Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

Soils Newsletter

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Contents

To Our Readers

Photo 1. Climate-smart agricultural practices for rice production in Viet Nam (photo credit: Q. Vu Duong)

Season's Greetings and a very Happy New Year to you all. Over the past year, the Soil and Water Management and Crop Nutrition (SWMCN) Subprogramme has made significant strides in enhancing the capacities of Member States in using nuclear and related techniques to develop climate-smart agricultural (CSA) practices and improve food security. Our work aims to address the challenges of climate change, declining soil fertility and land degradation, water scarcity, environmental pollution from fertilizers and microplastics as well as antimicrobial resistance (AMR). Towards this goal, we have increased our research and development (R&D) work, strengthened collaborations with both the public and the private sector, and fostered innovative solutions to develop new tools and applications using nuclear and related techniques. Using CSA practices, the SWMCN Subprogramme helped Member States to improve nutrient and water use efficiency, mitigating emissions of greenhouse gases (GHGs) and minimizing land degradation.

Our endeavors have aimed to contribute to the Atoms4Food Initiative. The SWMCN Subprogramme continues to provide technical assistance to the IAEA's Technical Cooperation Programme. Currently, we are engaged in supporting 54 Technical Cooperation Projects (TCPs), 42 national, ten regional and two interregional projects aimed at building capacity to enhance food security and reducing the negative impacts of climate change within Member States.

In 2024, we successfully completed two Coordinated Research Projects (CRPs): D15019 and D12014.

We are pleased to share some of our key scientific achievements from the past year. The TCP RAS5093 contributed to significant improvements in rice productivity in Asia. CSA practices helped farmers in Bangladesh, the Lao PDR, Myanmar, Nepal, Pakistan, and Viet Nam to increase their rice production on experimental plots by 1 to 2.5 tons per hectare compared to regional practices. In close collaboration with the Technical University of Madrid, Spain, CRP D15020, participating research agencies developed a novel method for measuring ammonia volatilisation at the field-scale and its mitigation.

The SWMCN Laboratory made key advancements including simplifying stable carbon-13 isotope measurements in plant materials using mid-infrared (MIR) spectroscopy, with initial success in cassava leaves. This work has paved the way for creating an MIR spectral database to facilitate rapid assessment of water conservation strategies.

The SWMCN Laboratory in collaboration with the Plant Breeding and Genetics and the Food Safety and Control Subprogrammes has undertaken R&D on the nexus of resource use efficiency, nutritional quality, and food safety in dryland crops under changing climate. A global virtual training course attracting over 120 participants was held.

The IAEA Scientific Forum, entitled "Atoms4Food: Better Agriculture for Better Life" was held during the IAEA General Conference 2024. Two panellists spoke about innovations in enhancing agricultural productivity. The Joint FAO/IAEA Center organised a side event on "Multi-disciplinary Approaches to Combat AMR in Food and Agricultural Systems towards Global One Health".

The IAEA Ministerial Conference on Nuclear Science, Technology and Applications and the Technical Cooperation Programme, was held in November 2024. The conference emphasised the Atoms4Food's role in improving crop resilience and productivity using nuclear and related techniques. It also highlighted the importance of private sector partnerships, exemplified by the new Partnership Agreement signed with Anglo-American to fund a CRP. Two invited representatives from the private sector emphasized the importance of fostering public-private partnerships.

October 2024 marked the 60th anniversary of the Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture. Established in 1964 as the Joint Division, the Joint FAO/IAEA Centre has played a pivotal role in promoting sustainable agricultural development and enhancing global food security by leveraging nuclear science and biotechnologies.

As we enter 2025, we commit to deepen our knowledge, foster innovative solutions, and strengthen private sector partnerships to address the challenges faced by our Member States. We will implement three new CRPs. The first CRP will integrate nuclear techniques with digital technologies to improve soil property mapping and soil moisture monitoring. The second CRP will strengthen preparedness and remediation strategies for agricultural areas impacted by soil contaminants. The third CRP, which is in collaboration with the private sector, will focus on building fertility of degraded land, reducing salinity and increasing crop productivity using polyhalite, a natural mineral containing several plant essential nutrients.

I would like to express my gratitude to our readers, counterparts, private sector partners and team members in supporting us in our journey. I would also like to invite you to continue to support us in our endeavours to use dedicated R&D and implement programmes to enhance food security, mitigate and adapt to climate change across the globe.

Mohammad Zaman
Head
Soil and Water Management and
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Staff News

Yu Cheng (China), began a one-year internship at the Soil and Water Management & Crop Nutrition (SWMCN) Laboratory in June 2024, funded by the China National Nuclear Corporation. She holds a master's degree in Environmental Management from the University of Queensland, Australia. At the SWMCN Laboratory, she is gaining hands-on experience in using portable Gamma-Ray Spectrometry to monitor soil properties such as texture, which she calibrates through soil particle size analysis in the laboratory. Additionally, she is applying remote sensing technologies to track soil moisture levels, generating valuable insights for agriculture, environmental management, and climate studies. This internship provides her with an opportunity to strengthen her expertise in nuclear and complementary techniques, including calibration methods, experimental design, and data analysis, while working alongside leading specialists in soil science.

Sônia do Amaral (Brazil) joined the Soil and Water Management & Crop Nutrition (SWMCN) Laboratory in November 2024 as a cost-free PhD fellow, funded by the Brazilian Foundation for Science and Technology, to work on micro-plastic biodegradation under CRP D15021. She is pursuing a PhD in applied nuclear physics with a focus on environmental sciences at the Physics Institute of the Federal Fluminense University, Brazil. Her primary research in Brazil centers on microplastic contamination, utilizing nuclear, stable isotope, and related techniques to assess the impact of this environmental stressor on agricultural soils and pristine ecosystems, such as Antarctica.

Abhishri Gupta (India) joined the Soil and Water Management & Crop Nutrition (SWMCN) Section as a Consultant in October 2024 for six months to help in project management, building partnerships with the private sector for extra budgetary resources under the Atoms4Food initiative, and provide technical inputs and editorial review of soil science and climate smart related reports and publications. She has an MSc in Global Change: Ecosystem Science and Policy from University College Dublin, Ireland and Justus Liebig University, Germany. She previously worked with the SWMCN section as an intern and assisted with the International Symposium on Managing Land and Water for Climate-Smart Agriculture held in July 2022 and guidelines for measuring greenhouse gases (GHGs). Her previous research activities include assessment of GHG measurements, carbon budgeting, biofuels, and the role of agriculture in increasing biofuel capacities and nature-based solutions for climate change.

Feature Articles

Effective quantification and abatement of ammonia emissions from fertilized crops

Why the Joint IAEA/FAO Centre is working on the quantification and abatement of this reactive nitrogen atmospheric pollutant

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Nitrogen (N) is an essential element for life as part of the proteins and DNA of most living organisms. Plants need this nutrient to develop normally. Likewise, animals need to ingest an adequate amount of protein including all essential amino acids. For this reason, N availability is essential in food production and food security. N enters cropping systems mainly through synthetic chemical fertilizers, animal manure and N fixation by legume plants. Once the crop is produced, it can be used for direct human consumption or as feed for livestock. A significant portion of the N consumed by animals ends up in manure. With good management, a portion can be recovered as N fertilizer for crops. Globally, each year approximately 200 teragrams of new N (Tg N) are applied into crops and grasslands, of which only 49 Tg N end up on our plates with 35 Tg N in crops and 14 Tg N for industrial use. In this way, the N use efficiency of the agri-food system is only 24%. The remaining N returns to the atmosphere as N_2, which represents a loss of a valuable resource, or is emitted as reactive N in the form of ammonia (NH_3), nitrate and oxides of N, impacting on both ecosystems and human health (Figure 1).

This lost N can be considered as "nitrogen waste." Global N waste represents a serious threat to environmental sustainability and compromises the ability of the agricultural sector to feed a growing population.

One of the key actions to decrease N waste is to abate NH_3 losses from fertilized crops worldwide. This reactive atmospheric pollutant harmfully impacts the health of ecosystems and society though the formation of particulate matter causing (e.g.) respiratory diseases.

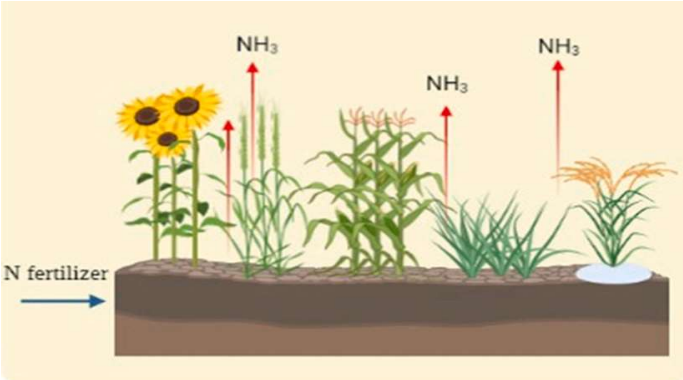

FIG. 1. Ammonia volatilisation in different crops. Source: Hurtado et al. (2024).

In addition, N synthetic fertilizers are about 60% of total fertilizers used worldwide. This is about 195 million tons of N in fertilizers. In the case of urea and ammonium-based fertilizers, ammonia losses could represent up to 40% of N applied to croplands thus leading to both direct economic and environmental issues. Economically, this N lost is just money spent by farmers leaving to the atmosphere.

From an environmental perspective, such N waste, once deposited or transformed as particulate matter in the atmosphere, causes serious impacts on both human and ecosystems health. The N deposited after volatilisation harmfully affects ecosystems through eutrophication and acidification of soils. The formation of particulate matter seriously impacts human health causing cardiorespiratory diseases. Overall, the cost of addressing these impacts, with volatilized ammonia as their core, has been estimated in a loss of annual welfare of 420 billion US Dollars due to premature death. The marginal abatement cost of ammonia emission is only 10% that of nitrogen oxides emission globally, highlighting the priority for ammonia reduction (Gu et al., 2021). In addition, implementing effective ammonia abatement actions would lead to 15 ± 4 billion USD fertilizer savings (Gu et al., 2023). Synthetic N fertilizers as well as livestock manures are behind ammonia losses from croplands. N from liquid manure, once applied on surface, may be lost to the atmosphere in significant amounts.

Huge efforts have been made in the last few decades by all concerned actors (e.g. the academia, public sector, fertilizer industry, and farmers) which have allowed the development and implementation of effective ammonia abatement strategies. This is observed in improved synthetic fertilizers and the incorporation of the fertilizer onto the soil just after application. Nevertheless, the first and most important step to effectively abate volatilized ammonia from croplands is a robust and precise measurement on-site at farm level.

There are a range of options to measure ammonia emissions on-site after fertilizer application, from expensive methods based on optical equipment to basic acid-traps to trap ammonia leaving the soil. The work promoted by the IAEA and led by Dr. Segundo Urquiaga (EMBRAPA, Brazil) through several IAEA funded Coordinated Research Projects (CRP) and Regional Cooperation Agreement for the Promotion of Nuclear Science and Technology in Latin America and the Caribbean (ARCAL) Technical Cooperation Projects (TCP) began this and was continued by Technical University of Madrid (UPM) in Spain.

Photo 1. set-ups of the Integrated Horizontal Flux Method (IHF) for on-site ammonia measurements. (photo credit: A. Sanz Cobeña (UPM)).

UPM has been working in the last decade to promote an effective quantification of ammonia under real conditions using a cost-effective micrometeorological technique, thus sensitive to changes in environmental conditions of the measurement area. The Integrated Horizontal Flux Method (IHF) has been proved to be highly reliable and robust enough in the on-site quantification of ammonia under real conditions (Photo 1).

