Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

Soils Newsletter

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Contents

To Our Readers

Photo 1. Farmers using climate-smart agricultural practices for rice production in Nepal (photo credit: Madhav Prasad Lamsal).

The Soil and Water Management and Crop Nutrition (SWMCN) team has been developing sustainable solutions to help Member States improve food security and address climate change. These include development and validation of new climate-smart agricultural practices, which further increased crop production, reduced emissions of greenhouse gases (GHGs), land degradation by erosion and salinity and agro-contaminants, and improved soil fertility.

These activities will contribute to the FAO and IAEA Atoms4Food Initiative, which seeks to provide Member States with sustainable solutions tailored to their specific needs by harnessing the advantages of nuclear science and technologies, along with other advanced technologies. The aim of our work is to strengthen Member States' capacity to increase crop productivity, while sustainably managing natural resources especially land and water. To optimize our services to Member States under the framework of the Atoms4Food Initiative, SWMCN initiated the identification of crosscutting opportunities such as Cosmic-Ray Neutron Sensing (CRNS), mapping soil physical and chemical properties and reducing salinity with appropriate private and public institutions.

SWMCN has also continued to provide technical support to the IAEA Technical Cooperation (TC) program. Several national TC Projects (TCPs) were initiated with the aim to reduce gaps in productivity of major crops using climate-smart agricultural practices this year. The SWMCN sub-programme is supporting 65 TCPs, of which 53 are national, 10 are regional, and two are interregional.

I would also like to share with you that two Coordinated Research Projects (CRPs) 'Enhancing Agricultural Resilience and Water Security Using Cosmic-Ray Neutron Technology (CRNS)' and 'Multiple Isotope Fingerprints to Identify Sources and Transport of Agro-Contaminants' have been successfully completed in the first half of 2024. The first one led to the development of a comprehensive CRNS data processing tool, several value-added products useful for agricultural applications of water management, and the publishing of 23 scientific papers in journals. The publication of a guideline 'Cosmic-Ray Neutron Sensing: Applications in Agricultural Water Management' as an FAO book is ongoing. The second CRP contributed to the development of new analytical methods to identify agricultural pollutants (nutrients and pesticides), and these methods were successfully tested and transferred to several Member States through TCPs. In CRP 'Developing Climate Smart Agricultural practices for mitigation of greenhouse gases', a new method capable of measuring ammonia volatilisation at field scale was developed and validated. Additionally newly developed climate smart agricultural practices contributed to further increase in crop productivity with lower GHG emissions and sequestration of carbon.

Research conducted at the SWMCN Lab (SWMCNL) reported that the deployment of CRNS in several Member States in 2024 enhanced soil moisture data collection through integration with high spatial and temporal satellite imagery, facilitating informed decision-making in agriculture and water and soil management initiatives. Collaboration with FAO further aims to integrate CRNS data into FAO's open-access Hand in Hand (HIH) Geospatial Platform, expanding accessibility and usability for Member States.

SWMNCL also supports a Peaceful Uses Initiative (PUI) project that focuses on bolstering the resilience of dryland crops to climate change. The project, supported by a EUR 500,000 pledge from the UK, aims to enhance water and nutrient efficiency, improve nutrition, and ensure food safety in key dryland crops.

In addition, SWMNCL contributes to an FAO project on Resilient Agrifood Systems (SoilFER) for soil mapping, which has been ongoing since May 2023, and aims to build national capacity for improving soil fertility information systems. The project, supported by the US Department of State, focuses on strengthening capacities and empowering stakeholders in target countries such as Ghana, Guatemala, Honduras, Kenya, and Zambia. Expansion plans include interventions in Mozambique and Tunisia with funding from Japan, promoting efficient fertilizer usage, sustainable farming practices, and enhancing soil health and agricultural livelihoods. SWMCNL's role is to help Member States capacity building for farmers and institutions, and implementing digital solutions for nutrient management.

Several staff members, PhD students, interns, and fellows from the SWMCNL showcased their research and development achievements at the annual European Geosciences Union General Assembly Meeting (EGU) 2024, held at the Austria Center Vienna from 14 to 19 April. They delivered a total of eleven presentations, with eight taking place in-person and three virtually. The SWMCNL highlighted its work on predicting soil moisture using machine learning, assessing soil texture through gamma ray sensing, utilizing mid-infrared spectroscopy (MIRS) for soil and plant analysis, and employing stable isotopes for experiments on climate-smart management, microplastics in soil, and nutrient and water use in wheat and coffee. The efforts of the team were prominently featured in different EGU sessions. I extend my gratitude to everyone for their outstanding contributions. More details about their presentations can be found in the newsletter.

