 11 of 17 (65 %) showed proficiency in the analysis of plant materials for $^{15}N$ abundance and 4 of 5 (80%) of the laboratories that have a mass spectrometer at their disposal and therefore the possibility to analyse $^{13}C$, showed proficiency in the analysis of plant materials for $^{13}C$ abundance. Total nitrogen concentration was performed well by 13 of 17 laboratories (76 %) and total carbon element concentration by 4 of the 5 participants (80%).

Individual comments on sources of error and possible improvements of the applied methods as well as graphs on individual long-term monitoring of performance were provided to each participant.
The outcome of this PT demonstrates that on the technical side initial steps for quality assurance and quality control implementation have been taken by most laboratories, although at varying levels. However to make these initial steps sustainable, proactive management commitments towards a comprehensive quality management system are required.

**Figs. 2, 3, 4, and 5: Overview of performance on stable isotope and total element analysis of three different plant samples (number of labs (percentage))**

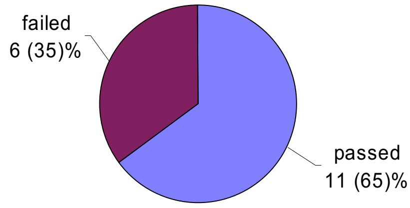



**Figure 2. % $^{15}N$ abundance determination**

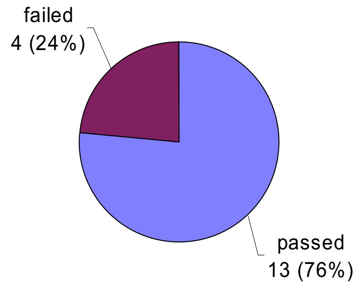



**Figure 3. % total N determination**

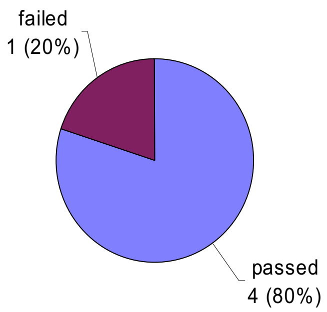



**Figure 4. ‰ $^{13}C$ abundance determination**

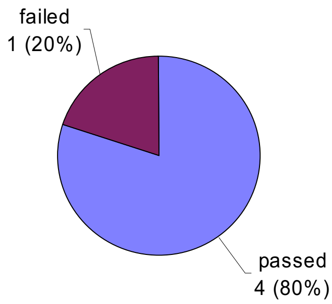



**Figure 5. % total C determination**

## MATERIALS AND METHODS

The plant test materials were produced in the organizer's laboratory and the relevant property values were assigned by the organizer. The process of production, analysis and reference value assignment is described below for the three test materials used in PT "EQA2005". The test samples were enriched in $^{15}N$ in the range of 0.55 to 1.12 % atom abundance, which is an enrichment level, often applied in isotope aided agricultural studies. $^{13}C$ isotopic abundance was at the natural abundance level. In order to estimate the level of quality management already implemented in the participating laboratory, a questionnaire had to be filled by the participant. It consisted of questions on the applied analytical method and specific questions on the quality control measures employed in determining the analytical results. For the reference value assignment the following instruments were used: Isotope Ratio Mass Spectrometer (Optima, GV Instruments) connected to a dry combustion analyzer (Carlo Erba 1500) for $^{15}N$ and $^{13}C$ isotope abundance determination as well as total N and total C element concentration analysis. This model is equipped with a built in diluter, therefore $^{15}N$ and $^{13}C$ can be analysed in a single measurement on one sample. Minimum sample intake was 10 mg. Additionally the modified Kjeldahl wet chemical method for total Nitrogen analysis was applied to obtain a separate Kjeldahl-N-value (Standard Operating Procedure (SOP) of the Soil Science Unit). The Optical Emission Spectrometers (OES, models FAN-NOI6 and FAN-NOI7) were used in previous studies on test materials with a wide range of nitrogen contents and $^{15}N$ enrichments to obtain a good estimate of the measurement uncertainty associated with the frequently applied method combination of Kjeldahl sample-preparation and $^{15}N$ abundance determination by OES.

**Production of the Plant Test Materials**

Ryegrass (*Lolium perenne*) and maize (*Zea mays*, hybrid) were grown in 4 x 4 m field plots on the experimental site in Seibersdorf from April to September 2004. Ryegrass seeds were distributed evenly over the plot. For maize the between row distance was 50 cm, the between plants distance was 18 cm. All plants were labeled with $^{15}$N-enriched ammonia sulphate (AS) solution in 3 split applications at 8, 46 and 73 days after planting (DAP) using watering cans for application of the diluted AS-solutions. Ryegrass received 75 kg nitrogen per ha, 1.4 % $^{15}$N atom abundance, uniformly distributed over all plants. Maize received 150 kg nitrogen per hectare, 2.4 % $^{15}$N atom abundance, in bands close to the stems onto the soil. Maize was cut 5 cm above ground (avoiding soil contamination of the stems) at 94 DAP and cobs and shoots were separated. Ryegrass was cut at 56 DAP, re-grown and harvested at 134 DAP using a commercial lawn mower with collection bag for the plant material.

The materials were chopped into 2 cm pieces immediately after the harvest and then dried for 48 hours at 70 ±1 °C in aluminum tubs (84 x 32 x 8 cm). The dry bulk materials were milled in an ultra centrifugal mill to a particle size of 0.2 mm. After milling, 9.8 kg dry shoots and 13.3 kg dry cobs for maize and 4.3 kg dry ryegrass material were obtained. Homogenization of the three bulk materials after milling was done in a concrete mixer of 150 L volume for 24 hours per material. Thorough cleaning of the mixer with water and drying with compressed air were performed between each new material to avoid cross contamination.