Originally developed in New Zealand and successfully implemented in the United Kingdom and Denmark, the UPM team has been leading most of the EU IHF on-site measurements in the last decade and has shown very good performances when compared with other measurement options (Herrero et al., 2021). Now under the CRP D15020, the team in collaboration with IAEA aims to promote the expansion of this robust and cost-effective measurement technology to countries in Latin America, Asia and Africa to gain insight on N wasted in the form of the harmful volatilized ammonia. The combination of this measurement approach together with key isotopic analyses of N in agricultural soils will help to close the knowledge gaps on N dynamics and fates, shape more sustainable agroecosystems both in economic and environmental terms, thus ensure food security without compromising ecosystems and human health.

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First Microplastic Standard Reference Material developed under CRP D15021

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The ubiquitous presence of microplastics in the environment has emerged as a critical environmental pollutant of the Anthropocene. Significant efforts have been directed at assessing microplastic pollution due to its potential ecological and human health impacts. Soils have gained attention as a significant sink for these tiny plastic particles, stemming from agricultural practices of sewage sludge application, mulch degradation, use of wastewater for irrigation and atmospheric deposition. However, one critical challenge in studying microplastics in soil lies in the fact that there are no standardized analytical protocols and the absence of a reference material for quality control of detection, quantification, and characterization. Addressing this gap, through the Coordinated Research Project (CRP) D15021 the SWMCN in collaboration with an IAEA Collaborating Centre in Kuwait, Kuwait Institute for Scientific Research, developed a Standard Reference Material (SRM) for microplastics in the soil.

Why Standard Reference Materials Matter

SRMs serve as benchmarks for assessing the accuracy of data reported by a research group. SRMs are also pivotal in establishing the comparability of analytical results across laboratories. An SRM provides a consistent material to test and refine methods for extracting, identifying, and quantifying plastic particles. This is particularly important given the diversity of polymer types, shapes, and sizes that complicate microplastic analysis. The SRM tailored for microplastics in soil could harmonize methodologies, paving the way for reliable data to inform environmental policy and remediation strategies.

Challenges in SRM Development

Developing an SRM for microplastics in the soil is a complex endeavor. The material must reflect the diversity of microplastics typically found in soils, including different shapes and types of polymers. Additionally, these particles need to be uniformly mixed with soil matrices while maintaining their integrity over time.

It is the first step soil samples were collected from agricultural areas. These samples were pooled together to generate a homogenous sample of more than 430 kg. The sample was then sieved through a cascade of sieves of sizes 5mm, 2mm, 1,000 µm, 500 µm, 333 µm, 250 µm, 125 µm, 63 µm and 45 µm and <45µm. Once these size fractions were collected, they were weighed, and the ratio of each size fraction was worked out. To remove any carryover of the microplastics from these soils into the SRM, the samples were heated at 560 ± 5ºC for 6 hours. The samples were cooled and stored in aluminium boxes.

The glass jars with aluminium lids were used and the soil samples were reconstituted in the same ratio of size fraction as they were found in samples when collected. 400 grams of reconstituted soil samples were impregnated with a known amount of microplastics of different size fractions between 300 and 5,000 µm and polymer types. The polymers were procured from Goodfellow, United Kingdom and cryomilled to different sizes by Environmental Solutions Cambridge Limited, United Kingdom. The Samples were prepared in a clean room under laminar flow using the best laboratory practices.

Applications and Impacts

The availability of an SRM for microplastics in soil is transformative. The Member States laboratories can use it to standardize methods and assess variability in results. This will enable laboratories to participate in an Interlaboratory comparison exercise to assess their capabilities

The development of an SRM for microplastics in soil represents a critical step in advancing our understanding of microplastic pollution. It underscores the importance of standardization in environmental science, fostering collaboration and innovation to tackle one of the most pressing environmental challenges of our time.

Exploring Radiocaesium Soil-to-Plant Transfer on a global scale: Insights from Pot Experiments

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Current models used to predict radiocaesium soil-to-plant transfer need to be validated and refined for use on a global scale, especially in regions where interest is growing in nuclear energy to support increasing demand for low-carbon energy. Radioactive caesium, particularly ^{137}Cs with a half-life of 30 years, can be released to the environment from nuclear power plants after a nuclear incident. Radioactive caesium released into the environment could eventually contaminate food production systems, posing potential health risks. Models available to predict ^{137}Cs soil-to-plant transfer were mainly developed for temperate regions in Europe following the Chornobyl accident, and their applicability to non-temperate conditions, such as in tropical regions, remains questionable.

Many efforts were done at IAEA working groups (e.g. MODARIA; CRP D15019) to gather data of radionuclide transfer in non-temperate environments, such as tropical regions, but data needed for ^{137}Cs soil-to-plant transfer modelling are still lacking. A crucial factor required for radiological impact assessments is the concentration ratio, CR (kg kg^{-1}), which quantifies the transfer of ^{137}Cs from soil (Bq kg^{-1} soil) to plant (Bq kg^{-1} plant part). In soil-plant systems, ^{137}Cs behaves similarly to potassium (K), leading to competition for plant uptake. In the soil, ^{137}Cs strongly binds to 2:1 type clay mineral. Radiocaesium Interception Potential (RIP) (mmol kg^{-1} soil) is a reliable indicator of how strongly the soil retains ^{137}Cs (Cremers et al., 1988).

In our study at SCK CEN (Belgium), we measured ^{137}Cs CR for grass from soils with diverse mineralogy at varying stages of soil development and we tested whether available models could realistically predict ^{137}Cs transfer from these soils to plant. We collected 38 soils from contrasting parent materials and weathering stages; these soils represent soil sequences from Kenya and the Philippines and 26 other locations worldwide. We analysed soil mineralogy by X-ray diffraction and determined a soil weathering index based on the mineral composition. Fresh, volcanic soils had a low weathering index, while highly weathered, tropical soils had a high weathering index. By measuring the RIP and correcting for clay content, we could study the effect of mineralogy on the ^{137}Cs behaviour in soils (Figure 1). ^{137}Cs was weakly adsorbed in young and highly weathered soils, and it was strongly adsorbed in moderately developed soils. Weathered tropical soils are often dominated by 1:1 type clay mineral, such as kaolinite, having lower ^{137}Cs binding abilities compared to temperate soils with 2:1 type clay mineral, such as illite. Moreover, the RIPs per unit clay correspond well to the range of RIPs of pure clay minerals that dominate in soils at certain weathering stages (Figure 1), such as illite in younger and kaolinite in weathered soils.

Next, we tested the model of Tarsitano et al. (2011) , which predicts ^{137}Cs transfer from soils based on clay content, soil organic matter, soil exchangeable K, NH_4 in soil solution and contact time of ^{137}Cs in the soil. Overall, the model performed well on our data ($R^2 = 0.78$ for p <0.001, RMSE = 0.46, mean observed over predicted ratio 2.9) for soils of various weathering stages (Figure 2) but it underestimated the CR (mean O/P = 5) for soils with low RIP (<1000 mmol kg^{-1} soil). The discrepancy between the measured and predicted CR values for soils with low RIP may be attributed to the constant RIP value per unit clay used in the model. This assumption disregards the effect of mineralogy on ^{137}Cs transfer to plants. While this assumption is reasonable for temperate regions where 2:1 clay mineral dominates the clay fraction (Figure 1), it is unrealistic for volcanic and tropical soils, as the RIP per unit clay in such soils was considerably lower than in the model default value for temperate soils, due to the absence of 2:1 clay, resulting in underestimating ^{137}Cs transfer to plants (Figure 2). We concluded that this model should be improved. The model should distinguish between soils dominated by different types of clay at contrasting stages of weathering that in turn determine soil RIPs. The challenge is that this soil information must be available for the model to be used on a global scale.

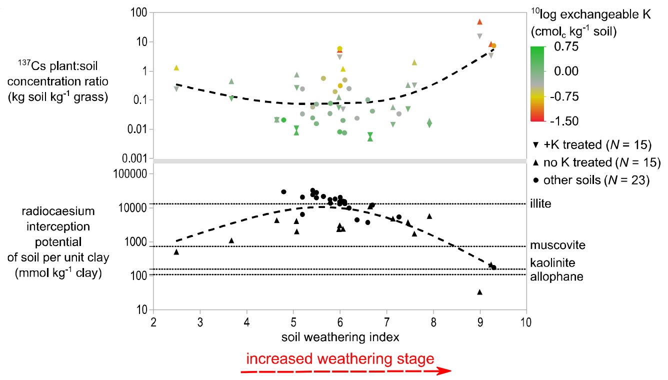

FIG. 1. Top: grass-soil ^{137}Cs concentrations ratios (log scale) in relation to calculated weathering index based on mineralogy. Data from soil studies with and without K fertilizer treatment are combined. Points on the graph are arithmetic mean CR values (n = 3) and are colored depending on exchangeable K content in soils (note log scale). Bottom: RIP of soil per unit clay (highest clay content) as soil weathering increases based on mineralogy. The dashed line is a cubic spline with standardized X values and a lambda of 3.0 for CR and 4.5 for RIP per unit clay. The dotted lines are RIP of allophane (111 mmol kg^{-1}, illite (10,000–16,000 mmol kg^{-1}, muscovite (740 mmol kg^{-1} and kaolinite (6–310 mmol kg $^{-1}$), taken from a wide range of international studies (references can be found in Vanheukelom et al. (2024)

Our findings highlight the risk of ^{137}Cs transfer to plants in highly weathered mineral soils. This study aims to provide crucial information on radionuclide transfer in tropical environments to support the application of food chain models and approaches for radiological environmental impact assessments. Understanding the dynamics of ^{137}Cs soil-to-plant transfer is important to ensure the safety of nuclear installations and minimise environmental and health impacts by assessing and mitigating radiological risks on a global scale. This work was recently published in the journal *Science of the Total Environment* (Vanheukelom et al., 2024).

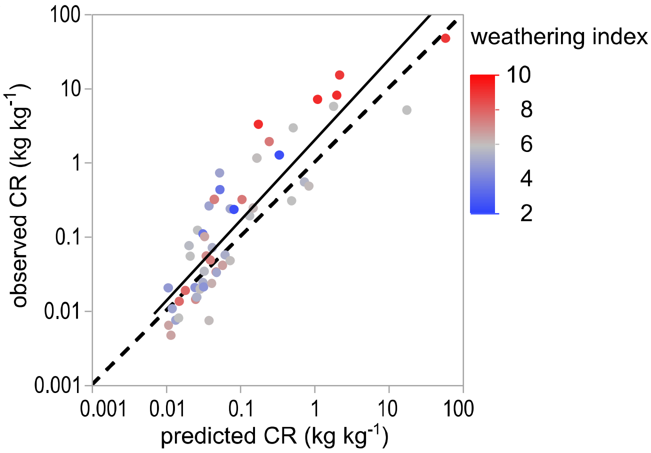

FIG. 2. Predictions of ^{137}Cs grass-soil concentration ratio with the model of Tarsitano et al. (2011) compared with observed CR values (N = 53). Points on the graph are mean CR values (n = 3). They are colored according to a calculated weathering index based on mineralogy, with the youngest equal to 2.5 (blue) and the oldest equal to 9.3 (red). The full line is the regression line, and the broken line is the 1:1 line.

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Highlight

The private sector at the IAEA Ministerial Conference

Zaman, M.