We would like to pay tribute to Joseph Adu-Gyamfi who left the Agency on 31 May 2024, after completing 15 years of service as Soil Scientist and Soil Fertility Management Specialist with the SWMCN Section. He provided technical assistance to CRPs and IAEA national, regional/interregional TCPs. Joseph's dedication was essential in addressing food security challenges, AMR, microplastic pollution, water scarcity and land degradation as reported in several success stories from Member States and scientific publications. Joseph will be missed by the team, his friendliness and dedication to the sub-programme, and we wish him all the best.

To conclude, I would like to thank all, our readers, counterparts, private sectors, and our team members for their support. SWMCN will continue to enhance food security, as well as climate change mitigation and adaptation in Member States.

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Staff News
Welcoming new colleagues:

Mariko Fujisawa (Japan) joined the IAEA in February 2024 as Agricultural Water Scientist. Prior to joining the IAEA, she worked for UNESCO Tashkent Office in Uzbekistan for 3 years to improve vocational education in agriculture and irrigation sectors as rural development. From 2015 to 2020 she worked for FAO HQ in Rome to support countries with conducting impact assessment and developing adaptation strategy to climate change in agriculture, as well as improving national agrometeorological services. Prior to her UN career, Mariko worked at University of Cape Town in South Africa as a post-doctoral researcher with focus on farmers' adaptation strategies to climate change in sub-Saharan African countries through field work and interview surveys. She holds a PhD in Agrometeorology from the University of Tokyo, Japan.

Jumpei Iwai (Japan) joined the SWMCN Laboratory in May 2024 as an intern. Jumpei is a master's student in the Plant Nutrition Laboratory of Faculty of Agriculture, Hokkaido University, researching radioactive caesium uptake by plants from soil. He will be working under CRP D15019 on 'Monitoring and predicting radionuclide uptake and dynamics for optimizing remediation of radioactive contamination in agriculture'. This internship opportunity will further explore mid-infrared spectroscopy (MIRS) modelling to measure the ratio of exchangeable radiocaesium to total radiocaesium MIRS analysis provides rapid, resource efficient, and non-destructive measurements and can be useful for soil fertility assessment.

Daisy Kwamboka Osoro (Kenya) joined the SWMCN Laboratory in May 2024, as an IAEA Marie Sklodowska Curie fellow. She is currently a MSc student at Egerton University in Kenya, specializing in dryland farming. She holds a BSc in Agriculture Extension and Education from Moi University in Kenya. After graduating in 2019, she became a biology and agriculture teacher at Loreto Boys Nakuru for a year, and later joined the PlantVillage project in 2021, where she worked with smallholder farmers across Kenya. Through extension services and training on climate change mitigation, pest and disease management, and sustainable agriculture, she had a positive impact on the livelihoods of farmers. In her master's degree, she has worked on determining the effect of biochar on cassava growth and yield in different agroecological zones in Kenya. She will validate carbon isotopic (^{13}C) technique for screening drought stress in cassava production systems in Kenya. Additionally, this fellowship will enable her to contribute to the validation of estimation techniques for ^{13}C signatures in cassava leaves based on Mid-Infrared Spectroscopy.

Mariana Vezzone (Brazil) has joined the SWMCN laboratory as a Senior Laboratory Technician (temporary assignment). She has been working on the development and validation of isotope techniques for enhancing carbon and nutrient management, assessing climate change impacts on resource use efficiency by dryland crops, and tracing microplastic soil contamination under CRP D15021. Mariana is an agricultural and environmental engineer from the Fluminense Federal University, Brazil with a PhD in Geology with a focus on Soil Science. Her previous research activities focused on soil and water conservation, mitigating the impact of human activities on both terrestrial and aquatic environments, use of waste products in agriculture, the restoration of degraded areas, and the optimization of resource utilization through the application of nuclear, stable isotope, and related techniques.

RETIRED colleagues

Joseph Adu-Gyamfi (Ghana), Integrated Soil Fertility Management Specialist at the SWMCN Section, retired from the Agency on 31 May 2024 after 15 years of service. He worked in the IAEA SWMCN Laboratories at Seibersdorf for seven years (2006–2013) as soil scientist/ plant nutritionist, and as acting Laboratory Head of the soil science unit (2011–2012), before joining the SWMCN Section in 2017 as an integrated soil fertility management specialist at the IAEA Headquarters in Vienna. Joseph initiated the development of methodologies using multi-isotope fingerprints to identify sources and fate of agro-pollutants and antimicrobial resistance (AMR) in the environment. He contributed to developing two novel methods of using oxygen stable isotopes of phosphorus (P) that enable the tracing of excess P that causes eutrophication in surface waters, and compound-specific isotopes techniques to identify the sources of pesticides. He developed a set of guidelines (*the toolbox*) for identifying the pollutant sources from fertilizers, pesticides, mining sites and household wastewaters that is published in Springer. Joseph initiated a CRP on assessing the fate and environmental impacts of plastic and microplastics in the soil and crop ecosystem using nuclear techniques. Joseph worked in several TCPs of Africa, Latin America & Caribbean, and Asia-Pacific. Joseph was a recipient of the IAEA Superior Achievement Award in 2018 and a Merit Award in 2023.