**Analytical Evaluation of the Plant Test Materials**

***Homogeneity***

The procedure of homogenization described above was tested in several previous experiments and proved to be sufficient to achieve adequate homogeneity with respect to the distribution of the analytes total nitrogen and total carbon, as well as $^{15}$N and $^{13}$C atom abundance.

***Establishing the Target Values***

The best practical estimate of the true value of the analyte concentration in the test material was adopted as the target value (commonly also referred to as 'reference value' in PTs). The most precise available analytical method, isotope ratio mass spectrometry (IRMS) coupled to a dry combustion elemental analyzer, was applied for determining $^{15}$N, $^{13}$C isotopic abundance and total N- and total C content of plant materials, traceable to Certified Reference Materials (CRMs), whenever possible. If substantial amounts of nitrates, nitrites and other compounds with N-N and N-O linkages are present in the sample, the value for total N-content of plant materials can be significantly lower with wet digestion compared to dry combustion method (Dumas) applied in the elemental analyzer. Therefore a 'Kjeldahl-N-value' (modified Kjeldahl method without pretreatment) for total N-content was determined.

A wide range of plant materials with different matrices has been analyzed for total N by the Kjeldahl method and the uncertainty estimated by the organizer for total nitrogen concentration in plant materials by Kjeldahl is based on this long term experience and the stated uncertainty of the CRMs[22] used during the quality control.

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[22] CRM129 (Commission of the European Communities, BCR, Belgium): Hay powder; GBW 07603 (The People's Republic of China): Bush leaves; NIST 8436 (National Institute of Standards & Technology, Canada): Durum wheat; NIST1547 (National Institute of Standards & Technology, Canada): Peach leaves

For all applied methods, the estimated uncertainties are sufficiently low for the intended application in glasshouse and field experiments for a wide variety of agricultural studies using $^{15}N$ enriched fertilizers or labeled organic materials and plant materials with known $^{13}C$ at natural abundance levels, such as biological nitrogen fixation, fertilizer use efficiency, belowground N- as well as organic matter turnover etc.Target Values and Associated Uncertainties.

To determine the target value, 18 analyses per test material were performed on 3 different days, i.e. 6 analyses per day. In each mass spectrometric analysis the four different analytes were determined in one run, i.e. $^{15}N$, $^{13}C$, total N and total C. The arithmetic means of these 18 analyses results were used as 'best estimate' of the true property values. The minimum sample intake was 10 mg[23].

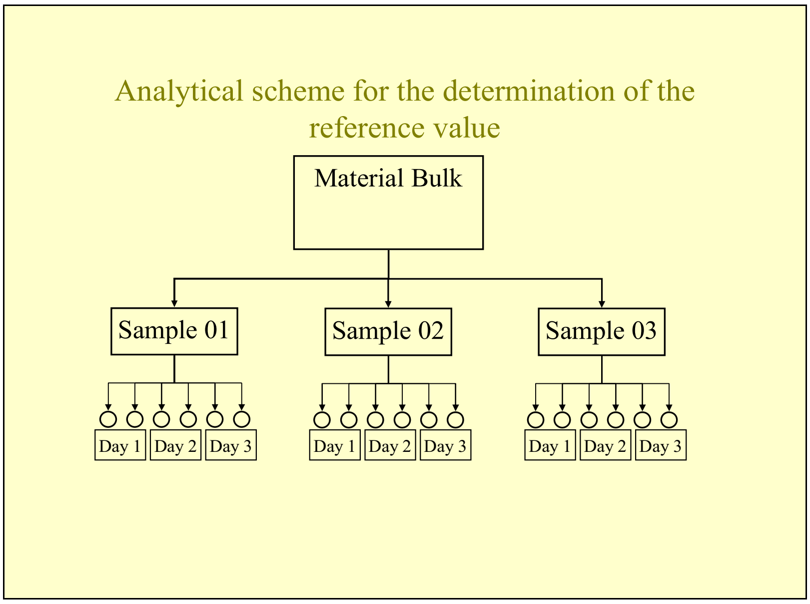



**Fig. 6. Analytical scheme for analysis of the test samples**

Evaluation scheme for the determination of the reference value

| | Sample 01 | Sample 02 | Sample 03 |
|---|---|---|---|
| Day 1 | Value 111<br>Value 112 | Value 121<br>Value 122 | Value 131<br>Value 132 |
| Day 2 | Value 211<br>Value 212 | Value 221<br>Value 222 | Value 231<br>Value 232 |
| Day 3 | Value 311<br>Value 312 | Value 321<br>Value 322 | Value 331<br>Value 332 |

**Table 2. Evaluation scheme for target value determination**

[23] Since the mass spectrometer used for test sample characterization is equipped with a diluter, carbon and $^{13}C$ as well as nitrogen and $^{15}N$ can be measured in one sample.

***Performance criteria***

Two different statistical parameters were calculated to assess the performance of the participating laboratories.

***(1) Relative Bias:***

To evaluate the relative deviation of the participant's value (Value $_{Analyst}$) from the target value (Value $_{IAEA}$) the relative bias expressed as a percentage was calculated:

$$relative\ bias\ [\%] = \frac{(Value_{Analyst} - Value_{IAEA})}{Value_{IAEA}} \times 100$$

***(2) The z-score:***

A widely used scoring system in PTs is the *z-score*. Using this approach has the advantage that results from different rounds of the scheme can be compared. It is calculated the following:

$$z - score = \frac{(Value_{Analyst} - Value_{IAEA})}{\sigma}$$

The target standard deviations (**σ**) for the different types of analysis were set at a value that corresponds to the level of performance that the organizer wishes the laboratories to be able to achieve [1] and are based on the organizer's previous experience:

***Evaluation criteria***

To state the overall performance of the participating laboratory in PT "EQA2005", the results were exclusively evaluated against the z-score test and received the status "passed", when the calculated ***z-score is smaller or equal to the value of ±2*** or "rejected", when the calculated z-score is exceeding the value of ±2.

