E. Fulajtar, L. Heng, M. Zaman, J. Halder, L. Mabit, J. Adu-Gyamfi

Use of nuclear techniques for enhancing climate smart agriculture
• October 1957, the First General Conference established the IAEA
• Headquarters in Vienna, Austria
• Opening the Vienna International Centre, August 1979
World Soil Day Celebration
Food Security, Soils and Climate-Smart Agriculture
Russian Research Institute of Floriculture and Subtropical Crops, Sochi
5 December 2019

IAEA
International Atomic Energy Agency
Department of Nuclear Sciences and Applications

- Division of Human Health
- Division of IAEA Environment Laboratories
- Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture
- Division of Physical and Chemical Sciences
- Seibersdorf laboratories
- Research Contracts Administration Section
World Soil Day Celebration
Food Security, Soils and Climate-Smart Agriculture
Russian Research Institute of Floriculture and Subtropical Crops, Sochi
5 December 2019

The Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture
Established on 1 October 1964

The FAO/IAEA Agriculture and Biotechnology Laboratories
Use of nuclear techniques in soil science

Soil and Water Management and Crop Nutrition (SWMCN) Subprogramme
Meeting the Challenges related to Climate Change

Activities

- Coordinated research projects
- Technical cooperation projects
- Research and Development
- Laboratory Services
- Publishing activities
Meeting the Challenges related to Climate Change

Coordinated Research Projects

Main objective
 Developing new nuclear techniques and improving methods

Management
 Managed by Programme Officers from NSA
 Concept: cooperation of scientists from developed and developing countries
 Duration: 5 years
 Budget: 500 kEuro in total

Implementation tools
 Consultant meeting
 Research contracts: 7 kEuro/year + meeting attendance
 Technical contracts: 10 kEuro/year + meeting attendance
 Research agreements: meeting attendance
 3 Research Coordination Meetings
 Support from Soil Lab
Technical Cooperation Projects

Main objective
- Disseminate nuclear technologies to Member Countries

Management
- Managed by Project Management Officers from TC
- Technical support by Technical Officers from NSA
- Concept: national or regional projects
- Duration: 2, 3 or 4 years
- Budget: 20 – 300 kEuro/year

Implementation tools
- Expert missions
- Fellowships and training courses (regional or national)
- Procurements
- Scientific visits
- Others (subcontracts, home based assignments)
Meeting the Challenges related to Climate Change

Research and Development

- Research activities carried by Soil Lab (supporting CRPs)

Laboratory services

- Laboratory intercomparison tests
- Training of fellows and training courses

Publishing

- Methodological handbooks
- Papers in scientific journals
- Presentations at conferences
- Awareness rising and dissemination
Tests of the suitability of $^{239+240}\text{Pu}$ for soil erosion assessment in Austria (Grabenegg agri. site) – Second year

Results of the test for the Grabenegg agricultural site

11 bulk cores collected (2-3 increments) end Q4_2017 + pre-treatment 24 samples [Q1_2018]

24 $^{137}\text{Cs}$ analysis in Seibersdorf [Q2] + 24 $^{239+240}\text{Pu}$ analysis at CNESTEN (Morocco) [Q3-Q4]

$^{137}\text{Cs}$ vs Pu along the transect

[RS] $^{137}\text{Cs} = 8180 \text{ Bq/m}^2$

[RS] $^{239+240}\text{Pu} = 56 \text{ Bq/m}^2$

Erosion rates ≤ 5 t/ha/yr
## Coordinated Research Projects

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<tr>
<th>No.</th>
<th>Code</th>
<th>Project Description</th>
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<td>D1.20.14</td>
<td>Enhancing agricultural resilience and water security using Cosmic-Ray Neutron Sensor</td>
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<td>2</td>
<td>D1.50.16</td>
<td>Minimizing Farming Impacts on Climate Change by Enhancing Carbon and Nitrogen Capture and Storage in Agro-Ecosystems</td>
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<td>3</td>
<td>D1.50.17</td>
<td>Nuclear Techniques for a Better Understanding of the Impact of Climate Change on Soil Erosion in Upland Agro-ecosystems</td>
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<td>4</td>
<td>D1.50.18</td>
<td>Multiple isotope fingerprints to identify sources and transport of agro-contaminants</td>
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<td>5</td>
<td>D1.50.19</td>
<td>Monitoring and predicting radionuclide uptake and dynamics for optimizing remediation of radioactive contamination in agriculture</td>
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## Technical Cooperation Projects