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During the opening session of the IAEA Ministerial Conference on Nuclear Science, Technology and Applications and the Technical Cooperation Programme in Vienna on 26 November 2024, Mr Tom McCulley, the CEO of Anglo American's Crop Nutrients business, announced its partnership with the IAEA, along with a generous financial contribution for launching a coordinated research project (CRP) under the Atoms4Food initiative that aims to address growing hunger around the world (Photo 1).

The CRP with Anglo American is focusing on the development of climate-smart agricultural practices to effectively manage and remediate salt-affected soils. One of the main objectives of the CRP is to measure and compare the benefits and effectiveness of applying polyhalite mineral and other commercially available soil additives to reclaim salt-affected soils, enhance crop productivity and quality under changing climate, and understand nutrient release and dynamics. Polyhalite is a naturally occurring mineral containing the nutrients potassium, sulphur, magnesium and calcium. Research is required to understand the full potential of this complex mineral.

The IAEA, through the Joint FAO/IAEA Centre, has extensive experience and expertise in the use of isotopic techniques to trace the dissolution and movement of nutrients in soils. The movement of nutrients in soils is key to understanding and comparing how natural minerals behave in soils containing natural polyhalite compared to commonly available fertilizers.

Furthermore, two CEOs of Chinese fertilizer companies: Mr Zhang Qingyong, Guangdong X United Agriculture which is a large scale agricultural inputs consortium, and Mr Luca Buzzatto, Zhengzhou Lubing Maoyi Co., Ltd a biostimulant and biofertilizer production company, attended the Ministerial conference (Photo 2) and emphasized the importance of private sector partnerships. Guangdong X United Agriculture and Shanghai Bi-Jing- a fertilizer manufacturing and distribution company provided financial support for IAEA pavilion at COP29, and they are keen to enter a partnership with IAEA for providing financial support for the forthcoming CRP.

Photo 1. CEO of Anglo American's Crop Nutrients business, and IAEA DG signed a new partnership agreement for a CRP. (photo credit: D. Calma/ IAEA)

Photo 2. CEOs from Guangdong X United Agriculture and Zhengzhou Lubing Maoyi Co., Ltd, and IAEA NA DDG (photo credit: M. Zaman/ IAEA)

Technical Cooperation Projects

Country/Region	TC Project	Description	Technical Officer(s)
Afghanistan	AFG5008	Strengthening Climate Smart Agricultural Practices for Wheat, Fruits and Vegetable Crops	M. Zaman
Angola	ANG5018	Enhancing the Productivity of Cereal Crops in the Country through Climate Smart Agricultural Practices	M. Zaman
Azerbaijan	AZB5004	Strengthening Best Soil, Nutrient, and Water Agricultural Practices for Cotton Production	M. Zaman
Bangladesh	BGD5036	Enhancing Crop Production under Changing Climatic Conditions through Resilient Crop Varieties and Sustainable Land Use Management Using Nuclear Techniques	M. Fujisawa
Belize	BZE5012	Use of Nuclear and Isotopic Techniques for Optimizing Soil-Water-Nutrient Management in Rainfed Agriculture Systems	M. Fujisawa
Bolivia	BOL0009	Strengthening National Capacities for the Development of Nuclear Technology Applications in Bolivia	M. Zaman
Bolivia	BOL5024	Strengthened National Capacities for the Identification of the Origin and Transport of Pesticides Compounds in Agricultural Watersheds	M. Fujisawa
Bosnia and Herzegovina	BOH5004	Building Capacity for Soil Erosion Assessment Using Nuclear Techniques to Implement Sustainable Land Management Measures	M. Zaman
Bulgaria	BUL5018	Improving Crop Water Productivity and Nutritional Quality of Orchards	M. Fujisawa
Burkina Faso	BKF5024	Improving Food Crops through Mutation Breeding and Best Soil and Nutrient Management to Ensure Food Security	M. Fujisawa and PBG
Cambodia	KAM5008	Introducing a Digital Soil Information System and Remote Sensing for Sustainable Land Use Management	H. Said Ahmed
Chad	CHD5012	Improving Soil and Water Management Systems Using Nuclear Techniques	H. Said Ahmed
Chile	CHI0023	Building Capacity for Nuclear Science and Technology Applications	M. Fujisawa and NAPC, NAFA
Colombia	COL5026	Enhancing Crop Productivity of Creole Potato Using Nuclear and Related Techniques	M. Zaman and PBG
Congo Rep. of	PRC5003	Protecting Water and Fertility in Agricultural Soils	M. Fujisawa
Costa Rica	COS7006	Strengthening National Capacities to Identify Sources of Contamination that Affect Highly Vulnerable Aquifers Using Isotopic and Conventional Techniques	M. Fujisawa and IH
Cuba	CUB5024	Strengthening National Capacities for the Adaptation or Mitigation of the Negative Impacts of Climate Change and the Sustainable Management of Land and Water, Through the Integrated Use of Nuclear Techniques	M. Fujisawa
Ghana	GHA5039	Mainstreaming Nuclear Based Climate Smart Agriculture Technologies into Sustainable Production	M. Zaman and PBG

Haiti	HAI5010	Strengthening National Capacities on Climate Smart Agricultural Practices of Rice, Yam, Maize, and Cassava	M. Fujisawa
Honduras	HON5011	Implementation of Soil, Water and Nutrient Management for Sustainable Coffee Production in Honduras using Nuclear Technologies	M. Zaman
Interregional project	INT5156	Building Capacity and Generating Evidence for Climate Change Impacts on Soil, Sediments and Water Resources in Mountainous Regions	G. Dercon
Interregional project	INT5159	Atoms4Climate Adaptation and Mitigation: Non-Power Technologies for the Terrestrial Landscape	G. Dercon with NAPC, NAFA
Lao PDR	LAO5006	Enhancing Crop Production with Climate Smart Agricultural Practices and Improved Crop Varieties	M. Zaman and PBG
Lesotho	LES5012	Improving Productivity of Potato and Sorghum through Mutation Breeding and Best Soil, Nutrient and Water Management Practices	M. Zaman and PBG
Mali	MLI5031	Improving Rice Productivity through Mutation Breeding and Better Soil, Nutrient and Water Management Practices	M. Zaman and PBG
Namibia	NAM5022	Enhancing Crop Production in Fragile Agrosystems	M. Fujisawa and PBG
Nicaragua	NIC7002	Improving Sustainable Management of Water and Soil Resources Using Nuclear and Isotope Techniques	M. Zaman
Nigeria	NIR5042	Developing Climate Smart Agricultural Practices and Soil Fertility for Increased Crop Productivity and Contributing to Food Security	M. Zaman
Pakistan	PAK5053	Strengthening and Enhancing National Capabilities for the Development of Climate Smart Crops, Improvement in Animal Productivity and Management of Soil, Water, and Nutrient Resources Using Nuclear and Related Techniques	M. Zaman with PBG and SIT
Palestine (T.T.U.T.J.)	PAL5011	Enhancing Food Security via Nuclear Based Approaches	M. Zaman
Panama	PAN1002	Strengthening the Operation of the Panama Canal through Erosion and Sediment Transport Analysis using Nucleonic Control System Applications, Radiotracers and FRN and CSSI methodologies	M. Fujisawa
Panama	PAN5028	Improving the Quality of Organic Cocoa Production by Monitoring Heavy Metal Concentrations in Soils and Evaluating Crop Water Use Efficiency	M. Fujisawa
Panama	PAN5029	Strengthening National Capacities to Combat Land Degradation and Improve Soil Productivity Through the Use of Isotope Techniques	M. Fujisawa
Peru	PER5035	Improving Pasture Production Through Best Soil Nutrient Management to Promote Sustainable Livestock Production in the Highland Region	M. Zaman
Peru	PER5037	Enhancing Sugarcane Production Through Improved Climate Smart Agricultural Practices	M. Zaman

Qatar	QAT5008	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	M. Zaman
Regional project Africa	RAF0063	Promoting Triangular Cooperation among Developing Countries and the Sustainability and Networking of National Nuclear Institutions for Development (AFRA)	M. Fujisawa
Regional project Africa	RAF5090	Supporting Climate Change Adaptation for Communities Through Integrated Soil–Cropping–Livestock Production Systems (AFRA)	M. Zaman and APH
Regional project Africa	RAF5092	Enhancing Agricultural Productivity for Improved Food Security in Africa (AFRA)	M. Zaman
Regional project Asia	RAS5091	Assessing and Mitigating Agro-Contaminants to Improve Water Quality and Soil Productivity in Catchments Using Integrated Isotopic Approaches	M. Fujisawa
Regional project Asia	RAS5093	Strengthening Climate Smart Rice Production towards Sustainability and Regional Food Security through Nuclear and Modern Techniques	M. Zaman
Regional project Asia	RAS5094	Promoting Sustainable Agricultural and Food Productivity in the Association of Southeast Asian Nations Region	M. Zaman with PBG and FEP
Regional project Asia	RAS5099	Developing Climate Smart Crop Production including Improvement and Enhancement of Crop Productivity, Soil and Irrigation Management, and Food Safety Using Nuclear Techniques (ARASIA)	M. Fujisawa PBG and FEP
Regional project Europe	RER5028	Improving Efficiency in Water and Soil Management	M. Fujisawa
Regional Project Latin America	RLA5089	Evaluating the Impact of Heavy Metals and Other Pollutants on Soils Contaminated by Anthropogenic Activities and Natural Origin (ARCAL CLXXVII)	M. Fujisawa
Regional Project Latin America	RLA5090	Improving Agriculture Productivity through Better Agricultural Practices and Improved Varieties (ARCAL CXCII)	M. Zaman
Saudi Arabia	SAU5004	Strengthening National Capacities for the Assessment of Groundwater Contamination with Radionuclides and their Environmental Effects on Soil and Agriculture Production	M. Zaman, S. Kumar
Seychelles	SEY5013	Developing and Promoting Best Nutrient and Water Management Practices to Enhance Food Security and Environmental Sustainability	M. Zaman
Sierra Leone	SIL5021	Improving Productivity of Rice and Cassava to Contribute to Food Security	M. Zaman and PBG
Sri Lanka	SRL5051	Introducing Climate Smart Agricultural Practices to Mitigate Greenhouse Gas Emissions	M. Zaman
Sudan	SUD5041	Enhancing Productivity and Quality of High Value Crops through Improved Varieties and Best Soil, Nutrient and Water Management Practices	M. Zaman and PBG
Togo	TOG5006	Improving the Productivity of Soybean (Glycine max L) Using Nuclear Techniques	M. Fujisawa and M. Zaman

Viet Nam	VIE5026	Building Capacity for Mitigating Greenhouse Gas Emissions and Combating Climate Change through Climate Smart Agricultural Practices	M. Zaman
Zambia	ZAM5035	Enhancing Resilient AgriFood Systems through Improved Crop Varieties and Soil Management Practices	M. Fujisawa and M. Zaman

Forthcoming Events

FAO/IAEA Events

Consultancy Meeting of CRP on Developing Climate Smart Agricultural Practices to Mitigate Soil Salinity, Enhance Crop Productivity and Build Soil Fertility through Nuclear and related techniques, 24-28 February 2025, Vienna, Austria

Technical Officers: M. Zaman & M. Fujisawa

First Research Coordination Meeting of CRP on Developing Climate Smart Agricultural Practices to Mitigate Soil Salinity, Enhance Crop Productivity and Build Soil Fertility through Nuclear and related techniques, Q3 2025, Vienna, Austria

Technical Officers: M. Zaman & M. Fujisawa

First Research Coordination Meeting of CRP D12015 on Combining Gamma Ray Sensing and Digital Technology for Soil Moisture and Soil Property Mapping, Q4 2025, Vienna, Austria

Technical Officers: H. Said Ahmed & M. Fujisawa

Second Research Coordination Meeting on Assessing the Fate and Environmental Impact of Plastics in Soil and Crop Ecosystems Using Isotopic Techniques, 6-10 October 2025, virtual.