A certificate stating participation in the PT is provided to all participants.
All laboratories received a certificate confirming the participation in EQA2005. Laboratories that achieved the status "passed" in all 3 test samples for the isotope analysis (i.e. $^{15}N$ and / or $^{13}C$ analysis) as well as for total analyte content analysis (i.e. total N and / or total C analysis) receive a certificate stating the ***successful participation*** in either of the combined analyses.

## RESULTS AND DISCUSSION

The majority (65%) of the 17 participating laboratories showed proficiency in the analysis of plant materials for $^{15}N$ abundance (Figure 2 and 7) and total nitrogen concentration was performed correctly by 13 laboratories (76%) (Figures 3 and 8). Four of the 5 laboratories that have a mass spectrometer coupled to a dry combustion analyzer at their disposal and therefore the possibility to analyse $^{13}C$ and total carbon showed proficiency in both types of analysis (Figure 4, 5, 9 and 10).

**Table 3. Summary of evaluation of all participants and instruments used for isotope analysis**

| | | $^{15}N$ / total N | | $^{13}C$ / total C | |
|---|---|---|---|---|---|
| laboratory code | instrument | analysis performed | evaluation status | analysis performed | evaluation Status |
| 01 | MS | yes | rejected | - | - |
| 02 | OES | yes | passed | - | - |
| 03 | MS | yes | passed | yes | Rejected |
| 04 | OES | yes | passed | - | - |
| 05 | OES | yes | rejected | - | - |
| 06 | OES | yes | passed | - | - |
| 07 | OES | yes | rejected | - | - |
| 08 | OES | yes | passed | - | - |
| 09 | MS | yes | rejected | yes | Passed |
| 10 | MS | yes | passed | - | - |
| 11 | OES | yes | passed | - | - |
| 12 | MS | yes | passed | yes | passed |
| 13 | OES | yes | passed | - | - |
| 14 | OES | yes | passed | - | - |
| 18 | OES | yes | passed | - | - |
| 19 | MS | yes | rejected | yes | passed |
| 21 | MS | yes | rejected | yes | passed |

The answers to the questionnaire on quality system implementation indicate that most laboratories have taken some initial steps of quality control measures like using reference materials for instrument calibration and method check, keeping logbooks and quality control charts that allow long-term performance monitoring and uncertainty estimation of the different analytical methods. The frequency of analysing quality control samples (QC samples) during a batch of routine samples and the frequency of instrument re-calibration is very variable.