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<td>AFG5008</td>
<td>Strengthening Climate Smart Agricultural Practices for Wheat, Fruits and Vegetable Crops</td>
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<tr>
<td>Algeria</td>
<td>ALG5031</td>
<td>Using Nuclear Techniques to Characterize the Potentials of Soils and Vegetation for the Rehabilitation of Regions Affected by Desertification</td>
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<td>Azerbaijan</td>
<td>AZB5003</td>
<td>Determining of Radioactive Substances in the Environment with a Focus on Water and Soil</td>
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<td>Bangladesh</td>
<td>BGD5033</td>
<td>Using Nuclear Techniques in Assessing River Bank Erosion</td>
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<tr>
<td>Burundi</td>
<td>BD5001</td>
<td>Improving Cassava Productivity through Mutation Breeding and Better Water and Nutrient Management Practices Using Nuclear Techniques</td>
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<tr>
<td>Cambodia</td>
<td>KAM5005</td>
<td>Enhancing Soil, Water and Nutrient Management for Sustainable Rice Production and Optimized Yield</td>
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<tr>
<td>Chad</td>
<td>CHD5009</td>
<td>Developing Sustainable Water Resources Management through the Use of Nuclear Isotopic Techniques in Drip Irrigation Systems</td>
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<tr>
<td>Costa Rica</td>
<td>COS5035</td>
<td>Building Capacity for the Development of Climate-Smart Agriculture in Rice Farming</td>
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<tr>
<td>Cuba</td>
<td>CUB5023</td>
<td>Strengthening National Capacities for the Development of New Varieties of Crops through Induced Mutation to Improve Food Security While Minimizing the Environmental Footprint</td>
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<td>GAB5003</td>
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<td>Gabon</td>
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<td>Improving Soil Fertility Management for Enhanced Maize, Soybean and Groundnut Production</td>
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<td>INT0093</td>
<td>Applying Nuclear Science and Technology in Small Island Developing States in Support of the Sustainable Development Goals and the SAMOA Pathway</td>
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<td>Building Capacity and Generating Evidence for Climate Change Impacts on Soil, Sediments and Water Resources in Mountainous Regions</td>
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<tr>
<td>Country</td>
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<tr>
<td>Iraq</td>
<td>IRQ5022</td>
<td>Developing Climate-Smart Irrigation and Nutrient Management Practices to Maximize Water Productivity and Nutrient Use Efficiency at Farm Scale Level Using Nuclear Techniques and Advanced Technology</td>
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<td>Kuwait</td>
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<td>Improving Production and Water Use Efficiency of Forage Crops with Nuclear Techniques</td>
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<td>Laos</td>
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<td>Lesotho</td>
<td>LES5009</td>
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<td>Madagascar</td>
<td>MAG5026</td>
<td>Biocontrol of Striga asiatica (L.) Kuntze through the development of tolerant rice and maize lines and its impact on microbiological and ecological functioning of soil</td>
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<td>Malawi</td>
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<td>Developing Drought Tolerant, High Yielding and Nutritious Crops to Combat the Adverse Effects of Climate Change</td>
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<tr>
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<td>MAL5032</td>
<td>Strengthening National Capacity in Improving the Production of Rice and Fodder Crops and Authenticity of Local Honey Using Nuclear and Related Technologies</td>
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<td>MLI5030</td>
<td>Developing and Strengthening Climate Smart Agricultural Practices for Enhanced Rice Production — Phase I</td>
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<tr>
<td>Mauritania</td>
<td>MAU5006</td>
<td>Contributing to the Improvement of Rice Crop Yields through the Application of Nuclear Techniques to Water Management and Soil Fertility</td>
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<td>MYA5027</td>
<td>Monitoring and Assessing Watershed Management Practices on Water Quality and Sedimentation Rates of the Inle Lake - Phase II</td>
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<td>Namibia</td>
<td>NAM5017</td>
<td>Improving Crops for Drought Resilience and Nutritional Quality</td>
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<tr>
<td>Pakistan</td>
<td>PAK5051</td>
<td>Developing Isotope-Aided Techniques in Agriculture for Resource Conservation and Climate Change Adaptation and Mitigation</td>
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<td>Panama</td>
<td>PAN5028</td>
<td>Improving the Quality of Organic Cocoa Production by Monitoring Heavy Metal Concentrations in Soils and Evaluating Crop Water Use Efficiency</td>
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<tr>
<td>Peru</td>
<td>PER5033</td>