We thank Joseph for his contribution to the SWMCN Subprogramme and wish him a happy retirement.

Feature Articles

The Montpellier Process: Pooling Collective Intelligence for Action

***Gerd Dercon*[1]**

[1]*Soil and Water Management and Crop Nutrition Laboratory, Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture, Seibersdorf, Austria.*

From 19 to 20 March 2024, the event titled 'The Montpellier Process - Pooling Collective Intelligence' was held in Montpellier, France. This gathering convened 300 participants from scientific and policy-making communities to deliberate on transforming food systems aligned with the goals of the 2030 Agenda for Sustainable Development.

The event - structured around three thematic sessions - aimed to foster a comprehensive discussion to enhance global food systems:

1. Knowledge: Sharing the ambitions, challenges, and needs of expert panels.
2. Intelligence: Facilitating interactive discussions to transcend fragmented intelligence.
3. Action: Developing a collaborative roadmap for pooling collective intelligence.

What is the Montpellier Process?

The Montpellier Process seeks to address today's challenges by fostering collaborative processes and knowledge sharing to achieve global goals by 2030 and beyond. This initiative requires a common vision and shared commitment of action. The process emphasizes the active role that knowledge communities should play in pooling collective intelligence about ongoing processes and identifying plausible and desirable futures. The essence of the process lies in its transformative impact, collectively redefining how we operate, engage, and collaborate as a globally inclusive knowledge community. Initiated in 2021, the Montpellier Process is supported by the University of Montpellier, its partners in the I-site excellence program, and CGIAR.

The March 2024 event brought together 300 experts and decision-makers from scientific, policy-making, and civil society backgrounds, representing 60 countries and five continents. Over two days, participants worked together to identify imperatives for global knowledge communities to accelerate and amplify their contributions to urgent food systems transformation. The aim was to shape further development of the Montpellier Process as an effective vehicle for convening international experts and organizations to collectively address current and future global challenges by strengthening engagements between science, policy, and society.

The IAEA supported the event in its capacity as Steering Committee member of the Montpellier Process, with Mr. Gerd Dercon representing the IAEA Department of Nuclear Sciences and Applications. Mr. Dercon also served as a co-facilitator in discussions and currently contributes to the outcome document, summarizing the agreed outcomes of the event.

Strategies to Achieve Objectives

The Community of Practice convened in Montpellier has delineated six strategies to achieve its objectives, offering potential pathways for the IAEA, particularly the Joint FAO/IAEA Centre, to contribute to their implementation:

1. **Strengthening Institutional Arrangements:** Enhancing collaboration among knowledge institutions, independent assessments, and intergovernmental Science Policy Interfaces (SPI) to ensure informed action. This includes replicating the Montpellier Process across various scales, fostering collaboration among existing SPIs, and creating safe learning spaces.
2. **Enabling Science Engagement:** Facilitating scientists' participation in policy processes through Policy Hubs and rapid response mechanisms to address emerging policies.
3. **Promoting Inclusion**: Emphasizing greater diversity and representation in SPIs, especially in leadership roles, and fostering a culture of inclusivity and transparency.
4. **Enhancing Communication**: Improving dialogue among science, policy, and society

communities to identify crucial questions and knowledge gaps while maintaining independence in addressing challenging issues.

5. **Diversifying the Knowledge Toolbox**: Ensuring a variety of tools are available and effectively utilized to support diverse policy contexts and inclusive processes.
6. **Navigating Public-Private Collaboration**: Recognizing the importance of engaging with the private sector, aligning on shared objectives, promoting transparency, and focusing on producing public goods.

These strategies offer potential pathways for the IAEA, particularly the Joint FAO/IAEA Centre, to contribute to their implementation. For example, scientists could engage more in policy development processes indirectly by incorporating these aspects into CRPs and TCPs, or directly by participating in SPI-related organizations and Steering Committees. Collaboration with non-traditional partners like CGIAR or the private sector is becoming more common at the IAEA. This could be further explored through case studies highlighting dialogue among science, policy, and society communities. Citizen science projects also offer a promising avenue for deeper engagement in the Montpellier Process.

Advancing Climate-Smart Agriculture in Latin America and the Caribbean: The key contribution of nuclear techniques

Alves, Bruno J.R[1]., Urquiaga, Segundo[1], Zaman, Mohammad[2]

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Latin America has 645 million inhabitants distributed across tropical and subtropical regions, with the Andean region being particularly notable for biodiversity. In most countries, agricultural food production relies on the natural fertility of the soils, which are mostly nutrient-poor. This has led to an increase in cultivated areas through deforestation, resulting in significant negative impacts on agriculture and environment such as substantial greenhouse gas (GHG) emissions, land degradation and low crop productivity. In the first two decades of the current century, Latin America experienced the largest relative cropland gain, with an expansion of 37 million hectares, or 49% of the existing area in 2003 (Potapov et al., 2022).