Technical Officers: M. Fujisawa & M. Zaman

Virtual Training Workshop on Enhancing Climate Change Adaptation and Disease Resilience in Tropical Perennial Cropping Systems, 13-17 October 2025, virtual.

Technical Officer: G. Dercon

Past Events

FAO/IAEA Events

Technical Support for Cosmic Ray Neutron Sensor Technology in High Mountain Watersheds, 23 to 31 May 2024, La Paz, Bolivia

Technical Officer: G. Dercon

Under the Technical Cooperation Project INT5156, "Building Capacity and Generating Evidence for Climate Change Impacts on Soil, Sediments, and Water Resources in Mountainous Regions," the IAEA, with technical support of the SWMCNL and Innsbruck University and Liverpool John Moores University experts, conducted an interregional training course in Bolivia on cosmic ray neutron sensor (CRNS) technology for snow water equivalent measurement and policy development. The training was held from 22 to 29 May 2024 at Universidad Mayor de San Andrés. The course included lectures and fieldwork, culminating in a scientific expedition to Huayna Potosí glacier, where participants installed a CRNS device at 5100 meters to transmit real-time snow data.

Gerd Dercon supported participants in using CRNS data for watershed management, collaborated with Bolivian officials to discuss technology integration, and explored new TC project opportunities, with these efforts covered by Reuters, CNN Brazil, and Argentinian Television.

Key Outcomes:

- **Real-Time Monitoring:** CRNS devices in the Huayna Potosí watershed aid Bolivia's water planning, especially as glacier retreat intensifies.
- **Glacier Monitoring Milestone:** The installation strengthens a network across the Andes and Himalayas for climate resilience.
- **Water Management Impact:** CRNS, alongside complementary sensors, enhances long-term water resource data critical for agriculture and urban planning.
- **Skilled Participants:** Attendees are equipped to implement similar technologies in their regions, with CRNS devices distributed across the Andes and Himalayas.
- **Scientific Integration:** The course demonstrated nuclear science's role in climate adaptation for mountainous regions.
- **Future Planning:** INT5156 final activities were outlined, with new projects identified for high-altitude climate adaptation.

Photo 1 Installation of CRNS device at 5100 meters to transmit real-time snow data (photo credit: G. Dercon, 2024).

Technical Cooperation Training on Applying Mid-Infrared Spectrometry (MIRS) Techniques for Environmental Monitoring and Soil Contamination Analysis in Brazil (BRA 7014), 25 to 31 August 2024, Rio de Janeiro, Brazil.

Technical Officer: M. Vlasimsky

A comprehensive training on Mid-Infrared Spectrometry (MIRS) for environmental monitoring and soil contamination analysis was successfully conducted in Rio de Janeiro, Brazil, from 25 to 31 August 2024 by SWMCNL staff member Magdeline Vlasimsky. Organised in collaboration with the Federal Fluminense University (UFF), the mission brought together local experts and researchers to explore innovative methods for monitoring microplastic contamination in soils and sediments. This training is part of the IAEA Technical Cooperation Project BRA7014, which aims at enhancing the resilience of Brazilian coastal ecosystems against oil spills and plastic debris.

Ten participants from UFF's 'Applied Nuclear Physics on Environmental Studies' research group attended the training. The activities focused on strengthening Brazil's capacity to apply infrared spectrometry techniques to address environmental challenges, particularly in detecting and managing plastic contamination in coastal soils and sediments.

Photo 1 A group photo of the SMWNC staff member and trainees at UFF (photo credit: R. Pereira, 2024).

Side Event on Multi-Disciplinary Approaches to Combating Antimicrobial Resistance at the 68th International Atomic Energy Agency (IAEA) General Conference, 16 September 2024, Vienna, Austria.

Wang, J.[1a], Wijewardana, V. [1a], Sasanya, J.[2a], Vlachou, C.[3a], Fujisawa, M.[4a], Maestroni, B.[3a], Dercon, G.[5a] and Heiling, M.[5a]

[1]Animal Production and Health Laboratory
[2]Food Safety and Control Section
[3]Food Safety and Control Laboratory
[4]Soil and Water Management and Crop Nutrition Section
[5]Soil and Water Management and Crop Nutrition Laboratory,
[a]Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture, International Atomic Energy Agency, Austria

Antimicrobial resistance (AMR) is a critical global health threat, complicating infection treatment in humans and animals, increasing healthcare costs, and raising mortality risks. In response to this challenge, a side event titled *"Multi-disciplinary Approaches to Combat AMR in Agrifood Systems towards One Health"* was held during the 68th IAEA General Conference. This side event was organized by three subprogrammes of the Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture: Animal Production and Health, Food Safety and Control, and Soil and Water Management and Crop Nutrition.

The event emphasized the importance of the One Health approach, integrating human, animal, and environmental health through knowledge-sharing and cross-institutional, multidisciplinary collaboration. It highlighted the essential role of innovative nuclear and nuclear-derived technologies, as well as biotechnologies, in combating AMR. Additionally, research and development (R&D) initiatives within Coordinated Research Projects (CRPs) and successful national efforts to combat AMR through nuclear solutions were showcased.

Panelists from the G20 Health and Development Partnership, FAO and WHO underscored the need for cross-sectoral collaboration to develop sustainable AMR solutions. The Joint FAO/IAEA Centre reaffirmed its commitment to supporting AMR initiatives through research and capacity building efforts, aligned with the One Health approach.

Key discussions stressed the importance of data-driven strategies to monitor AMR, and called for stronger collaboration among governments, research institutions, and financial organizations. The event also highlighted real-world success stories, such as the use of isotopic techniques to monitor antimicrobial use and promote sustainable practices in the livestock sector.

A competition for young scientists showcased innovative solutions leveraging nuclear technologies to address AMR. Emerging researchers from around the world contributed groundbreaking ideas: Eddy Sukmawinata from Indonesia focused on nuclear technologies for AMR control; Leonie Bettin from Germany developed gamma-irradiated vaccines to combat zoonotic Chlamydia infections; Purity Kwamboka from Kenya proposed irradiated para-probiotics using Cobalt-60 as an alternative to antibiotic growth promoters; Zina Alfahl from Ireland emphasized the role of nuclear technologies and young scientists in AMR mitigation; and Seyedsina Bagherighadikolaei from Iran presented poultry vaccination strategies to reduce AMR. These contributions underscore the power of scientific innovation in addressing global AMR challenges.

The Joint FAO/IAEA Centre remains dedicated to empowering Member States in addressing AMR, providing technical support and promoting effective disease control strategies. These efforts align with FAO's Action Plan on AMR (2021-2025) and the *Reduce the Need for Antimicrobials on Farms for Sustainable Agrifood Systems Transformation*

(RENOFARM) initiative, contributing to global health security and pandemic preparedness.

Visit to the International Atomic Energy Agency Radioecology Laboratory in Monaco, 7 to 9 October 2024, Monaco, France.

M. Heiling

Maria Heiling visited the IAEA Radioecology Laboratory in Monaco from 7 to 9 October 2024, with a focus on exploring advanced methodologies and technologies for plastic pollution research. The visit aimed to foster collaboration and facilitate knowledge exchange, particularly in the analysis and understanding of microplastics.

The key objectives were to compare analytical technologies, discuss the strengths and limitations of various equipment used for plastic pollution analysis, share research protocols, and gain insights into the laboratory's experiences in harmonizing methodologies. The visit also included hands-on exercises, employing both microscopic and spectroscopic techniques to identify microplastics.

The collaboration between IAEA laboratories is promising. By exchanging test samples and optimizing protocols, both labs can enhance the accuracy and effectiveness of their research. Future collaborations could benefit from shared expertise, standardized procedures, and joint initiatives aimed at advancing the understanding of plastic pollution.

Regional Training Course on Water and Soil Management, under European Regional Technical Cooperation (TC) project RER5028 'Improving Efficiency in Water and Soil Management', 7 to 11 October 2024, Vienna and Seibersdorf, Austria.

Technical Officer: M. Fujisawa

The RER5028 project has the overall objective to strengthen the regional capacity in applying nuclear techniques for improving land and water management under changing climate in European region. Eighteen counterparts from ten European Member States participated in a training course hosted by TCP at the IAEA headquarters in Vienna. The topics of Climate Smart Agriculture (CSA) practices with focus on water management were covered by IAEA experts, and one day was dedicated to the SWMCN Laboratory in Seibersdorf, where the participants learned advanced equipment and methodology. The participants were also trained in designing national and regional TCPs based on the inputs provided during the training course.

Photo 1. Participants of Regional Training Course under RER5028 (photo credit: J. O'Brien, 2024).

SWMCN Participation Highlights from the World Food Forum, 16 to 18 October 2024, Rome, Italy.

H. Said Ahmed

During the World Food Forum, held at the headquarters of the Food and Agriculture Organization of the United Nations (FAO) in Rome, Italy, the SWMCN Joint FAO/IAEA Centre, presented its work on how nuclear and related techniques can provide innovative solutions to global food security challenges at the Science and Innovation Booth.

During the opening of the Science and Innovation Forum, FAO Director-General Mr Qu Dongyu emphasized the significant impact of the FAO/IAEA partnership through the Joint Centre on global agriculture over the past 60 years. IAEA Director-General Mr Rafael Mariano Grossi also highlighted the long-standing collaboration between the IAEA and FAO, which has been strengthened through the Seibersdorf laboratories and contributed to increased crop yields, enhanced biodiversity, and the promotion of climate-smart agriculture. Mr. Grossi stated, "With the Atoms4Food initiative, we are able to assist Member States in their efforts in areas (ranging) from soil and water management to pest control."

Photo 1. Exhibition booth for the Joint FAO/IAEA Centre, featuring the Soil and Water Management and Crop Nutrition Subprogram alongside four other subprograms, at the World Food Forum held at the headquarters of the Food and Agriculture Organization of the United Nations (FAO) in Rome, Italy. (photo credit: M. Casling, 2024).

On Monday, 16 October 2024, the Science and Innovation Booth was open from 13:00 to 19:00 and successfully engaged a diverse audience, including country representatives, delegates, members of academia, and FAO staff. Notable visitors included IAEA Director-General Rafael Mariano Grossi, Deputy Director-General of the IAEA's Department of Nuclear Sciences and Applications Ms Najat Mokhtar, and Director of the Joint FAO/IAEA Centre Ms Dongxin Feng.

Coordination Meeting for Interregional TC Project INT5156 on "Building Capacity and Generating Evidence for Climate Change Impacts on Soil, Sediments, and Water Resources in Mountainous Regions", 28 October 2024 to 1 November 2024, Chengdu and Moxi Town, China.

Technical Officer: G. Dercon

Mr. Gerd Dercon participated in the coordination meeting for the IAEA Technical Cooperation (TC) Project INT5156, held from 28 October 2024 to 1 November 2024, at the Institute of Mountain Hazards and Environment, Chinese Academy of Sciences. Sessions took place in both Chengdu and Moxi Town, where representatives from seven countries in the Andes and Himalayas, along with experts from Europe, Africa, South America, and Asia, gathered to review project progress and plan for the final project year.

The meeting focused on consolidating achievements and sharing lessons learned from INT5156, which aims to strengthen climate resilience in high-altitude regions. Participants engaged in technical refresher sessions on interpreting data from Cosmic Ray Neutron Sensors (CRNS) and constructing low-cost hydrometeorological monitoring devices, equipping them with essential skills for accurate monitoring of soil moisture and water resources.