**Summary graphs: z-Score plots sorted by analyte in three different plant test samples**

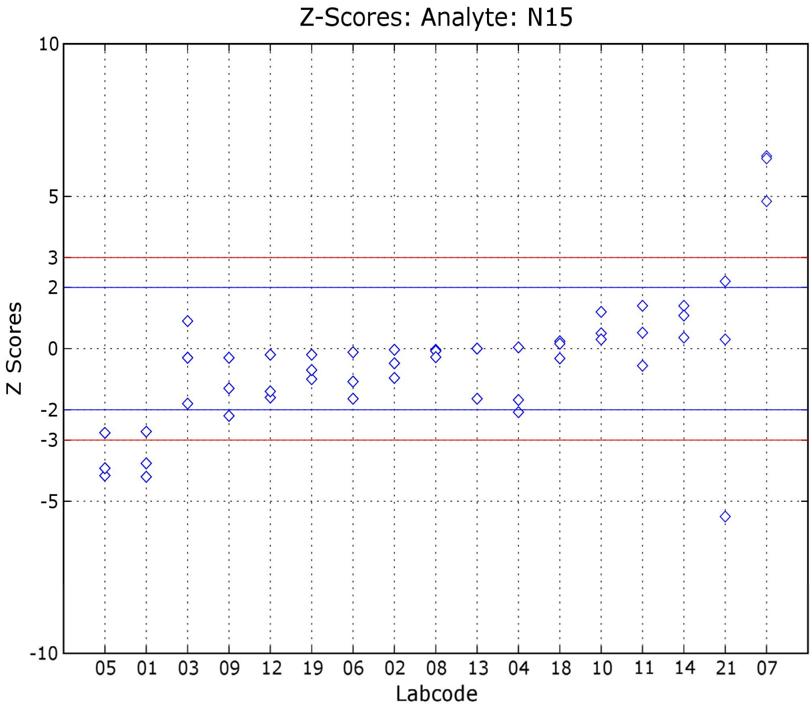



**Figure 7. % $^{15}$N isotopic abundance determination**

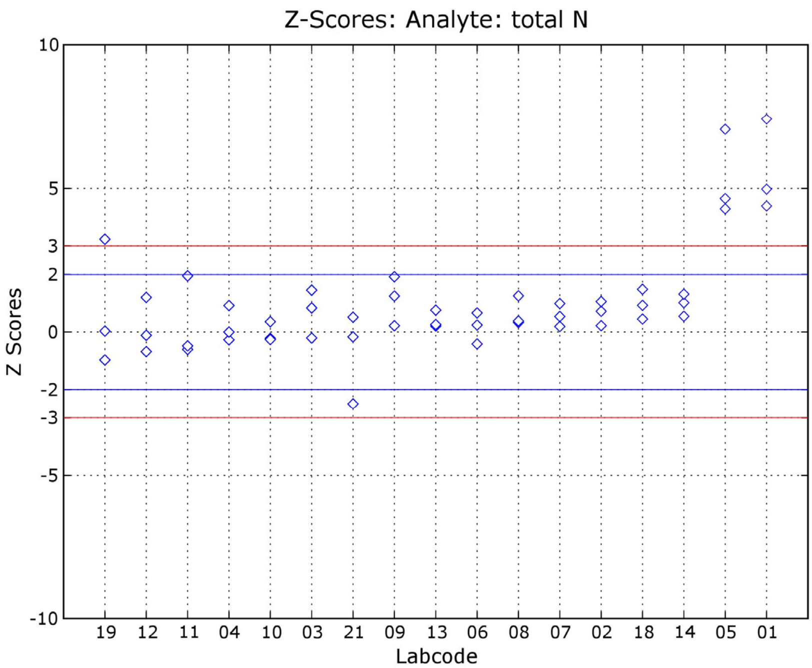



**Figure 8. Weight % total nitrogen determination**

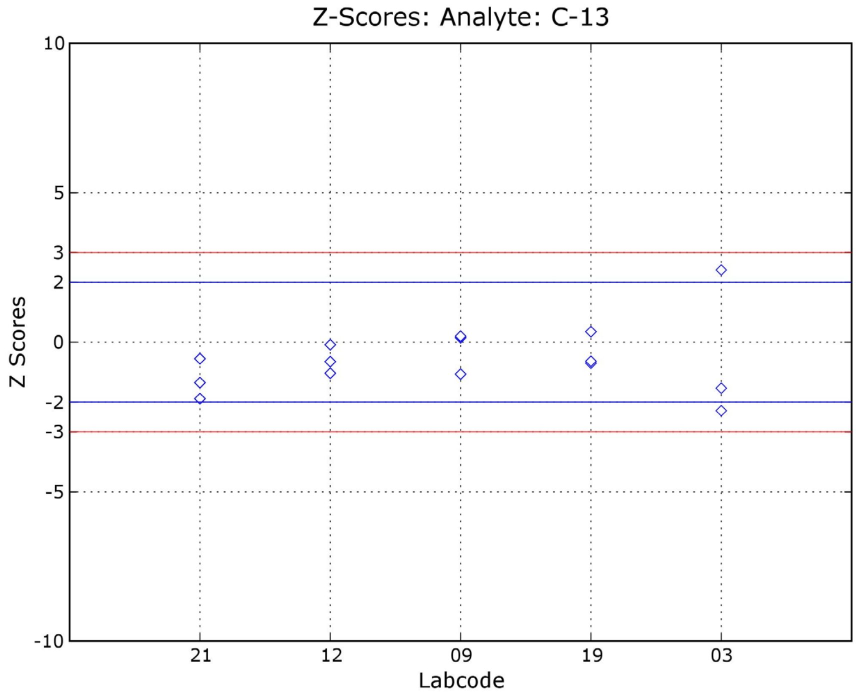



**Figure 9. Delta ‰ C-13 isotopic abundance determination**

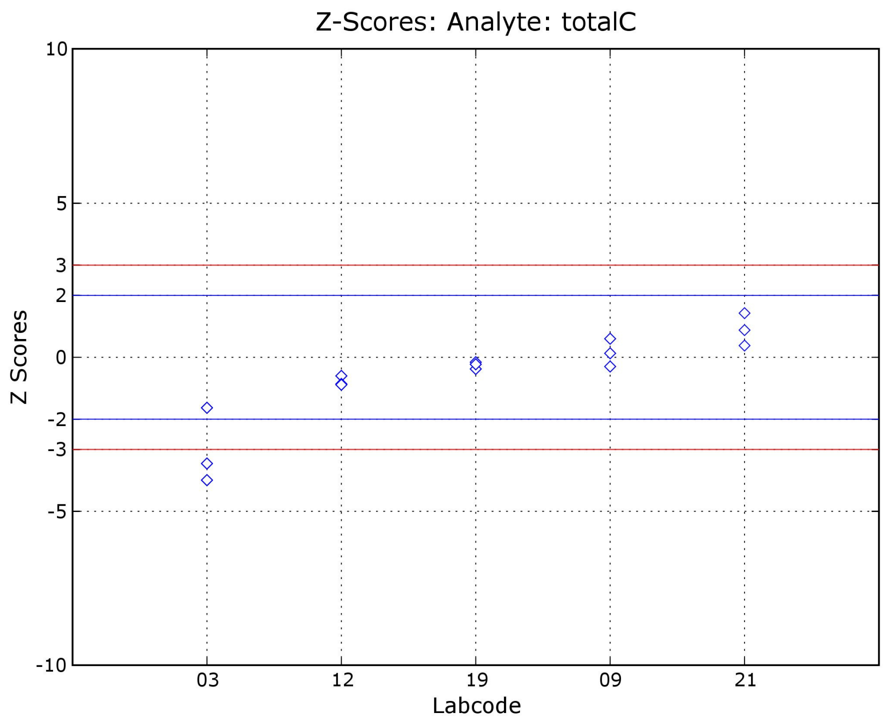



**Figure 10. Weight % total carbon determination**

# 6. Appendices

## 6.1. Publications

■ IAEA 2005: Nutrient and Water Management Practices for Increasing Crop Production in Rainfed Arid/Semi-Arid Areas. IAEA-TECDOC Series No. 1468 (2005) Responsible officers: **Ms Lee Heng** and Mr Gamini Keerthisinghe. http://www-pub.iaea.org/MTCD/publications/PubDetails.asp?pubId=7270

■ Bayala, L. and **Heng, L.K.** 2005. Hydraulic lift study in native tree species in an agroforestry parkland of West African dry savanna. FAO/IAEA Technical Meeting Combating Soil Degradation to Enhance Food Security in Africa: The Role of Nuclear Techniques in Developing Improved Soil, Water and Nutrient Management Practices. Nairobi, Kenya.