In Latin America and the Caribbean (LAC) countries, almost a quarter of their food production is exported, including a significant portion of the global supply of grains, vegetables, fruits, and animal protein (milk and meat) to earn foreign exchange. However, recent reports by the Food and Agriculture Organization (FAO) of the United Nations highlight that food insecurity remains a challenge in the region. This is because production systems are largely oriented towards commodities, with a primary focus on increasing gross domestic product (GDP). Staple foods such as rice, beans, potatoes, cassava, maize, and sweet potatoes, which are primarily cultivated by small farmers, take more time to benefit from technological improvements. Inefficient production systems result in suboptimal yields, contributing to excessive GHG emissions due to poor farming practices. With a partial contribution of agriculture to atmospheric warming by the accumulation of GHGs, climate extremes (drought and flooding) increase the risk of crop failure and productivity losses, which require mitigation and adaptation. Therefore, a change to more efficient production systems is so important for LAC, where the adoption of climate-smart agricultural (CSA) practices can make a significant difference in improving the livelihoods of the farmers.

Climate-smart agriculture focuses on three basic pillars. **The first pillar** relates on improving agricultural productivity to address food insecurity, aiming to optimize the use of every square meter converted from natural environments while ensuring social and environmental responsibility. Given the actual threats climate change poses to humanity, the second pillar is oriented towards **aligning food**

systems to achieve a reduced carbon footprint or emitting low GHGs. The last pillar considers **the need to implement adaptation measures** to conserve natural resources (soil and water) under changing climate.

The Joint FAO/IAEA Centre of the IAEA through its Technical Cooperation Programme is spearheading efforts to realize CSA on a global scale. Through the Regional Cooperation Agreement for the Promotion of Nuclear Science and Technology in Latin America and the Caribbean (ARCAL), 17 countries led by Mexico, alongside major food producers such as Argentina, Brazil, Colombia, and Peru, have tackled crucial agricultural development priorities and devised CSA solutions for dissemination to farmers. Research endeavors aimed at developing innovative techniques to enhance crop productivity as well as conserving natural resources. Through the use of ^{15}N isotopic techniques, efforts are underway to improve nitrogen (N) fertilizer use efficiency (NUE) and assess alternative nitrogen sources. The considerable fossil energy consumption involved in the synthesis, processing, and transportation of nitrogen fertilizers, coupled with the nitrous oxide emissions from agricultural soils, contributes majorly to GHG emissions in upland cropping systems. Utilizing fertilizers enriched with ^{15}N enables the tracking of N fertilizer fate, facilitating the redesign of 4R stewardship (right source, rate, place, and time) to align with evolving crop demand and management conditions.

Moreover, to reduce N fertilizer usage, many countries are adopting biological N fixation (BNF), integrated methods for pest control and root stimulation, with ongoing validation of their effects on yields and NUE. Where feasible, nitrogen-fixing plants are recommended for incorporation into crop rotations as an alternative N source. Monitoring the effectiveness of BNF involves techniques based on the natural abundance of ^{15}N, with the goal of enhancing the process through the use of more efficient rhizobial strains or ensuring N is not depleted from the soil due to imbalanced inputs and outputs of this nutrient. Initial adoption of these practices suggests a potential reduction of up to 30% in current N application rates. Furthermore, in extensive areas of LAC, particularly in tropical regions, soil organic matter plays a vital role in enhancing nutrient and water retention, as well as providing a suitable structure for aeration and root development. The use of the ^{13}C isotope has proven invaluable in investigating the effects of crop rotation components on soil carbon dynamics, storage and persistence.

Scientists from the LAC have participated in training courses organized by the IAEA on the safe and targeted use of nuclear science and technology through several IAEA funded CRP and ARCAL TC projects. The aforementioned ARCAL project 5090 benefited from in-person training on the use of ^{15}N, focusing on fertilizer management and biological N fixation, with participants from Argentina, Brazil, Chile, Costa Rica, Cuba, the Dominican Republic, Ecuador, Mexico, Nicaragua, Panama, Paraguay, Peru, Venezuela, and Uruguay. Other nuclear techniques have been introduced previously, which have been considered essential for the development of successful options for more sustainable cropping systems in LAC.

Photo 1. Using climate smart agricultural practices for maize production in Brazil.

Long Night of Research: Exploring Nuclear Science in Agriculture
24 May 2024, VIC, Vienna

***M. Heiling*[1]**

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On 24 May 2024, the International Atomic Energy Agency (IAEA), in collaboration with other Vienna-based International Organisations participated in the Austria-wide Long Night of Research promoting science to people of all ages. At this event, the SWMCN section presented interactive exhibits which allowed youngsters and adults to learn about how nuclear science and technolgy offer advantages in understanding and managing complex interactions of soil, water, and nutrients to sustainably enhance crop productivity. How scientists can gather precise information to produce more crop using less water, were some of the presented elements. This event showcased IAEA's commitment promoting nuclear science and technology for peace and development through innovative research.