Photo 1. Visiting the INT5156 Cosmic Ray Neutron Sensor in Yajiageng, near Moxi Town, at an altitude of 4 100 meters in the eastern Tibetan region. This sensor, managed by the Chinese Academy of Sciences, monitors soil moisture in a high-altitude shrub meadow ecosystem, where sheep and yaks graze. (photo credit: G. Dercon, 2024)

Key outcomes included the development of an action plan for the project's final year, emphasizing data sharing, publication of monitoring results, and outreach strategies to broaden the project's impact. Participants also conducted field excursions to Mt. Gongga and CRNS sites, including Yajiageng and Hailuogou Glacier, to observe the practical application of their work and gain hands-on experience (Photo 1).

Presentations from participating countries, such as Argentina, Bolivia, Chile, China, Ecuador, Nepal and Pakistan, highlighted project accomplishments and challenges across various mountainous regions. Interactive group discussions enabled in-depth thematic exchanges, culminating in a summary of lessons learned and a strategic roadmap for future climate adaptation projects.

The meeting concluded with formal recommendations derived from the week's discussions and field insights, laying a foundation for future IAEA-supported climate adaptation initiatives in mountain environments. Mr. Dercon's involvement facilitated knowledge exchange, strengthened collaboration, and reinforced the capacity-building and strategic planning essential for ongoing climate adaptation efforts in high-altitude regions.

Coordinated Research Projects

Project Number	Ongoing CRPs	Project Officer
D15019	Remediation of Radioactive Contaminated Agricultural Land	G. Dercon
D15020	Developing Climate-Smart Agricultural Practices for Mitigation of Greenhouse Gases	M. Zaman
D15021	Assessing the Fate, and Environmental Impact of Plastics in Soil and Crop Ecosystems Using Isotopic Techniques	M. Fujisawa and M. Zaman
D15022	Isotopic Techniques to Assess the Fate of Antimicrobials and Implications for Antimicrobial Resistance in Agricultural Systems	M. Zaman and M. Fujisawa

Remediation of Radioactive Contaminated Agricultural Land (D15019)

Technical Officer: G. Dercon

The innovative monitoring and modeling techniques proposed in CRP D15019 aimed to enhance societal preparedness and improve the remediation of agricultural areas affected by large-scale nuclear accidents. This project focused on developing, testing, and validating new field, laboratory, and machine learning tools to predict and monitor radionuclide transfer in crops and their dynamics at the landscape level, particularly in under-explored environments such as arid, tropical, and monsoonal climates, as well as in the main crop categories affected by such incidents.

The research methodology included laboratory, greenhouse, and field-based studies using stable isotopes of caesium and strontium. These were combined with time- and space-dependent modeling and machine learning approaches to predict the uptake and movement of radiocaesium and radiostrontium in crops following large-scale nuclear accidents impacting food and agriculture.

To optimize remediation efforts at the landscape level, operational research was applied to select, refine, and prioritize remediation techniques. Protocols were developed for innovative spatio-temporal decision support systems for agricultural land remediation, incorporating machine learning, operations research, and Geographic Information System (GIS) techniques.

This CRP involved participation from eleven countries, including research contract holders, technical contract holders, and agreement holders, following recommendations from an IAEA consultants' meeting in February 2019.

Regular progress meetings were held to refine and align national research projects with the CRP's objectives and work plan. Notable advancements included laboratory experiments aimed at improving the remediation of radioactive contamination in farmland. The project sought to develop new isotopic techniques and employed advanced mathematical models to better predict soil properties and optimize remediation strategies.

Significant mid-term progress was reviewed and presented at international symposiums in 2022 and 2023. Ongoing PhD research and published studies contributed to improve our knowledge on optimizing the remediation of radioactive contamination in food and agriculture. One PhD study, successfully defended in December 2023, focused on enhancing soil remediation decision-making following large-scale nuclear emergencies. Another PhD study on radiocaesium dynamics is nearing completion, with the defense expected by the end of 2024.

The final Research Coordination Meeting (RCM) was held in July 2024 in Vienna, marking the conclusion of this CRP. The final report is currently being prepared, and a comprehensive summary of the findings will be provided in the next newsletter. With the project reaching its closure, the CRP is set to officially wrap up with the final submission of results and guidelines, offering a lasting contribution to the field of agricultural remediation after nuclear accidents.

Photo 1. Meeting participants of Final RCM D15019 (photo credit: A. Toloza, 2024).

Developing Climate Smart Agricultural practices for carbon sequestration and mitigation of greenhouse gases (D15020)

Technical Officer: M. Zaman

Changing climate systems whose effects have been visible globally are causing tremendous suffering for humans. However, increases in GHGs in the atmosphere by anthropogenic processes have been evident as the main cause of global warming. Agriculture is one of the major sources of GHG emissions causing about 25% of the total global emissions. Adaptation and mitigation are regarded as the main strategies to effectively reduce the effects of global climate change. Reduction in GHG emissions from agriculture and enhancing C sequestration in soils are crucial mitigation strategies. Climate smart agriculture (CSA) practices including appropriate soil-crop-water management can help ensure food security by increasing crop production while improving soil health and reducing GHG emissions. CSA practices can also reduce fertilizer and water input by increasing their efficient use. The adoption of CSA practices is an appropriate means to fight against the adverse effects of climate change. CRP D15020 aims to develop such CSA practices for the benefit of Member States.

The second RCM for this CRP was held from the 7 to 11 October, 2024 wherein the participants discussed the results of their research work since the previous RCM. The results from field trials conducted by researchers in different Member States provided significant insights on emissions of GHGs, NH_3 volatilisation, C sequestration and crop productivity. In Bangladesh field experiments in rice paddy systems demonstrated that strip tillage can reduce N requirements by 50% for the same yield target as compared to conventional tillage systems. The use of biochar reduced NH_3 emission in triple rice season by 37% and in combination with Nitrapyrin increased NUE from 35% to 40%.

Photo 1. Meeting participants of Second RCM D15020 (photo credit: J. O'Brien, 2024).

In Viet Nam field trials on paddy rice systems demonstrated that urea-NBPT significantly reduced NH_3 emissions and increased rice productivity. In Ethiopia it was seen that gasifier cook stoves are suitable for cooking and biochar production, and increase fuel efficiency by 30%, thus reducing the amount of fuel wood required. The addition of biochar to the composting process was found to conserve P and K and reduce Ca and Mg losses. GHGs particularly CH_4 and N_2O decreased by 51-71% during the composting process as compared to composting without biochar.

In Brazil, experiments in mixed pastures showed that soil acts as a sink for N-urine with 35% increase in treatments assessed from ^{15}N labelled urine. There was a 30% recovery in plants from N absorption in shoots. N urine leaching losses between 10-12% occurred while in another experiment 65% of urine N was recovered in soil plant systems (35% lost via NH_3 volatilisation and leaching). CH_4 emissions were observed to have significantly reduced in mixed grass and legume pastures.

In Spain, a novel method was developed and validated for the measurement of NH_3 emissions at field scale. In China, improving nitrogen use efficiency in rice led to a 27% reduction in NH_3 emission losses and a 31% reduction in N_2O emissions.

Forty-five papers have been published in peer reviewed journals over the course of this RCM.

Assessing the Fate, and Environmental Impact of Plastics in Soil and Crop Ecosystems Using Isotopic Techniques (D15021)

Technical Officers: M. Fujisawa and M. Zaman

This CRP (2023 to 2028) aims at assessing the fate and impacts of plastics and microplastics in agricultural soils using isotopic and related techniques. The CRP also aims at establishing a network of CRP Member States for developing common strategies to effectively mitigate the plastic pollution in agricultural soils and crops and minimize the possible negative impacts of plastics and microplastics on soil health and ecosystem services.

The CRP involves nine Member States: seven research contract holders (Brazil, China, Ghana, Kuwait, Malaysia, Morocco, and Viet Nam), two technical contracts (both from Germany) and one agreement holder (Norway).

The CRP established four working groups on key topics, and each group has progressed well in its second year, and the progress to date includes:

- A standard protocol for microplastic analyses in soil has been drafted and is under review for discussion. It is to harmonize the reporting of microplastics among the participants in the CRP and for Member States;
- A library of plastics has been established and a range of 12 plastic types widely used in agriculture were identified;
- The effective protocol for isolation of bacteria from soil was identified; and
- A standard reference material for microplastics in soil has been developed.
- A preliminary experimental result of microplastic migration in sludge-applied agricultural soil indicated microplastics are restricted to the top 10 to 15 cm, and sewage sludge has been identified as a major source of microplastic input into soils.

It should be mentioned that booklet "Nuclear and isotopic techniques to assess the fate and impacts of plastic pollution on soil ecosystems and the environment" was published in FAO Knowledge Repository in 2024.

CRP participants meet regularly online to share their experimental designs and initial results. The second RCM is scheduled to be held in Q4 of 2025, where the accomplishments will be discussed and assessed, any adjustments required will be made and the way forward for the implementation will be finalized.

Isotopic Techniques to Assess the Fate of Antimicrobials and Implications for Antimicrobial Resistance in Agricultural Systems (D15022)

Technical Officers: M. Fujisawa and M. Zaman

This CRP (2021-2026) aims at developing guidance about the fate, dynamics and persistence of Antimicrobials (AM) and Antimicrobial Resistance (AMR) in agricultural systems based on nuclear and related techniques. The CRP further aims at supporting Member States to develop common strategies to mitigate the spread of AM in agricultural systems.

Eight Member States are participating: four research contract holders (Brazil, China, South Africa, and Viet Nam), three agreement holders (China, Norway, and United States of America), and two technical contract holders (Germany and Australia).

To date, the progress includes:

- Development of ^{13}C labelled SMX which was shared with the participants for the lab and field experiments;
- Development of a set of protocols including (1) SMX extraction from soil, water, and plant samples, (2) Pre-experiments for lab and field experiments, and (3) DNA extraction and analysis from soil and water samples;
- A new GC-IRMS has been successfully installed in the SWMCN Laboratory in Seibersdorf, Austria for compound stable isotope analysis of SMX; and

It should be mentioned that during the 68th IAEA General Conference from 16 to 20 September 2024 at IAEA headquarters, a side event "Multi-disciplinary Approaches to Combat Antimicrobial Resistance (AMR) in Food and Agricultural Systems towards Global One Health" was held on 16 September 2024. The CRP partner from Germany presented the scope of the CRP with a focus on the use of isotopic techniques including producing and applying ^{13}C labelled SMX to trace AM and AMR in agricultural systems (more details see "past event").

This CRP is mainly funded through an extrabudgetary contribution by the FAO. The final RCM will be held in 2026.

Developments at the Soil and Water Management and Crop Nutrition Laboratory

Enhancing Crop Monitoring for Precision Agriculture with Unmanned Aerial Vehicle-Based Multispectral Imagery

Said Ahmed, H.[1], Toloza, A.[1], Mitchell, J.[1], Mbaye, M.[2], Dercon, G.[1]

[1]Soil and Water Management & Crop Nutrition Laboratory, Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture, International Atomic Energy Agency, Austria

[2]Senegalese Institute of Agricultural Research (ISRA), Regional Centre of Excellence on the Improvement of Plant Adaptation to Drought (CERAAS), Senegal

Highlights:

- UAV-based multispectral technology enables efficient, real-time, large-scale crop monitoring with high spatial resolution for precision agriculture.
- Multispectral imagery for biomass calculation complements cosmic ray neutron sensor technology, while stable isotope techniques help calibrate crop status information derived from multispectral imagery.
- Precision agriculture using UAVs enhances crop health monitoring and improves water management.