<td>Application of Nuclear Techniques for Assessing Soil Erosion and Sedimentation in Mountain Agricultural Catchments</td>
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<tr>
<td>Qatar</td>
<td>QAT5008</td>
<td>Developing Best Soil, Nutrient, Water and Plant Practices for Increased Production of Forages under Saline Conditions and Vegetables under Glasshouse Using Nuclear and Related Techniques</td>
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<tr>
<td>Regional project Africa</td>
<td>RAF5079</td>
<td>Enhancing Crop Nutrition and Soil and Water Management and Technology Transfer in Irrigated Systems for increased Food Production and Income Generation (AFRA)</td>
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<tr>
<td>Regional project Africa</td>
<td>RAF5081</td>
<td>Enhancing Productivity and Climate Resilience in Cassava-Based Systems through Improved Nutrient, Water and Soil Management (AFRA)</td>
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<td>RAF5081</td>
<td>Enhancing Productivity and Climate Resilience in Cassava-Based Systems through Improved Nutrient, Water and Soil Management (AFRA)</td>
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<tr>
<td>Asia</td>
<td>RAS5073</td>
<td>Climate Proofing Rice Production Systems (CRIPS) Based on Nuclear Applications, Phase II</td>
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<td>Asia</td>
<td>RAS5080</td>
<td>Developing Sustainable Agricultural Production and Upscaling of Salt-Degraded Lands through Integrated Soil, Water and Crop Management Approaches - Phase III</td>
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<tr>
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<td>RAS5083</td>
<td>Reducing greenhouse gas emissions from agriculture and land use changes through climate smart agricultural practices</td>
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<tr>
<td>Asia</td>
<td>RAS5084</td>
<td>Assessing and improving soil and water quality to minimize land degradation and enhance crop productivity using nuclear techniques</td>
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<td>Asia</td>
<td>RAS5089</td>
<td>Enhancing the Sustainability of Date Palm Production in States Parties through Climate-Smart Irrigation, Nutrient and Best Management Practices (ARASIA)</td>
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<tr>
<td>Latin America</td>
<td>RLA5076</td>
<td>Strengthening Surveillance Systems and Monitoring Programmes of Hydraulic Facilities Using Nuclear Techniques to Assess Sedimentation Impacts as Environmental and Social Risks (ARCAL CLV)</td>
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<td>Latin America</td>
<td>RLA5077</td>
<td>Enhancing Livelihood through Improving Water Use Efficiency Associated with Adaptation Strategies and Climate Change Mitigation in Agriculture (ARCAL CLVIII)</td>
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<td>Latin America</td>
<td>RLA5078</td>
<td>Improving Fertilization Practices in Crops through the Use of Efficient Genotypes in the Use of Macronutrients and Plant Growth Promoting Bacteria (ARCAL CLVII)</td>
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<td>Latin America</td>
<td>RLA5084</td>
<td>Developing Human Resources and Building Capacity of Member States in the Application of Nuclear Technology to Agriculture</td>
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<td>Rwanda</td>
<td>RWA5001</td>
<td>Improving Cassava Resilience to Drought and Waterlogging Stress through Mutation Breeding and Nutrient, Soil and Water Management Techniques</td>
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<tr>
<td>Senegal</td>
<td>SEN5041</td>
<td>Strengthening Climate Smart Agricultural Practices Using Nuclear and Isotopic Techniques on Salt Affected Soils</td>
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<td>Serbia</td>
<td>SRB5003</td>
<td>Strengthening the Capacities for Soil Erosion Assessment Using Nuclear Techniques to Support the Implementation of Sustainable Land Management Practices</td>
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<td>Seychelles</td>
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<td>Supporting Better Sustainable Soil Management as Climate Change Adaptation Measures to Enhance National Food and Nutrition Security</td>
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<td>Sierra Leone</td>
<td>SIL5021</td>
<td>Improving Productivity of Rice and Cassava to Contribute to Food Security</td>
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<td>Slovenia</td>
<td>SLO5004</td>
<td>Improving Water Quality in Vulnerable and Shallow Aquifers under Two Intensive Fruit and Vegetable Production Zones</td>
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<tr>
<td>Sudan</td>
<td>SUD5037</td>
<td>Application of nuclear and related biotechnology techniques to improve crop productivity and livelihood of small scale farmers in drought prone areas of Sudan</td>
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<td>Togo</td>
<td>TOG5002</td>
<td>Improving Crop Productivity and Agricultural Practices Through Radiation Induced Mutation Techniques</td>
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<tr>
<td>Zambia</td>
<td>ZAM5031</td>
<td>Improving the Yield of Selected Crops to Combat Climate Change</td>
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</table>
Soil Erosion and soil conservation
Salinity and Nutrient Toxicities
Water Scarcity and Low Water Use Efficiency
Low Soil Fertility and Poor Crop Nutrition