Photo 1. Children are shown how to use an isotopic tracing game by SWMCN staff member.

Photo 2. A Marie Skłodowska-Curie Intern demonstrates how the SWMCN Section uses nuclear and remote sensing techniques to help farmers to have more efficient irrigation.

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
Algeria	ALG5031	Using Nuclear Techniques to Characterize the Potentials of Soils and Vegetation for the Rehabilitation of Regions Affected by Desertification	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
Botswana	BOT5024	Improving Selected Legumes and Cereals against Biotic and Abiotic Stresses for Enhanced Food Production and Security	M. Zaman and PBG
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
Burundi	BDI5005	Enhancing Productivity of Staple Crops Using Nuclear-derived Technologies	M. Zaman and PBG
Cambodia	KAM5008	Introducing a Digital Soil Information System and Remote Sensing for Sustainable Land Use Management	H. Said Ahmed
Central African Republic	CAF5014	Strengthening Capacity for Enhancing Cassava Production and Quality through Best Soil Nutrient Management Practices	M. Zaman
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. Zaman 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
Egypt	EGY5027	Strengthening Capacities for Combating Soil Erosion and Restoring Soil Fertility to Support Sustainable Soil and Water Management Practices and Rehabilitation of Degraded Soils for Enhanced Production and Food Security	M. Zaman
Ghana	GHA5039	Mainstreaming Nuclear Based Climate Smart Agriculture Technologies into Sustainable Production	M. Zaman and PBG
Haiti	HAI5008	Strengthening National Capacities for Enhanced Agricultural Crop Productivity	M. Zaman
Haiti	HAI5010	Stengthening National Capacities for Enhanced Agricultural Crop Productivity	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	Atoms4Cllimate 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
Malaysia	MAL5033	Strengthening national capacity in food and animal feed for food safety and security	M. Zaman and FSC
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	NIC2002	Strengthening of National Capacities in Energy Planning and Geothermal Resource Assessments through the Application of Isotopic Analytical Methods	M. Zaman
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	PAN5029	Strengthening National Capacities to Combat Land Degradation and Improve Soil Productivity Through the Use of Isotope Techniques	M. Zaman
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	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

Rwanda	RWA5001	Improving Cassava Resilience to Drought and Waterlogging Stress through Mutation Breeding and Nutrient, Soil and Water Management Techniques	M. Zaman and PBG
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 and IH
Senegal	SEN5041	Strengthening Climate Smart Agricultural Practices Using Nuclear and Isotopic Techniques on Salt Affected Soils	M. Zaman
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
Thailand	THA5057	Enhancing Capabilities for the Application of Isotopic Techniques for Enhanced Water Resource Management	M. Zaman
Togo	TOG5006	Improving the Productivity of Soybean (Glycine max L) Using Nuclear Techniques	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. Zaman
Zimbabwe	ZIM5026	Improving Soil Quality for Optimizing Selected Cereal and Legume Productivity in Smallholder Farms	M. Zaman

Forthcoming Events

FAO/IAEA Events

Fourth Research Coordination Meeting of CRP D15019 on Monitoring and Predicting Radionuclide Uptake and Dynamics for Optimizing Remediation of Radioactive Contamination in Agriculture, 15 to 19 July 2024, Vienna, Austria

Technical Officer: G. Dercon

Second Research Coordination Meeting of CRP D15020 on Developing Climate Smart Agricultural Practices for Mitigation of Greenhouse Gases, 7 to 11 October 2024, Vienna, Austria

Technical Officer: M. Zaman

NON-FAO/IAEA Events

Past Events

FAO/IAEA Events

Regional Workshop on Soil-Water Management Practices to Reduce Agro-Contaminants and Improve Water Quality, under TC project RAS5091 'Assessing and Mitigating Agro-Contaminants to Improve Water Quality and Soil Productivity in Catchments Using Integrated Isotopic Approaches', 18 to 22 March 2024, Bahadurgarh, Haryana, India

Technical Officer: J. Adu-Gyamfi

The regional Technical Cooperation (TC) Project RAS5091 'Assessing and Mitigating Agro-Contaminants to Improve Water Quality and Soil Productivity in Catchments Using Integrated Isotopic Approaches' has the overall objective to improve agricultural catchment, water, and soil management practices in the Asia–Pacific region by enhancing the capacity of countries to assess and mitigate agricultural contaminants. Twelve project counterparts from 9 Asia-Pacific Member States participated in the meeting hosted by the Global Centre for Nuclear Energy Partnership, Bahadurgarh, Haryana, India. The workshop participants drafted guidelines for monitoring agro contaminants to improve soil and water quality in transboundary rivers and agricultural catchments for implementation. The workshop enhanced human capacities to develop their technical capabilities to monitor agro-contaminants in catchments and transboundary rivers.