■ Bernard, C., **Mabit, L**. and Laverdière, M.R. 2005. Using fallout radionuclide $^{137}Cs$ to assess the magnitude and spatial extent of soil erosion and sediment production areas in the Boyer River watershed (Québec, Canada). In: Geophysical Research Abstracts (CD-Rom), Volume 7, EGU General assembly 2005, ISSN: 1029-7006. Abstract EGU05-J-06075. pdf , 2 pages.

■ Çağirgan, M. İ., Özbaş, M.O., **Heng, L.** and Afza, R. 2005. Genotypic Variability for Carbon Isotope Discrimination in the Mutant and Improved Lines of Barley. Issue 3, September 2005, IEHS.

■ **Heiling M, Arrillaga J L** and **Hood-Nowotny, R** and **X. Videla** (IAEA fellow) (2006, worked on during 2005) Preparation of ammonium 15N amd nitrate-15N samples by microdiffusion for isotope ratio analysis by optical emission spectrometry. Communications in Soil Science and Plant Analysis 37, 337-346.

■ IAEA. Ed. **G. Hardarson** Guidelines on Nitrogen Management in Agricultural Systems. (In press)

■ **Mabit, L.,** Bernard, C. and Laverdière, M.R. *Assessment of erosion in the Boyer River watershed (Canada) using a GIS oriented sampling strategy and* $^{137}Cs$ *measurements* (Article written in 2005 and submitted to CATENA)

■ **R. Shaheen** (IAEA fellow) and **R. C. Hood-Nowotny** (previous SSU staff) (2005) Carbon isotope discrimination: potential for screening salinity tolerance in rice at the seedling stage using hydroponics. Plant Breeding 124, 220 – 224.

## 6.2. Travel and scientific meetings

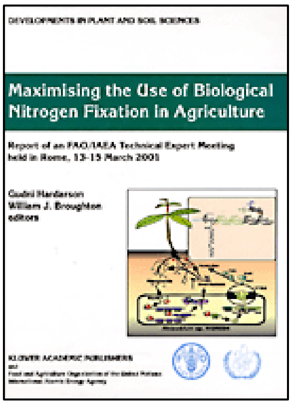
**Mr. Gudni Hardarson**, 2005-05-02 to 06, traveled to Ulaanbataar and Darkhan, Mongolia to plan the work for TC Project MON5014 with the counterpart in details; to plan greenhouse and field experiments for the next growing season in 2005 and to do some preliminary training of the project staff.
**Ms. Lee Heng**, 2005-04-09 to 14 attended an ICARDA workshop, Aleppo, Syria. Lee was invited to attend a workshop on water productivity in crops at no cost to the Agency.
**Mr. Lionel Mabit**, 2005-10-10 to 12, attended an FAO Meeting in Rome, Italy to participate and give an oral technical presentation at the FAO Regional workshop presenting Priority Actions Programme (PAP)/Regional Activity Centre (RAC) and FAO experiences in combating land degradation in Mediterranean coastal areas (Technical Officers: Long Nguyen and Lionel Mabit).

## 6.3. Awards

### ■ Best scientific paper published in the journal “Vecteur Environnement”

**Messrs Lionel Mabit** and **Claude Bernard** received the 2005 “Arnold-Drapeau Award” for the best scientific paper published in the journal “Vecteur Environnement” edited by the Réseau Environnement (www.reseau-environnement.com), in Quebec. The awarded paper was entitled: “Quantifying Soil Erosion and Study of the Origin of Sediments Clogging the Spawning Ground of the Boyer River (Quebec)”.

### ■ Departmental Award




In February 2005, **Mr. Gudni Hardarson**, Head of the Soil Science Unit, received the Departmental Award for the best Technical Report published during the year 2003. The publication entitled "Maximising the Use of Biological Nitrogen Fixation in Agriculture" was a report of an FAO/IAEA Technical Expert Meeting held in Rome, 13-15 March 2001. It was published by Kluwer Academic Publishers and FAO/IAEA both as a hard cover book and as an issue of Plant and Soil, Volume 252 (1) 2003. Incorporating contributions from microbiologists, molecular biologists, plant breeders and soil scientists this volume reports the results and recommendations of an FAO/IAEA meeting of twelve experts on biological nitrogen fixation

## 6.4. TCPs and CRPs supported

**Operational Projects and Technical Officers at the SSU responsible for implementation**

| TCP | Title | Technical Officer |
|---|---|---|
| CPR/5/014 | Increasing the Productivity of Crop/Livestock Production System | G. Hardarson |
| KEN/5/026 | Isotope Techniques for Assessment of Water and Nitrogen Use Efficiency in Cowpea and Maize Intercropping Systems | L. Heng |
| LIB/5/010 | Establishing a Drip Irrigation-fertigation System Using Nuclear Techniques | L. Heng |

| | | |
|---|---|---|
| MON/5/014 | Application of Isotopes in Soil and Plant Studies | G. Hardarson |
| SEN/5/028 | Enhancement of Biological Nitrogen Fixation and Phosphorus Use Efficiency in Cowpea under Drought Conditions | G. Hardarson |
| SIL/5/008 | Contribution of Nitrogen Fixing Legumes to Soil Fertility in Rice-based Cropping Systems | G. Hardarson |
| SIL/8/002 | Improved Water Management Technologies in the Inland Valley Agro-Ecology | L. Heng |
| SLO/5/002 | Protecting Groundwater and Soil against Pollutants Using Nuclear Techniques | L. Heng |
| YEM/5/002 | Drip Irrigation and Fertigation for Improved Agricultural Productivity | L. Heng |

## 6.5 Fact sheets presented to the General Conference 2005 (See copies below)

1 - Assisting Member States to achieve international analytical standards

2 - Biological nitrogen fixation: the source of N nutrient to increase yields

3 - The use of radionuclide techniques in soil erosion studies

4 - Water in agriculture: the role of nuclear techniques

# Assisting Member States to achieve international analytical standards

Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

**Martina Aigner** [1]

*M.Aigner@iaea.org*

For more than forty years the IAEA has been assisting laboratories in its Member States to maintain and improve the quality and reliability of analytical data. This is achieved by organizing worldwide and regional intercomparison studies and 'proficiency tests' and by providing appropriate reference materials.