In modern agriculture, unmanned aerial vehicles (UAVs), or drones, equipped with multispectral cameras are revolutionizing crop health monitoring and agricultural resource management. Multispectral imaging-utilizing five or six spectral bands such as Green, Blue, Red, Red Edge, Near Infrared (NIR), and Thermal-enables the calculation of vegetation indices like the Normalised Difference Vegetation Index (NDVI), allowing for precise assessments of crop status by capturing variations in health, leaf moisture, biomass, and overall vigour.

UAV-based systems provide high-resolution, real-time data that augment traditional ground-based methods. Multispectral imagery captured by UAV cameras can detect crop stress, such as water deficiency or nutrient imbalances, allowing farmers to respond quickly and prevent yield losses. This technology supports precision farming by providing accurate insights into crop performance, which is crucial for optimizing water and nutrient management across both irrigated and rainfed systems.

Spectral imagery of crops from multispectral cameras complements soil data collected through nuclear techniques, such as cosmic ray neutron sensors (CRNS), and satellite imagery for large-scale soil moisture assessments. The calibration of CRNS is crucial for improving soil moisture data, particularly when the biomass water equivalent-the water stored in plant matter-affects CRNS readings. Accurate assessment of biomass and its water equivalent using UAV multispectral imagery is therefore essential for CRNS calibration. By measuring the water content in vegetation, its influence can be adjusted or removed during calibration. This leads to more accurate soil moisture readings from CRNS, improving water management practices.

Additionally, stable isotope techniques, such as carbon-13 isotope analysis, can further calibrate stress assessments derived from multispectral imagery, ensuring that vegetation health indicators are precise and reliable. By integrating these methods, UAV-based multispectral imagery provides a useful tool for both biomass estimation and precise soil moisture measurement.

Furthermore, biomass is a critical indicator of crop productivity, representing the total above-ground plant material. Accurate biomass estimation is essential for evaluating the effectiveness of water and nutrient applications and for determining crop yield potential. UAVs allow for continuous biomass monitoring throughout the season, enabling adjustments to irrigation and fertilisation strategies under irrigated conditions while guiding decisions to maximize yield. These data also support the calibration of crop productivity models. Additionally, UAV-based monitoring facilitates the early detection of nutrient deficiencies, allowing for timely interventions to mitigate potential yield losses. In rainfed conditions, UAV technology provides detailed insights into crop health, enabling farmers to implement precision agriculture practices that enhance productivity despite variable water availability.

Ongoing research at the SWMCNL focuses on developing UAV-based approaches for crop monitoring across two experimental fields in Austria: the Hydrological Open Air Laboratory (HOAL) in Petzenkirchen and the SWMCNL experiment fields at the Austrian Agency for Health and Food Safety GmbH (AGES) research station in Grabenegg (Photo 1), as well as long-term field trials on different tillage management systems in University of Natural Resources and Life Sciences (BOKU) fields in Marchfeld.

The data collected will further complement and enhance nuclear and stable isotope techniques as discussed in previous sections. This SWMCNL research is in its preliminary stages, aiming to advance crop monitoring using UAV-based multispectral imaging. Initial results from the Grabenegg field site (Photo 1) offer insights into the long-term effects of crop residue retention on biomass development and water stress parameters. This site has been managed by the SWMCNL team for over ten years, and frequent imagery collection will help better understand the impact of residue retention, particularly during Austria's dry summers. Stable isotope techniques will be employed to calibrate the data and further unravel the underlying processes.

Photo 1. UAV with Multispectral Camera Capturing Grabenegg experimental Field in Near-Infrared Band and True Color for Vegetation Health and Biomass Analysis (photo credit: A. Toloza, 2024).

By providing high-resolution, real-time data on crop health, water stress, nutrient imbalances, and biomass, this methodology has the potential to become a valuable tool for farmers and agricultural researchers. The ultimate goal is to improve crop sustainability and resilience by enabling timely, precise interventions, helping crops adapt to changing environmental and climatic conditions. This approach will also optimize irrigation and nutrient management, contributing to more efficient and sustainable farming practices.

Understanding the Climate Change Nexus: Water and Nutrient Use Efficiency, Nutritional Quality and Food Safety in Dryland Agriculture through Nuclear Techniques

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Highlights

- 28 experts met to discuss research gaps in climate change effects on resource use efficiency, nutritional quality and food safety of dryland crops.
- A training workshop was held to raise awareness of the impact of climate change on dryland crops for 130 participants from 53 Member States.

Drylands which represent 40% of the world land and are home to one third of human population are under continuous threat from desertification due to land degradation, climate change and improper soil management. Climate change due to increased emissions of greenhouse gases (GHGs) is one of the most pressing challenges with profound implications for global food security. Data by the IPCC shows that anthropogenic emissions of the three major GHGs including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) have increased significantly since the industrial revolution in the mid of the 18th century. The impact goes beyond food security to include the complex relationships between water and nutrient efficiency, nutritional quality, and food safety. These negative impacts of climate change not only affect crop physiology but also have serious implications for soil quality health and fertility, microbial communities and their activities, and ultimately, food safety and quality. By taking interdisciplinary and integrated R&D approach, we can devise strategies to boost the resilience of dryland agriculture and ensure sustainable food production under changing climate.

The Peaceful Uses Initiative (PUI) project, titled *"Ensuring Food Security and Safety by Future-Proofing Dryland Crops under Climate Change"*, funded by the UK Government, addresses this critical nexus. Our research focuses on how elevated CO_2 levels, rising temperatures, and changing precipitation patterns affect crop productivity and water and nutrient use efficiency. We also examine the negative impacts of climate change on crop nutritional quality, including the heightened risk of mycotoxin contamination and increased uptake of heavy metals, which pose significant threats to food safety.

To address these challenges, the PUI research team conducted an extensive literature review to identify the gaps and the effects of climate change on dryland crops. Our desktop study revealed that drought is the predominant focus in scientific studies, with niche areas examining mycotoxin production and heavy metal uptake. However, emerging research topics include crop improvement and the application of omics technologies. Over the past decade, there has been a notable rise in studies exploring adaptation strategies, modeling, and the use of machine learning.

Climate change directly affects crop growth, physiology, quality and yield. Elevated CO_2, drought, increased temperature have different impacts on plants, and when combined, can interact in complex ways. For example, elevated CO_2 through the CO_2 fertilisation effect can mitigate drought's effect on crop productivity to a certain extent. Climate change also alters water availability, soil pH, organic carbon mineralisation, microbial communities, and nutrient and heavy metal availability, all of which influence crop growth and provide conducive conditions for mycotoxin production. Climate change leads to different trends in fungal population dynamics, resulting in the emergence of mycotoxins even in areas with no history of prior contamination. Furthermore, the enhanced uptake of heavy metals from plants compromises food safety, thereby placing an additional burden on the Member States to enhance their analytical and surveillance capacities. Enhancing these measures is essential to safeguard public health, ensure compliance with food safety standards, facilitate trade, and prevent food rejection and waste. These factors have significant implications for both food safety and security.

To explore this nexus further, various isotopic techniques offer valuable insights into biological and environmental processes. For example, $\delta^{13}C$ helps assess plant responses to drought and heat waves, while $\delta^{15}N$ measures nitrogen use efficiency, including nitrogen translocation within the plant. Techniques like $\delta^{18}O$ and $\delta^{2}H$ provide crucial data on water use efficiency. By combining $\delta^{13}C$ and $\delta^{18}O$, we can study stomatal sensitivity to stress, revealing how plants manage heat by either closing their stomata to reduce transpiration or opening them to increase transpiration for cooling. Additional techniques, such as ^{13}C pulse labeling for carbon allocation, compound-specific isotope ratios for biomarkers, and X-Ray Fluorescence (XRF) for rapid metal profiling, collectively deepen our understanding of how dryland ecosystems respond to climate stress.

A variety of experimental platforms can be utilized for the application of isotopic techniques, each of which is suited to specific conditions and research needs. These include field-based heat units to simulate temperature effects, rain shelters for controlled water simulations, open-top chambers to simulate both temperature and CO_2, free-air CO_2 enrichment (FACE) systems for elevated CO_2, temperature free-air controlled enhancement (T-FACE) for temperature effects, and closed growth chambers for controlled temperature, water, and CO_2 experiments. These platforms allow us to manipulate environmental conditions and simulate multiple climate change parameters, providing crucial insights into their combined effects on crop performance and resource use efficiency.

Despite the progress made worldwide, our review shows that several research gaps remain. Most studies simulate only one or two climate change drivers due to experimental limitations, underscoring the need for a deeper understanding of the combined effects of multiple stressors. We also need to refine methods and technologies for better tracking of these processes. Collaborative studies are essential to fully explore interactions and combined responses to climate change.

In our PUI project, *"Ensuring Food Security and Safety by Future-Proofing Dryland Crops under Climate Change,"* multi-analyte methods for the detection and determination of mycotoxins and heavy metals in crops are being developed and validated, to be transferred to Member States laboratories, contributing to national monitoring programmes and the generation of valid occurrence data for risk assessment and risk management decisions. These analytical methods are based on various nuclear and complementary techniques, such as Surface-enhanced Raman Scattering (SERS Raman), portable electrochemical immunosensors, Liquid Chromatography - Mass Spectrometry (LC-MS/MS) with isotope dilution and Supercritical Fluid Chromatography - Mass Spectrometry (FSC-MS) for mycotoxin testing, and X-Ray Fluorescence (ED-XRF) (Photo 1), portable sensors and Inductively Coupled Plasma Mass Spectrometry linked to Liquid Chromatography (LC-ICP-MS) for elemental profiling in crops and food products.

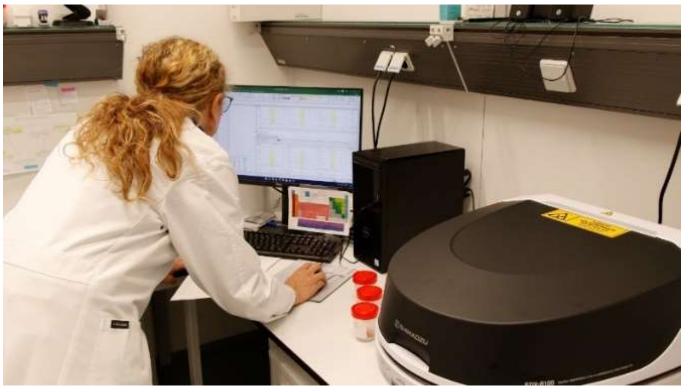

Photo 1. Rapid analysis of metals in crops and food products at the FAO/IAEA Laboratories with the ED-XRF technique (photo credit: M. Islam, 2024).

The next steps involve interdisciplinary experiments that for instance simulate elevated CO_2, drought, and nutrient stress to assess their combined effects on C_3 and C_4 plants using isotopic and nuclear techniques under controlled condition (Photo 2).

Photo 2. Closed chamber experiment initiated at the FAO/IAEA Laboratories simulating elevated CO_2, progressive drought, and nutrient stress in C_3 (wheat) and C_4 (sorghum) plants for understanding their impact on water use efficiency and nutritional quality (photo credit: M. Vezzone, 2024).

As knowledge gaps exist on the identity, the multitude and the complicated interlinkages of safety issues in crops driven by climate change, the next steps will also focus on improving analytical methods for both known and emerging chemical contaminants, along with methodologies to monitor changing trends in the application of agrochemicals. This project draws on the combined expertise of three FAO/IAEA Joint Centre laboratories: the Plant Breeding and Genetics Laboratory (PBGL), the Soil and Water Management and Crop Nutrition Laboratory (SWMCNL), and the Food Safety and Control Laboratory (FSCL). Through this integrated research, we aim to provide valuable insights to help guiding agricultural practices and policy-making, ensuring a sustainable and secure food supply under a changing climate.