Photo 1. Participants of RAS5091, Regional Workshop on Soil-Water Management Practices to Reduce Agro-Contaminants and Improve Water Quality (photo credit: Mehetre S., 2024).

IAEA Regional Training Course on Climate Smart Agriculture to Improve Soil Fertility, Combat Salinity, Enhance Nutrients and Water Use Efficiencies and Increase Productivity of Major Crops in Asia, 15 to 26 April 2024, Selangor, Malaysia

Technical Officer: M. Zaman

The Regional Training Course on Climate Smart Agriculture successfully concluded in Bangi, Malaysia, running from 15 to 26 April 2024. This event was attended by 39 participants, including 16 females and 23 males from 17 Asia Pacific countries. The 10-day course aimed to enhance participants' technical knowledge on food production, addressing soil fertility degradation, inefficient nutrient, and water management, GHG emissions, and mitigation strategies. It emphasized the role of nuclear science and technology in developing Climate Smart Agriculture practices to improve soil fertility, combat salinity, and increase crop productivity. Participants engaged in lectures, hands-on activities, and field visits to learn practical solutions for agricultural resilience and sustainability. The course fostered regional cooperation and knowledge exchange, aiming to build a more resilient agricultural sector capable of addressing climate change challenges.

Photo 1. Participants of RAS5099, RAS5093, RAS5094, IAEA Regional Training in Selangor, Malaysia.

First Coordination Meeting of ARCAL Project RLA5090 'Improving Agriculture Productivity through Better Agricultural Practices and Improved Varieties (ARCAL CXCII)',
29 April to 3 May 2024, Ciudad del Este, Paraguay

Technical Officer: M. Zaman

The Regional Cooperation Agreement for the Promotion of Nuclear Science and Technology in Latin America and the Caribbean (ARCAL), Project 5090, 'Improving Agriculture Productivity through Better Agricultural Practices and Improved Varieties' aims to increase crop yields in Latin American and the Caribbean region through the demonstration and transfer of Climate Smart Agriculture (CSA) practices. The first Coordination Meeting (29 April to 3 May 2024) took place in Ciudad del Este, Paraguay and brought together participants from 14 LAC countries to discuss successful CSA experiences, focusing on staple food crops from each country. Additionally, in-person training on using ^{15}N techniques to validate nitrogen fertilization strategies and biological sources was conducted. The expected outcomes include increased yields, reduced greenhouse gas emissions, and enhanced adaptation strategies to boost the resilience of agriculture in the region.

Photo 1. Participants of First Coordination Meeting of ARCAL Project RLA5090 'Improving Agriculture Productivity through Better Agricultural Practices and Improved Varieties (ARCAL CXCII)', Ciudad del Este, Paraguay.

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 lmpact of Plastics in Soil and Crop Ecosystems Using lsotopic 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

Enhancing Agricultural Resilience and Water Security using Cosmic-Ray Neutron Sensor (D12014)

Technical Officer: H. Said Ahmed

This CRP (2019–2024) aims to test the use of cosmic ray neutron sensors (CRNS) and gamma ray sensors (GRS) for irrigation scheduling and the management of extreme weather events. CRNS provides large-scale, real-time soil moisture data, which is highly valuable for water management. The objectives of the CRP are to:

1. Advance the capabilities of CRNS for Best Management Practices (BMP) in irrigated and rainfed agriculture.
2. Integrate CRNS, GRS, remote sensing, and hydrological modeling to improve agricultural water management and its resilience.
3. Develop approaches using CRNS and GRS for long-term soil moisture monitoring in agroecosystems.

The final output of the CRP is a set of methods and guidelines for irrigation scheduling, and drought management. The CRP was approved in March 2019 and involves 9 member states: five research contract holders (two from Brazil, two from China, and one from Mexico), two research agreement holders (Denmark and the UK), and four technical contract holders (Italy, the Netherlands, Spain, and the USA).

The first Research Coordination Meeting (RCM) was held from 26 to 30 August 2019 at the IAEA HQ in Vienna, Austria. In autumn 2019, the installation and calibration of CRNS began at selected study sites of project partners, along with stationary soil moisture measurements. The project started about six months before travel restrictions emerged in spring 2020 due to COVID-19. By that time, all partners had established some CRNS monitoring sites and collected the first soil moisture time series.

In winter 2019 and spring 2020, the first results of the CRP were published in international scientific journals and presented as oral presentations and posters at the online EGU General Assembly (4-8 May 2020 in Vienna). These publications included interpretations of soil water content datasets collected by the SWMCN Laboratory team at a stationary monitoring station in Petzenkirchen, Austria.