Participation in proficiency testing schemes ensures an objective means of assessing and demonstrating the quality of the obtained laboratory data and reinforces the confidence of end-users in the reliability of the reported analytical results.

*Fig. 1. Analytical training at the Seibersdorf laboratories*

The External Quality Assurance (EQA) programme currently operated by the Soil Science Unit of the FAO/IAEA Agriculture and Biotechnology Laboratory in Seibersdorf, Austria encompasses:

1. Training on the implementation of basic quality systems in isotope laboratories;
2. Production and provision of purposely tailored information materials, standard operating procedures and handbooks on quality assurance;
3. Production and provision of liquid and natural matrix reference materials;
4. Organisation of annual proficiency tests on isotope abundance determination of $^{15}N$ and $^{13}C$, the most common stable isotope tracers in agricultural research;
5. Continuous technical advice to participating laboratories on analytical issues, including on-line troubleshooting and direct communication.

**The External Quality Assurance programme**

The program aims at:

1. Providing start up support in the establishment of laboratory-internal quality control systems;
2. Providing initial recognition of the capabilities of participating laboratories to control their analytical and measurement processes;
3. Supporting the activities of participation laboratories to establish ISO-Standards and achieve accreditation by National authorities;

*Fig. 2. Reference materials for $^{15}N$ and $^{13}C$ in different matrices*

[1] Soil Science Unit of the FAO/IAEA Agriculture and Biotechnology Laboratory

4. Monitoring the quality and sustainability of the analytical performance over several years.

Overall, the IAEA with its EQA assists Member States to achieve their aims of providing national laboratory isotopic analyses of recognized international standards.

This is to certify that

*the $^{15}N$ working group of*

*CCHEN, Comisión Chilena de Energía Nuclear, Chile*

has successfully participated in and completed the

**Proficiency Testing Exercise "EQA2004"**

on total N- and $^{15}N$ isotope abundance analysis of plant materials

initiated by the Soil Science Unit of the
**FAO/IAEA Agricultural and Biotechnology Laboratory**
**Seibersdorf, Austria**
in the year 2004

The exercise included the following analyses:

- Total nitrogen content of three unknown plant materials
- $^{15}N$ isotope abundance analysis of three unknown plant materials

………………………………
**Martina Aigner**
**EQA-office, Soil Science Unit**
FAO/IAEA Agricultural and Biotechnology Laboratory
Seibersdorf, Austria

………………………………
**Gudni Hardarson**
**Head, Soil Science Unit**
FAO/IAEA Agricultural and Biotechnology Laboratory
Seibersdorf, Austria

*Fig. 3 Sample certificate for quality performing laboratories*

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**Soil and Water Management and Crop Nutrition Section: www-naweb.iaea.org/nafa/swmn/index.html**

# Biological nitrogen (N) fixation – The source of N nutrient to increase yield

Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

Maria Heiling [1] and Gudni Hardarson [1]

*M.Heiling@iaea.org and G.Hardarson@iaea.org*

**Biological nitrogen fixation (BNF) – the symbiosis that saves money**

Nitrogen is an essential plant nutrient. It is the nutrient that is most commonly deficient, contributing to reduced agricultural yields throughout the world. Developing countries used more than 55 million metric tonnes of nitrogenous fertilizer in 2003, worth billions of US dollars. Such fertilizer expenditure can be significantly reduced by incorporating biological nitrogen fixed leguminous crops into cropping systems.

For example, 2.6 million tonnes of N, worth approximately US $1500 million/year is fixed by soybean on 18.4 million ha in Brazil, a substantial saving for farmers in terms of reducing N fertilizer use.

*Fig. 1. Rhizobium nodules on a legume root*

In leguminous crops, a symbiotic relationship between a bacterium called Rhizobium and legumes can provide large amounts of nitrogen to the plant and subsequently to soils where they are grown. In this process the bacteria form nodules on the root system and convert the nitrogen coming from air into molecules that can be absorbed by the plants. Aside from their fertilizing properties, legumes are rich in protein and constitute a very important role in human and animal nutrition.

In the Soil Science Unit (SSU) of the FAO/IAEA Agriculture and Biotechnology Laboratory fellows from all over the world receive training in the use of $^{15}N$ stable isotope techniques to optimize nitrogen fixation. Several parameters such as the placement of the nodules on the legume root system, the amount of soil mineral nitrogen and phosphorus fertilizer applied and the temperature have an impact on the amount of nitrogen fixed by the plant. It is therefore important to identify the relative importance of these parameters on biological N fixation. The $^{15}N$ isotope dilution method is an appropriate technique to test the biological nitrogen fixation in the laboratory first. This useful knowledge can then be communicated to farmers and can be tested under field conditions.

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[1] Soil Science Unit of the FAO/IAEA Agriculture and Biotechnology Laboratory

**Biofertilizers:** The SSU's expertise in BNF studies can enable us to assist Member States with biofertilizer programmes. Biofertilizers are materials carrying microorganisms that are capable of fixing atmospheric nitrogen or solubilizing insoluble soil phosphate and making nitrogen and phosphorus available to growing crops.