In parallel, the PUI project team has organised a series of virtual consultancy meetings and global training courses to further develop interdisciplinary research and disseminate knowledge on the nexus of water and nutrient use efficiency, nutritional quality, and food safety in dryland agriculture, highlighting the application of nuclear techniques.

Using Mid-Infrared Spectroscopy (MIRS) to Predict Carbon-13 ($\delta^{13}C$) Signatures as Indicators of Intrinsic Water Use Efficiency (WUEi) and Drought Stress in Cassava

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Highlights:

- The SWMCNL cassava leaf mid-infrared spectral (MIRS) library, over 830 samples from four countries (Colombia, the Democratic Republic of the Congo, Kenya, and United Republic of Tanzania), demonstrates the suitability of MIRS for predicting ^{13}C values in plant material of the same species.

- The strong performance of machine learning techniques, such as Random Forest, even with a large and diverse dataset of over 200 cassava varieties, highlights their potential for reliable prediction of drought stress and intrinsic water use efficiency in cassava.
- ^{13}C signature values range from -31.9‰ to -21.2‰, highlighting the representativeness of the dataset.
- Member States are invited to participate in the continued building of the database through contributing samples for measurement.

The urgent challenge of optimizing agricultural water use under a changing climate has driven the development of various innovative techniques. A study led by the SWMCN Laboratory, in collaboration with institutions, including two CGIAR centres, is investigating the potential of MIRS to predict carbon-13 ($\delta^{13}C$) signatures in cassava. This research, covering diverse geographical regions such as Colombia, the Democratic Republic of the Congo, Kenya, and United Republic of Tanzania, seeks to understand the potential of MIRS as a cost-effective and accessible technique (compared to alternative methods) for cassava, a major crop for food security in developing countries.

By accurately predicting $\delta^{13}C$ values, farmers, through agricultural research organizations, can gain valuable insights for managing water use and optimizing crop resilience to climate change, particularly under water-scarce conditions. $\delta^{13}C$ is a well-established indicator of how efficiently plants use water and their response to drought. This study aims to simplify the measurement of these signatures using MIRS, offering a more accessible and cost-effective alternative to the more complex and expensive traditional methods, such as Isotope Ratio Mass Spectrometry (IRMS).

The study analysed over 830 cassava samples collected from diverse environmental conditions and more than 200 cassava varieties, providing a robust dataset for developing predictive models using MIRS. The $\delta^{13}C$ signature values, ranging from -31.9‰ to -21.2‰, underscore the dataset's representativeness (Figure 1).

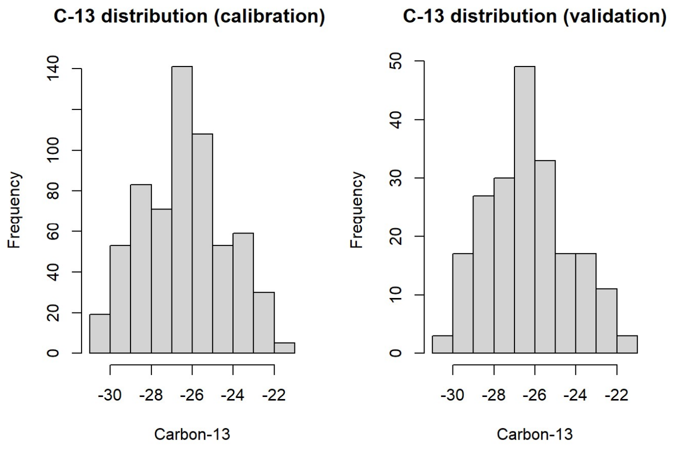

FIG 1. Histogram of the $\delta^{13}C$ values of the cassava leaf samples used for modelling.

To predict $\delta^{13}C$ signatures, the research team applied two main modelling techniques to the 830-sample library: Partial Least Squares Regression (PLSR) and Random Forest (RF) (Figure 2). The traditional PLSR model uses a multivariate statistical technique that reduces the complexity of the data while maintaining its predictive power. In this study, PLSR effectively linked MIRS data to $\delta^{13}C$ values, demonstrating strong predictive capabilities. For the full dataset, PLSR achieved a calibration R^2 of 0.83 and a root mean square error (RMSE) of 0.84, with similar performance in validation ($R^2 = 0.75$, RMSE = 0.98).

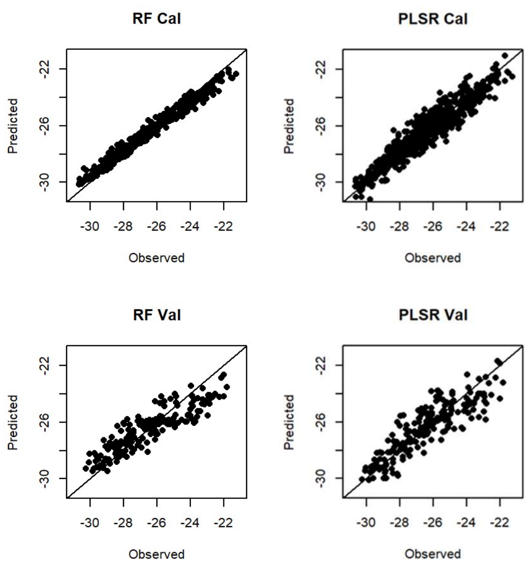

FIG 2. Predicted versus observed plots for the cassava spectral library using 830 samples using random forest (left) and PLSR (right) modelling.

However, the RF model outperformed PLSR in terms of predictive accuracy (Figure 2). RF, a machine learning algorithm that builds an ensemble of decision trees, demonstrated superior calibration performance with an R^2 of 0.97 and an RMSE of 0.39. In the validation phase, RF maintained strong predictive accuracy ($R^2 = 0.79$, RMSE = 0.85), suggesting that RF may be better suited for capturing complex, non-linear relationships between MIRS spectra and $\delta^{13}C$ values.

Both the preliminary PLSR and RF models showed that, despite some variability, MIRS can be a powerful tool for predicting $\delta^{13}C$ in cassava leaves across different growing conditions. With the ongoing refinement of these models and use of the insights gained from this study, particularly using diverse field samples, broader adoption of MIRS could be used to improve agricultural research and practice.

Member States are invited to participate in the continuation of this exciting work through reaching out to our staff about sharing samples for measurement and addition to the database.

Leveraging Stable Isotopes and Multispectral Imaging for Sustainable Water Management in Coffee-Banana Systems

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Highlights

- Stable isotopes ($\delta^{13}C$) and remote sensing are used to monitor water stress in coffee-banana intercropping systems with layered canopies.
- Drones equipped with multispectral cameras provide real-time, large-scale monitoring of thermal and water stress, while $\delta^{13}C$ data enhance the calibration of information derived from multispectral imagery.
- Results support sustainable water management in coffee-banana intercropping, strengthening climate resilience in agriculture.
- Insights gained can also enhance water management in other mixed cropping systems with layered canopies.

The PUI project, *"Enhancing Climate Change Adaptation and Disease Resilience in Banana-Coffee Cropping Systems in East Africa,"* funded by the Belgian government, has enabled SWMCNL to expand its research and development activities worldwide. In partnership with Fluminense Federal University (Brazil), SWMCNL is advancing innovative methodologies to evaluate water use efficiency in coffee-banana intercropping systems, promoting sustainable agricultural practices that address climate challenges.

Intercropping systems, like coffee-banana cultivation, are highly promising for enhancing agricultural resilience. By improving water and soil conservation, these systems optimize water and nutrient use efficiency. Coffee-banana intercropping, in particular, provides a model for building resilience in water-limited environments and fostering sustainable practices; bananas offer shade for the more sensitive coffee plants, while the root systems of the two crops complement each other through different rooting depths.

This research employs advanced tools such as carbon isotope analysis and UAV-based multispectral analysis to identify key indicators of drought-induced water stress in mixed cropping systems with complex canopy structures. These indicators include carbon isotope ratios ($\delta^{13}C$), leaf temperature, and other plant characteristics.

Large-scale, real-time assessments of thermal and water stress are conducted using drones equipped with multispectral cameras, while MIRS assesses the physical, chemical, and biological properties of soil. This comprehensive approach provides insights into the role of soil in plant responses to water stress within these intercropping systems. The findings are expected to optimize coffee-banana intercropping practices, boosting both climate resilience and economic viability, and have potential applications in improving other mixed cropping systems with layered canopies.

Laboratory- Techniques for Biochar Production in Carbon Cycling Research

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Biochar, a stable carbon-rich material, is produced via the pyrolysis of biomass at temperatures typically ranging from 400 to 600ºC under oxygen exclusion or low-oxygen conditions. It has gained significant attention in recent years due to its potential to improve soil properties and sequester carbon in soil for extended periods before decaying and returning to the atmosphere. Biochar has also been reported to improve soil quality by raising soil pH, improving nutrient availability, and increasing water holding capacity and plant-available water (Edeh *et al.,* 2020).

Maize is one of the most widely grown crops worldwide, with an annual production of approximately 1,162 million tons in 2021 (FAOSTAT, 2022). The dry weight ratio of maize straw to maize grain is reported to be 1:1 (Lal, 2005), resulting in a large volume of maize residues produced annually. Given their abundance, renewability and low-cost, maize residues can be an important source for biochar production. However, there is limited information on the dynamics of maize-based biochar in soil, particularly regarding its carbon storage potential and stability.

Before starting SWMCN Laboratory research on maize biochar dynamics, preliminary experiments were conducted to identify the most effective methods for producing maize biochar at the laboratory scale. Traditional biochar production often requires specialized equipment such as pyrolysis furnaces to control heating rate, final temperature, duration and oxygen content, which can limit the accessibility for many researchers. In this study, we present an energy- and cost-effective approach to biochar production using sealed porcelain crucibles and a high temperature muffle oven, which are readily available in many laboratory settings. The experiment was conducted in SWMCN Laboratory and Terrestrial Environmental Radiochemistry Laboratory (TERCL) of the IAEA Laboratories in Seibersdorf (Austria).

The pyrolysis was conducted in a muffle oven at seven different temperatures, increased incrementally from 250°C to 550°C in 50°C intervals. This range was selected to investigate the effects of temperature on the recovery rate (weight of produced biochar versus weight of initial dry biomass matter) and properties of the resulting biochar, such as pH, EC, and MIRS based characterization of the biochar's molecular structure, reflecting stability.

For testing laboratory-scale maize biochar production, maize stover from previous SWMCN Laboratory experiments was used. The stover was ball-milled to ensure high-density packing in the crucibles, thereby minimizing oxygen exposure. After processing, 60 g of maize material was loaded into 300 mL heat-resistant porcelain crucibles, covered with heavy steel lids that were slightly loose to allow air to escape, thereby limiting oxygen access during the charring process. Excess oxygen presence at high temperatures would cause combustion instead of pyrolysis of the maize. The crucibles were then placed in the oven and pyrolyzed for 1 hour at the stated temperatures, with heating at a rate of 7ºC min^{-1}. The residence time and heating rate were selected based on a comprehensive review of existing literature, which consistently demonstrates that aside of temperature, residence time is a critical factor in determining the physical and chemical characteristics of the resulting biochar. The obtained biochar samples were analysed for recovery rate, pH and electrical conductivity (EC).