Soil-related problems to be addressed
1. Minimising impact of agriculture on climate change
   - Agriculture contributes to GHG emissions by 30%; therefore they need to be reduced.
   - Nuclear techniques help to reduce the agricultural greenhouse gas (GHG) emissions and thus reduce the temperature increase and impact of extreme weather events (drought and flood).

2. Achieving food security under the conditions of climate change
   - Rising human population (current 7.3 billion, will reach 9 billion by 2050) requires more food.
   - Food security problem affects especially developing countries.
   - Nuclear techniques help to achieve food security.
Greenhouse gases (GHGs)

Carbon dioxide (CO$_2$):
- Mainly from fossil fuel burning (57%), land use changes and deforestation (17%). Can stay for 40 years in atmosphere.

Nitrous oxide (N$_2$O):
- N$_2$O is a powerful GHG as well as ozone depleting gas, mainly originate from N fertilizer, animal manure and urine. Its half life 120 years and 300 times more powerful than CO$_2$ in Global Warming.

Methane (CH$_4$):
- CH$_4$ originate from animals (cow, sheep, goat, buffalo, deer, camel), paddy (rice) soil and wetland, half life 12 years.
Agriculture: The victim or the source of GHGs?

Agriculture is the victim of climate change but it also contributes 24% to the total GHGs due to:

- Increasing demand of food and animal protein for growing human population
- Increased nitrogen fertilizer use (112 million t/year)
- Increasing number of dairy animals (260 million worldwide; majority in developing MS)
- Conversion of peatland into farming (in Asia and Africa)
Deforestation:

- The world's forests continue to shrink due to conversion into agriculture land.

- 130 million hectares of forest - an area almost equivalent in size to South Africa - have been lost since 1990.

- Africa and South America are the most affected areas.
Sources of agricultural greenhouse gases (Mt CO2-eq)

- Methane from cattle enteric fermentation: 1792 Mt CO2-eq
- Nitrous oxide from fertilised soils: 413 Mt CO2-eq
- Fertiliser production: 410 Mt CO2-eq
- Biomass burning: 672 Mt CO2-eq
- Rice production: 616 Mt CO2-eq
- Farm machinery: 158 Mt CO2-eq
- Irrigation: 369 Mt CO2-eq

Cool Farming: Climate impacts of agriculture and mitigation potential, Greenpeace, 2008
80% of degraded land is located in developing countries!
Soil Erosion

• Harsh arid climate, extreme rainfalls and inappropriate land management are making the soil more prone to erosion.

• Soil erosion affects 1.9 billion ha (65% of global soil resources; 80% in developing countries) and the affected area increases at alarming rate.