### The role of below ground nitrogen

Most biological nitrogen fixation studies concentrated on the above-ground part of the plant. Through a $^{15}N$ stem labelling method, scientists have the opportunity to investigate what is going on below ground. Greenhouse experiments are being planned in the SSU to shed more light onto this poorly understood area. Using this method the plant incorporates $^{15}N$-labelled urea. The transfer of $^{15}N$ from $^{15}N$-labelled urea into the plant and subsequent accumulation in soil can then be quantified. SSU is also training fellows on using this technique in developing countries.

*Fig. 2. Common bean labelled with highly $^{15}N$-enriched urea*

**Ongoing technical contracts and technical cooperation projects with nitrogen component**

| Project | Country |
|---|---|
| BRA 12969 BNF contribution to sugar cane crop by endophytic nitrogen fixation | Brazil |
| URU 12845 Survey of indigenous diazotrophic bacteria associated to maize in Uruguay | Uruguay |
| CPR/5/014 Increasing the productivity of crop / livestock production systems | China |
| MON/5/014 Application of isotopes in soil and plant studies | Mongolia |
| SIL/5/008 Contribution of nitrogen fixing legumes to soil fertility in rice-based cropping systems | Sierra Leone |

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**Soil and Water Management and Crop Nutrition Section: www-naweb.iaea.org/nafa/swmn/index.html**

# The use of radionuclide techniques in soil erosion studies


Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

Lionel Mabit [1] and Claude Bernard [2]

*L.Mabit@iaea.org and C.Bernard@iaea.org*


Soil erosion is a natural process that can be accelerated dramatically following improper land use and/or management. Human activities can result in erosion rates that are many times greater than natural rates. Worldwide, erosion is considered to be the most widespread and serious form of soil degradation.

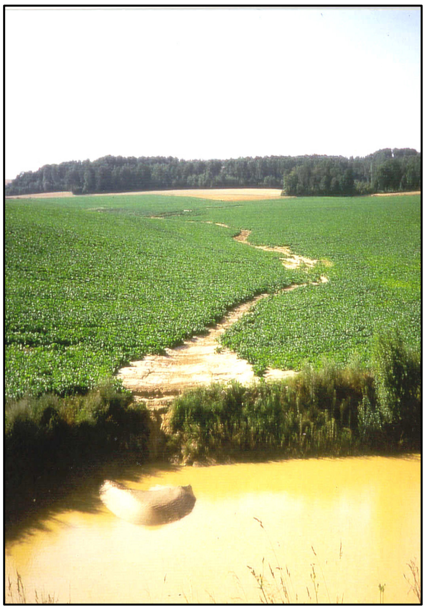

*Fig. 1. Soil erosion, an agricultural and environmental problem*

Erosion is of concern since it can reduce soil productivity as a result of export of inorganic and organic material and nutrients out of the cultivated fields. These are the so-called 'on-site' impacts of erosion. Some of the exported materials, and the associated elements, find their way to water bodies The result is a degradation of the water quality due to suspended solids, sedimentation, eutrophication and pesticide toxicity, what is currently referred to as off-site impacts.

*Fig.2. Soil sampling for FRN-based erosion study (Courtesy: Y. Li)*

Despite its importance, many countries lack reliable and comprehensive data on the problem, its magnitude and spatial extent. One of the reasons is that producing representative and reliable data on erosion is a long and resource intensive process.

Fallout radionuclides (FRNs), such as $^{137}Cs$, $^{210}Pb$ and $^{7}Be$, have proven to be very powerful tracers of soil movements, that can complement more conventional approaches. Starting in the mid-1990's the IAEA has been actively involved in supporting coordinated research activities to further develop several methodological aspects related to the use of these isotopes and in the dissemination of the techniques among Member States, through the joint efforts of the Soil and Water Management and Crop Nutrition Section (SWMCN) of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture and the Soil Science Unit (SSU) of the FAO/IAEA Agriculture and Biotechnology Laboratory.

*Fig.3. Reduced tillage to control erosion*

A first Coordinated Research Project (CRP), from 1996 – 2001, helped to test and validate the basic assumptions underlying the use of FRN, to accelerate the development of conversion models used to translate FRN data into soil movements and to evaluate the effect of specific land use management on soil erosion. A second CRP, planned for 2003 – 2007, builds on the results of the first one to assess the efficiency of different soil conservation practices, to continue the validation of conversion models and the development of user-friendly software to run these models.


[1] Soil Science Unit of the FAO/IAEA Agriculture and Biotechnology Laboratory
[2] Soil and Water Management and Crop Nutrition Section of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture

Besides CRPs, the IAEA is also involved in several national and regional technical cooperation projects (TCPs) that are related to the use of FRNs for erosion measurements (see table below). Through technical cooperation, technical and scientific capacity is built in the participating countries by providing scientific equipment as well as technical training, scientific and expert visits.

The IAEA is also supportive of Member States by hosting several scientific visitors and fellows, for their training, so they can benefit from the expertise of the SSU and SWMCN staff and from the equipment and research facilities in the Agency's laboratories, Seibersdorf. A new individual fellowship programme on ''Erosion process assessment using nuclear techniques'' has been created at the SSU. The programme covers all the topics related to the use of FRNs to estimate erosion: introduction to erosion processes, sampling strategy at the field and/or watershed scale, sample preparation for gamma analysis, introduction to geostatistical analysis, mapping, analysis and interpretation of data, conversion models.

*Fig. 4. Field training on the use of FRN for erosion studies (Courtesy: L. Li)*

Finally, in order to support the research and technical cooperation programs, internal research projects using $^{137}Cs$ to quantify soil loss risks at the watershed scale are being implemented by the SSU, in collaboration with Boku University (Universität für Bodenkultur).