In spring and summer 2020, fieldwork limitations arose due to travel restrictions, lockdowns, and home office requirements, interrupting soil moisture monitoring at some sites and delaying the installation of CRNS and GRS at others. However, in late summer and autumn, measurements and installations at new sites continued, leading to significant scientific achievements in the first year. These results were published in three research papers in international scientific journals and presented in two oral presentations at the 6th International COSMOS Workshop from 8 to 10 October in Heidelberg, Germany.

The Second RCM was held virtually from 7 to 11 June 2021. The main achievement of this meeting was initiating the preparation of methodological guidelines. The lockdowns and home office periods were used efficiently for writing several publications and preparing inputs for the first volume of CRNS guidelines for agricultural water management, a major output of the project. The final revision of these guidelines was completed and will be published in 2024 as an FAO book. Early 2023, the mid-term evaluation of the CRP was successfully completed, with the main achievements summarized as follows:

- Developing CRNS data processing tools.
- Creating a CRNS Excel Spreadsheet for small data set processing.
- Developing the crspy software tool for large data set processing (a Python-based tool).
- Creating an algorithm for neutron count signal smoothing by noise filtering.
- Testing new soil moisture monitoring techniques.
- Using new CRNS equipment (FINAPP) that does not require helium.
- Developing agriculture value-added soil moisture products.
- Creating an algorithm for root zone soil moisture estimation.
- Creating an algorithm for rainfall estimation from CRNS data.
- Using CRNS data to validate remote sensing (Sentinel-1) soil moisture products and constructing high-resolution soil moisture maps.

23 research papers were published in scientific journals. Significant progress in the methodological development of CRNS technology was summarized in: 'Cosmic-Ray Neutron Sensing: Applications in Agricultural Water Management' (FAO book) CRNS guidelines.

Another achievement was testing a new kind of CRNS (that does not require helium) and comparing its results with traditionally used CRNS. The findings were published in a peer-reviewed journal in January 2024. Results of another study were published, presenting the first time to connect CRNS with soil erosion research-an innovative approach to explore the complex relationships between soil water content and soil redistribution processes using CRNS and fallout ^{137}Cs.

The final RCM was held from 4 to 7 March 2024 in Vienna, Austria.

Photo 1. Group photo. Third and final meeting.

Multiple Isotope Fingerprints to Identify Sources and Transport of Agro-Contaminants (D15018)

Technical Officer: J. Adu-Gyamfi

This five-year CRP (2018–2022) aimed to:

- Develop protocols and methodologies for using multiple stable isotope tracers to monitor soil, water and nutrient pollutants from agriculture,

- Establish proof-of-concept for an integrated suite of analytical stable isotope tools, and

- Create guidelines to adapt the new toolkit to a variety of agricultural management situations.

Nuclear techniques include:

- A combined stable isotope ($\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C$, $\delta^{15}N$, $\delta^{13}C$-DIC, $\delta^{15}N$-NO_3, $\delta^{18}O$-NO_3, $\delta^{18}Op$, $\delta^{34}S$) techniques, and

- A compound specific isotope (CSSI)-based monitoring approach

for evaluating in-situ degradation, transport, transformation, and fate of pesticides.

The final RCM was held (in hybrid form) in Vienna, Austria from 9 to 12 October 2023 and the final review of the CRP with the Committees for Coordinated Research Activities (CCRA) was held on 15 May 2024 with a presentation of the CRP achievements by the Project Officer. The CCRA considered the CRP as successful and recommended for a publication under iaea.org. The major outputs from the CRP have been presented on page 19 of the previous *Soils Newsletter Vol. 46 No.2 (Jan 2024).*

Remediation of Radioactive Contaminated Agricultural Land (D15019)

Technical Officer: G. Dercon

The innovative monitoring and modelling techniques proposed in this CRP D15019 aim to enhance societal readiness and capabilities to optimize the remediation of agricultural areas affected by large-scale nuclear accidents. This project involves the development, testing, and validation of new field, laboratory, and machine learning tools. These tools are designed to predict and monitor the transfer of radionuclides in crops and their dynamics at the landscape level, specifically focusing on under-explored environments like arid, tropical, and monsoonal climates, and the main crop categories affected by such incidents.

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

To guide remediation efforts at the landscape level, operational research is being employed to select, optimize, and prioritize remediation techniques. Protocols are being developed for innovative spatio-temporal decision support systems for agricultural land remediation, integrating machine learning, operations research, and Geographic Information System (GIS) techniques.

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

Progress meetings have been held to refine and align national research projects with the CRP's objectives and work plan. Notable advancements include laboratory experiments improving the remediation of radioactive contamination in farmland. The team aims to develop new isotope techniques and utilize advanced mathematical approaches to better predict soil properties and optimize remediation strategies.

Significant mid-term progress was reviewed and showcased at international symposiums in 2022 and 2023. Ongoing PhD studies and successful publications and presentations are contributing to the advancement of knowledge in optimizing the remediation of radioactive contamination in food and agriculture. A PhD study focusing on more effective soil remediation decision-making in response to large-scale nuclear emergencies, was successfully completed in December 2023.