• Worldwide economic cost of soil erosion is US $400 billion y\(^{-1}\) (on and off-farm). This includes essential plant nutrient losses, poor water quality with reduced aesthetic value, deposition of sediments in dams and water reservoir.

• Slow soil formation rate: for 1 cm of fertile soil to develop, it takes about 100 to 300 years.
• Globally about 250,000 to 500,000 ha of arable land is lost to production every year due to salinization.
• Salinization can cause yield decreases of 10 to 25% for many crops and prevent cropping altogether when it is severe.
Nutrient Imbalance

• Strongly weathered tropical soils (oxisols, etc.) have poor fertility and low nutrient content.

• Approximately 40% of the world’s arable soils are acidic leading Al, Mn and Fe toxicities, with P, Ca, Mg, and K deficiencies.

• Acidic soils mobilize many of toxic heavy metals and results in increased plant uptake of toxic substances which end up in human and animal food chains.

• Regular lime applications can correct most soil acidity problem and improve soil health.
Water Scarcity and Low Water Use Efficiency

12% used for crop production

70% of all water withdrawn

world’s land surface

total world’s water uses
70% of global freshwater is used by agriculture
Water use efficiency is below 40% meaning 60% of the applied water is lost
• **Subsistence family farming** in developing countries is lacking balanced chemical *fertilizers* due to high cost.

• **Low nutrient use efficiency** on farm is always a challenge (NUE <40%; PUE<20%).

• **Climate change worsen nutrient depletion**, deterioration of soil fertility, loss of crop productivity and income decrease.
Nuclear Techniques Used in Soil Science

General principles

- Wide range of nuclear techniques can be used
- Isotopes, neutrons and X-rays are used
- Two groups of isotopes can be used:
  - Stable isotopes
  - Radionuclides
- Two approaches are used:
  - Observation of independent environmental processes (natural abundance of isotopes and neutrons)
  - Man-designed experiments (isotopic labelling techniques, emitting neutrons and X-rays)
1. Comparing proportion (expressed as isotope signature) of 2 or more isotopes of the same element in the same substance or chemical compound, (used mostly for stable and for few radioactive isotopes of major biogenic elements: Carbon, Hydrogen, Oxygen, Nitrogen, Sulphur, Phosphorous) to trace chemical processes of environmental circulation of these elements
   • Two isotopes of one element differs in number of neutrons and consequently in their atomic weight.
   • Isotopes of one element differing by their weight have different capability to enter into chemical reactions and physical processes.
   • Mutual proportion of two isotopes in compound entering into chemical reaction or into physical process is different than their proportion resulting from the chemical reaction or physical process.
   • Investigating the differences in isotope signatures of environmental objects such as air, water, soil, plant tissues, etc. we can trace the circulation of biogenic elements and water.
2. Comparing amounts of one isotope at two different places
   • Fallout radionuclides used as erosion tracers
   • Physical processes of transport

3. Measuring the energy of free neutrons in environment
   • Used for soil water measurements
   • Emitting own neutrons
   • Measuring naturally occurring neutrons (cosmic rays)

4. Bombarding elements by X-rays (X-ray fluorescence)
Isotopes

- The chemical properties of a single element are nearly identical (exception isotopes of hydrogen)
- The physical properties of isotopes are different from each other since these properties often depend on mass
Isotopes

- Isotopes are samples of an element with different numbers of neutrons in their atoms (Source: Climatica)
- 275 isotopes of the 81 stable elements
- 800 radioactive isotopes (natural and synthetic)
Nuclear Techniques Used in Soil Science

- **$^{15}$N**
  - To quantify biological nitrogen fixation to save N fertilizers

- **$^{15}$N $^{32}$P**
  - To quantify the flow and fate of N fertilizers to improve fertilizer use by crops

- **$^{13}$C**
  - To assess adaptation of crop tolerance to drought and salinity

- **$^{18}$O $^{2}$H**
  - To estimate sources and fluxes of water to improve WUE

To assess soil organic carbon storage ‘sequestration’
N-15 technique precisely measure N$_2$O emissions and identify the Nitrogen source (fertilizer versus soil N) enable us to adjust fertilizer N rate to crop need and demand.
Isotopic compositions of N

Atmospherically-derived nitrogen and fertilizer nitrogen have light $\delta^{15}$N values.