Our results indicated that as temperature increases, the biochar recovery rate decreases, stabilizing at around 30% (Figure 1), while pH rises to approximately 11.0 (Figure 2). The minimal standard error values indicate the high reproducibility and consistency of the chosen method for biochar production, demonstrating its effectiveness and reliability. Analysis of these parameters, along with MIRS data, revealed that optimal stability was achieved at around 500°C (Figure 3). The samples are also undergoing further analysis for carbon (C), nitrogen (N), hydrogen (H), and oxygen (O) content to provide more detailed results and validate the MIRS findings.

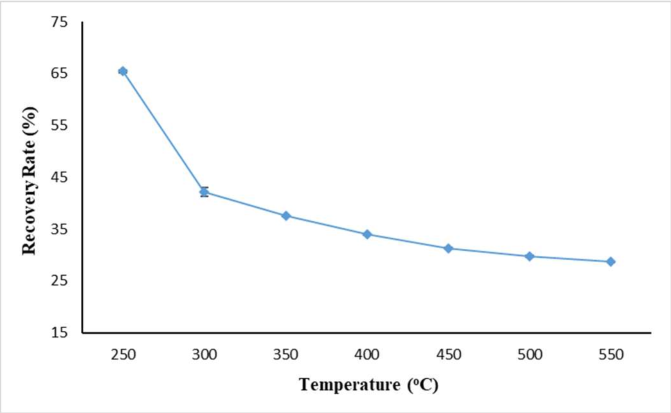

FIG 2. Recovery rate (%) of maize-based biochar obtained at different temperatures (°C).

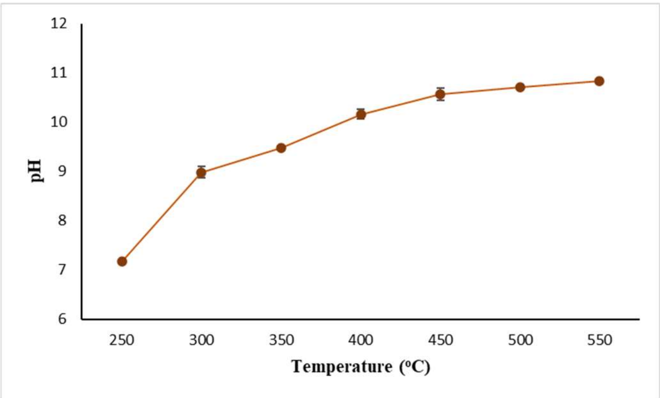

FIG 2. pH of maize based biochar at different temperatures.

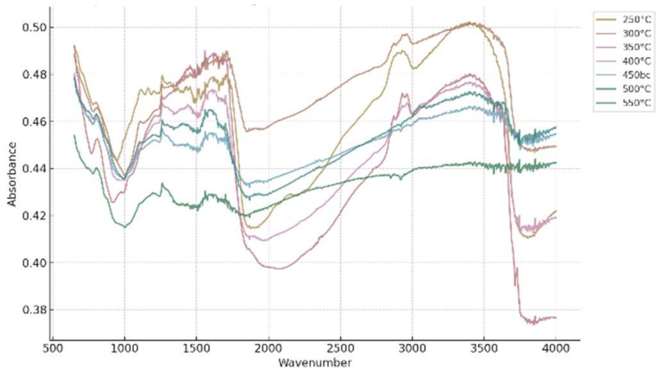

FIG 3. Mid-Infrared Spectroscopy analysis of maize based biochar at different temperatures

This study offers a cost-effective approach for the production of biochar using porcelain crucibles, a viable option for laboratory-scale biochar production from feedstocks including precious stable isotope labelled plant materials. Based on these outcomes, the SWMCN Laboratory team has now prepared stable carbon isotope labelled maize stover. The use of ^{13}C-labelled maize stover as a feedstock material for biochar production will pave the way for a broader understanding of biochar's role in soil carbon cycling and helping in the development of sustainable agricultural practices.

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Investigating Nitrous Oxide Pathways and Soil Carbon-Nitrogen Interactions Using Isotopic Techniques to Mitigate Greenhouse Gas Emissions

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Effective carbon (C) and nitrogen (N) management in soils is essential for reducing GHG emissions, particularly nitrous oxide (N_2O) and carbon dioxide (CO_2), from agricultural soils.

In 2024, the SWMCNL team initiated a study to test innovative dual carbon and nitrogen isotope-based methods for understanding the biological pathways that drive N_2O and CO_2 production in soils, as well as how these emissions can be effectively managed. By applying ammonium nitrate fertilizers labelled with the nitrogen-15 (^{15}N) isotope, N movement can be tracked across these pathways, helping us identify the specific conditions that lead to either N_2O production from ammonium or nitrate in ammonium nitrate fertilizer, or its reduction to nitrogen gas (N_2), which is environmentally harmless.

Additionally, the SWMCNL team is examining the impact of different carbon forms on GHG emissions by using stable carbon isotope (^{13}C) labelled crop residues and biochar. Labile carbon sources, such as plant litter, and recalcitrant carbon, like biochar, interact with soil N in distinct ways that influence these emissions. Soil microbes play a crucial role in these interactions, as labile C from plant litter provides an immediate energy source, stimulating rapid microbial activity. In contrast, the more stable recalcitrant C in biochar can enhance long-term carbon sequestration while immobilizing N in a form that reduces its availability for N_2O production.

To gain deeper insights into these processes, a large-scale incubation study was set up using soils sampled from long- and medium-term field experiments conducted in Grabenegg, Austria by University of Natural Resources and Life Sciences (BOKU) and Austrian Agency for Health and Food Safety GmbH (AGES). One soil has been amended with NPK (N, phosphorus, potassium) fertilizers for over forty years, while the other soil has been treated with both NPK and biochar (derived from hardwood) over a two-year period, beginning in 2022 (Photo 1). In October 2024, soil samples were collected from the upper root zone 10cm depth.

Soil samples collected from both sites for the incubation experiment have been enriched with double-labelled N fertilizers ($^{15}NH_4NO_3$ and $NH_4{}^{15}NO_3$ both at 60 atom% ^{15}N) as well as ^{13}C-labeled biochar (derived from maize) and ^{13}C-labeled plant litter, both of which were produced at the SWMCNL. The combination of treatments used is explained in Figure 1.

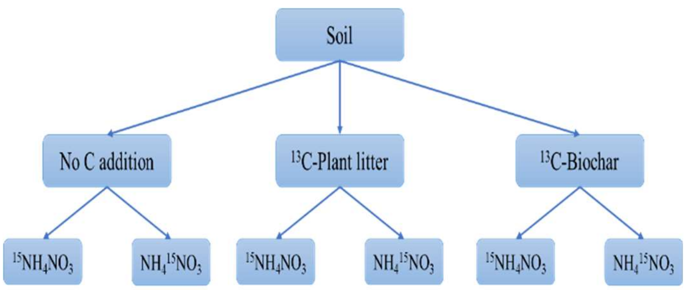

FIG. 1. Description of treatments used in the incubation experiment.

The study will focus on measuring $^{15}N_2O$, $^{15}N_2$, $^{13}CO_2$, Particulate Organic Matter, and Mineral-Associated Organic Matter, and mineral-N ($^{15}NH_4$, $^{15}NO_3$) at specified intervals. Results from these analyses will be shared in the upcoming July newsletter.

Enhancing the extraction of conventional and biodegradable microplastics in soil

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The presence of microplastics (MP) in the environment has emerged as a significant concern. In agricultural soils, MPs influence the physical and chemical soil properties, thereby potentially affecting soil fertility. Assessing MP pollution in agricultural soils is a crucial initial step in understanding the potential risks and implications for food production and human health. However, the lack of standardized methods for assessing MP types and concentrations in soils poses a significant limitation for assessing mitigation strategies and developing legislative policies.

The SWMCNL, under CRP D15021, is testing and adapting MP extraction protocols from soils, including the assessment of potential isotope fractionation and the stability of biodegradable MP during extraction and sample processing steps. The extraction methods were refined in three key aspects: (1) Optimizing the sequence and frequency of density separation and soil organic matter (SOM) removal, (2) Evaluating the effectiveness of chemical reagents for SOM elimination and adjusting reagent volumes, and (3) Assessing the stability of properties and isotopic values after extraction. A key aspect of this method optimization is to avoid alteration of the MP during the entire extraction process, which is essential to ensure the reliability of isotopic analysis in tracing the sources and environmental pathways of MP, as well as in preserving the integrity of data used to study the biogeochemical cycling of all MP types.

The MP recovery rates were assessed using microscopic analysis (Figure 1). Preliminary results demonstrate the improvements in recovery rates and the effectiveness of the adapted protocol. Isotopic stability of carbon-13 is now being determined using an elemental analyser (Vario Isotope Select, Elementar, Langenselbold, Germany) coupled to an isotope ratio mass spectrometer (Isoprime 100, Elementar UK, Manchester, United Kingdom).

This work marks a step toward enhancing the extraction of both conventional and biodegradable MP from soils. The following steps will involve refining and validating these methods by testing the extraction of MP in different soil types. This study offers a more reliable approach to identify and quantify MPs in agricultural soils, thereby enabling a deeper understanding of their environmental fate.

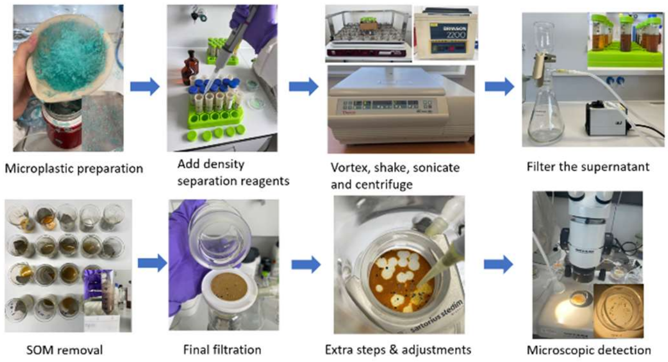

FIG. 1. Schematic representation of the experimental procedures tested at the SWMCNL for microplastic (MP) extraction. The process includes MP preparation, density separation, soil organic matter (SOM) removal, chemical treatment, and microplastic recovery analysis (photo credit: C. Jiang, 2024).

Science Day "Healthy Soil"

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The Soil and Water Management & Crop Nutrition Laboratory (SWMCNL) participated in the "Healthy Soil" Science Day, organised by the University of Natural Resources and Life Sciences (BOKU), Vienna, on 18 October 2024 at the BOKU laboratories. Key partners included "Oceanblue," which focuses on microplastics in water; the Austrian Federal Government's "Microplastic-Free Alliance" project (2022–2025); the Austrian Agency for Health and Food Safety GmbH (AGES); and BOKU.

The event aimed to share our research and make science accessible to the public through information booths, laboratory tours, results from the Citizen Science Project "City-Zen Soil," and a quiz. During the event, we presented our soil incubation studies using stable carbon isotopes to assess the impact of microplastics on soil carbon stability and expanded our network with Austrian laboratories working on microplastic pollution in agricultural soils.

Photo 1. A Science Day participant receives guidance on collecting a sample for stable isotope analysis during a hands-on demonstration (photo credit: A. Toloza, 2024).

Analytical Services

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In 2024, 8892 samples were analysed for stable isotopes and 120 samples were measured for fallout radionuclides respectively in the SWMCN Laboratory. Most analyses were carried out for supporting Research and Development activities at the SWMCNL focused on the design of affordable isotope and nuclear techniques to improve soil and water management in climate-smart agriculture.

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Websites and Links

- Soil and Water Management and Crop Nutrition Section:
  https://www.iaea.org/topics/land-and-water-management
- Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture:
  https://www.iaea.org/topics/food-and-agriculture
- Food and Agriculture Organization of the United Nations (FAO):
  http://www.fao.org/home/en

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