**On-going Technical Cooperation projects with an erosion component**

| Project | Country |
| --- | --- |
| ALG/5/021 – Optimizing irrigation systems and surface water management | Algeria |
| CPR/5/015 – Assessment of soil erosion and effectiveness of soil conservation measures | China |
| CHI/5/048 – Integrated watershed management for the sustainability of agricultural lands | Chile |
| HAI/5/003 – Enhancing crop productivity through the application of isotope nuclear techniques | Haiti |
| PHI/5/031 – Assessment of erosion and sedimentation processes for effective formulation of soil conservation and water quality protection measures | Philippines |
| RAS/5/043 – Sustainable land use and management strategies for controlling soil erosion and improving soil and water quality | China, Indonesia, Malaysia, Mongolia, Myanmar, Pakistan, Philippines, Sri Lanka, Thailand, Vietnam |
| SRL/5/038 – Application of isotope techniques for soil erosion studies | Sri Lanka |
| TAD/5/002 – Assessment of soil erosion and sedimentation for land use | Tajikistan |

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# Water in agriculture: The roles of nuclear techniques

Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

Lee Heng [1] and Long Nguyen [2]

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Agriculture accounts for nearly seventy per cent of the world's demand for fresh water. Improper management of this resource has contributed extensively to the current water scarcity and pollution problems in many parts of the world and is a serious challenge to future food security and environmental sustainability. Addressing these issues requires an integrated approach to soil, water, plant, and nutrient management at the plant-rooting zone, where water use for food and agriculture and farm management can significantly modify the quantity and quality of both surface and groundwater. Nuclear technologies can contribute significantly to alleviate constraints/limitations to agricultural productivity and thus fight hunger and poverty by providing quantitative, precise, specific and dynamic information about the key components of productivity and sustainability (sources, availability, uptake and losses) of major nutrients and water.

The Soil and Water Management and Crop Nutrition (SWMCN) sub-programme is assisting Member States to develop and promote the adoption of nuclear-based technologies for optimizing water and nutrient management practices, which support intensification of crop production and the preservation of natural resources.

To ensure food security and sustainable water management for agriculture there is a need to produce more food per drop of water used in the agricultural sector. That is to increase both the crop water productivity (CWP) and water use efficiency (WUE) without any negative impact on downstream water quantity and quality. The IAEA is currently conducting CWP studies in various parts of the world (China, Kenya, Turkey and Uzbekistan) using nuclear and associated techniques to assess soil and water management and water saving technologies to increase crop productivity and reduce crop failure for the farmers.

*Fig. 1. Crop water productivity study in Kenya (Courtesy: I.V. Sijali)*

*Fig. 2. Fertigation study in the Syrian Arab Republic (Courtesy: M. Janati)*

One of these technologies is fertigation, which is the direct application of water and nutrients to plants through a drip irrigation system. It is an effective means of improving agricultural water management practices as the requirements of the crops can be regulated, hence improving the efficiency of water and fertilizer use, leading to better management of scarce and expensive resources and often a higher yield. The SWMCN sub-programme has been coordinating various technical cooperation projects (TCPs) on fertigation and the Soil Science Unit (SSU) at the Agency's Laboratories, Seibersdorf has been working on various technical aspects of water management, as well as training of fellows to use nuclear and associated techniques such as soil moisture neutron probes in the assessment of water and fertilizer use efficiencies.

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[1] Soil Science Unit of the FAO/IAEA Agriculture and Biotechnology Laboratory

[2] Soil and Water Management and Crop Nutrition Section of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture

Other aspects of soil water management, such as basic theories on soil physical and hydraulic properties, soil water balance, evapotranspiration, WUE and CWP calculations, irrigation scheduling and crop simulation modelling, are provided regularly to both individual and group fellowship training courses.

*Fig. 3. Fellowship training at the Agency's laboratories, Seibersdorf*

Natural variation in the abundance of stable isotopes (e.g. $^{18}O$ and $^{2}H$) exists in our environment (soil, rain, plant and water), which can be utilized to provide unique information on fluxes of water and the identification of water sources utilized by plants. The natural abundance isotopic technique has been successfully utilized in the dry savannah regions of Africa (Burkina Faso and Niger) to quantify the contribution of hydraulically lifted water to sustainable food production in the rain-fed agriculture while combating desertification.

**Ongoing TCPs and research activities on soil water management**

| Project | Country |
|---|---|
| ALG/5/021 – Optimising irrigation systems and surface water management | Algeria |
| CMR/5/013 – Use of nuclear techniques in soil, nutrient and water studies | Cameroon |
| GHA/5/032 – Enhancing production and use of cassava | Ghana |
| KEN/5/026 – Isotope techniques for assessment of water and nitrogen use efficiency in cowpea/maize intercropping systems | Kenya |
| LIB/5/010 – Establishing a drip irrigation/fertigation system using nuclear techniques | Libyan Arab Jamahiriya |
| MON/5/014 - Application of isotopes in soil and plant studies | Mongolia |
| SIL/8/002 – Improved water management technologies in the Inland Valley agro-ecology | Sierra Leone |
| TUR/5/024 – Improving crop productivity through nuclear and related techniques | Turkey |
| UGA/5/025 – Integrated nutrient management for increased and sustainable crop production on small-holder farms | Uganda |
| YEM/5/002 – Drip irrigation and fertigation for improved agricultural productivity | Yemen |
| KEN12715 – Improving crop water productivity for crop production in semi arid areas through improved water management practices | Kenya |
| TUR12716 – Monitoring and assessment of temporal soil water variability in two-course dryland crop rotation systems | Turkey |
| CRP12899 – Bio-economic analysis of water use efficiency for crop productivity in North China region | China |
| UZB12900 – Cotton and winter wheat water productivity study in Uzbekistan | Uzbekistan |
| BKF12520 – Hydraulic lift study in native tree species in an agroforestry parkland of West African dry savannah | Burkina Faso |
| NER12521 – Hydraulic lift study in two native tree species in an agroforestry parkland of the West African dry savannah | Niger |

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