Animal-derived nitrogen (such as manure or septic-tank) is typically heavier.

Source: Vitoria et al. 2004
Nitrous oxide is produced from 4 different microbial processes.

- N-15 technique identifies the exact microbial process which enables us to put more control on that process to reduce N₂O.
Carbon-13 techniques

- Precisely measure both CO₂ and CH₄ emissions from different agroecosystems
- Identify their exact sources (different plant residues and organic matter in soil)
- Determine C storage (sequestration) in soil
- Labelling plant materials with carbon-13
Simplified Water Cycle

- **Snow**: Snowfall that accumulates on land.
- **Precipitation**: Rainfall that replenishes water bodies.
- **Snowmelt**: Melting snow, contributing to runoff.
- **Surface Runoff**: Water flowing across land surfaces.
- **Evapotranspiration**: Water vapor released from plants and soil.
- **River Discharge**: Water flowing into rivers.
- **Evaporation**: Water vapor released into the atmosphere.

Water flows below the ground in groundwater.
Isotopic ratios are reported in standard "\( \delta \)" notation as deviations in per mil (‰) from the Vienna-SMOW (Standard Mean Ocean Water)

Is defined as: \( \delta^{18}O \) (or \( \delta D \)) = \( 1000\left( \frac{R_{\text{sample}}}{R_{\text{VSMOW}}} - 1 \right) \)

\( R \equiv \frac{[^{18}O]}{[^{16}O]} \) (or \( R \equiv [D]/[H] \))
Stable isotope variability in precipitation

Warm
Low elevation
Low latitude

Cold
High elevation
High latitude

$\delta^{18}O$

-10%
-16%
-26%
-34%
-4%
-12%
-20%
0%

Principles of oxygen isotope fractionation
Decay of $^{14}$C allows groundwater dating
Components of runoff
Soil Moisture Neutron Probe

Measure soil moisture to determine when and how much to irrigate, thereby helping farmers to save water. Also ideal for saline conditions.

Cosmic Ray Neutron Sensor

Measure area-wide soil moisture (70 cm depth; 300 m radius (i.e. 30 ha in area))
Role of Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture

Joint FAO/IAEA Division through Soil and Water Management and Crop Nutrition Programme promotes the use of nuclear techniques for soil moisture assessment through:

• Coordinated Research Projects
• Technical Cooperation Projects
• Research and Development activities of Soil Lab
Validation of soil moisture assessment by remote sensing

Input data for hydrological modelling

Soil moisture monitoring using CRNS

Validation of soil moisture assessment by remote sensing

CRNS data

Stationary CRNS

Remote sensing

CRNS data

Hydrological model MIKE-SHE

Soil moisture maps
Improving irrigation management

- Traditional irrigation (poor WUE)
- Modern irrigation (improved WUE)

Further improving WUE by irrigation scheduling and heterogeneity mapping

Improving dryland management

- Overgrazing control

Flood forecast

- Early warning system

CRNS data
Minimizing Water Pollution from Agriculture
Nuclear Techniques Used (continued)

Fallout radionuclides:  
\(^{137}\text{Cs},^{210}\text{Pb}\) and \(^{7}\text{Be}\)

To estimate erosion and sedimentation

Compound Specific Stable Isotope Analyses (CSSI)

To identify the sediment sources

\(^{13}\text{C}\) in fatty acids of different ecosystems

Native Forest

Pasture

Clear felled Pine

Exotic Pine
Scheme of the $^{137}$Cs and soil redistribution by erosion: undisturbed, eroded and deposition site.
$\delta^{13}C$ of grassland (Source 5)

$\delta^{13}C$ of wheat (Source 1)

$\delta^{13}C$ of maize (Source 2)

$\delta^{13}C$ of coniferous forest (Source 3)

$\delta^{13}C$ of deciduous forest (Source 4)

$\delta^{13}C$ of sediment (Mixture of Sources 1-5)
During 1 year over 600 downloads
Thank you for your attention