The final RCM is scheduled for July 15 to 19, 2024, in Vienna.

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

Technical Officer: M. Zaman

Climate Change due to continued increased anthropogenic emission of GHGs is a global threat to food security. Direct and indirect GHG emissions from agriculture, forestry and other land-uses changes contribute approximately 25% of the global anthropogenic GHG emissions. Data by the Intergovernmental Panel on Climate Change (IPCC) clearly show 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 and as a result, the Earth's average surface air temperature has increased about 1.2°C. This warming of the Earth has led to extreme weather events such as frequent heat waves, droughts, floods, and uneven distribution of rainfall, rising sea levels and melting of glaciers. The GHGs with the largest global warming potential are N_2O and CH_4, which predominantly originate from agriculture. The objectives of this CRP are to develop and validate climate-smart agricultural (CSA) practices, based on isotopic and related techniques, to increase soil carbon (C) sequestration, mitigate GHG emissions and limit gaseous losses of ammonia (NH_3) and dinitrogen (N_2) from agricultural ecosystems, with the aim to enhance agricultural productivity and sustainability. The CRP involves 13 member states: 7 research contract holders (Argentina, Bangladesh, Brazil, China, Costa Rica, Ethiopia, and Viet Nam), 6 technical contract holders (Austria, Germany, New Zealand, Pakistan, Peru and Spain), and one agreement holder (China). Latest 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. Technical University of Madrid validated the precision and robustness of micrometeorological technique for NH_3 emission. They also reported that split application of chemical fertilizers and fertigation have the most potential to decrease N_2O emissions from chemical fertilizer applied to soils.

Field results of Embrapa Agrobiologia, Brazil showed that forage legume can fix a large amount of N through biological nitrogen fixaxation (BNF) and thus reduce dependence on using chemical N fertilisers in pasture-legume system. Research and development work at Justus Liebig University in Germany verified that CRDS system equipped with special autosampler can precisely measure CO_2, CH_4, and N_2O concentrations as well as their isotopic signatures (^{13}C and ^{15}N) in 12 and 20 mL gas samples. Updated ^{15}N tracing analysis tool Ntrace has been verified and released for the analysis of gross N transformation rates in soil-plant systems. Cover crops in semi arid environment of Argentina contributed to 6.2 Mg ha^{-1} of C storage in soil during a 5-years soybean-maize cropping system under no-tillage. By adopting CSA practices, Bangladesh researchers showed that rice production was increased by 12 to 27% over farmer's practices. Field studies from China provided significant insights on the role of natural wetlands which can sequester a significant amount of C. Exploring the potential of composting municipal organic waste and human excreta for economic benefits and GHG mitigation, Ethiopian scientists reported that there could be a huge potential (343 Gg compost) by 2050 in Addis Ababa, Ethiopia, which could supply 5 Gg of N and 2.2 Gg of P. This huge compost production could mitigate 1,143 Gg CO_2-eq year-1 by 2050. Soil carbon sequestration potential of such compost could be 7 Gg C. Researchers in Viet Nam validated CSA practices which led to reduced emissions of GHGs and NH_3 volatilisation as well as increased rice production.

Four papers have been published in peer reviewed scientific journals. The second RCM is scheduled to be held in Vienna, Austria in 2024-Q4.

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 (2023–2028) aims to study the fate and impacts of plastics and microplastics present in agricultural soils using nuclear and related techniques. The CRP also aims to establish a network of CRP member states in developing common strategies to effectively mitigate the plastic pollution of agricultural soils and crops. Specifically the objectives of this CRP are to:

(1) Develop, evaluate, and standardize integrative isotopic and standard approaches for identifying and elucidating the fate of plastics and microplastics in agricultural soils,

(2) Apply the isotopic and related techniques for assessing the fate and impact of plastics and microplastics in agricultural soils under different environmental conditions, and

(3) Provide knowledge and guidance for informed decisions that help minimize the possible negative impacts of plastics and microplastics on soil health and ecosystem services.

The CRP was approved in September 2022. It involves 9 Member States: seven research contract holders (Brazil, China, Ghana, Kuwait, Malaysia, Morocco, and Vietnam), two technical contracts (both from Germany) and one agreement holder (Norway). The RCM was held from 3 to 6 March 2023 in Vienna (hybrid) with the virtual participation and presentations from FAO, the Austrian Agency for Health and Food Safety (AGES) and the IAEA Marine Environment Laboratories in Monaco. A SoilPlasticApps (https://www.minagris.eu/index.php/resources/soilplastic-app) developed by MINAGRIS (https://www.minagris.eu/) that help scientists understand how much plastic ends up in soils was presented. Four working groups (WGs) were established during the meeting namely:

- WG1: Develop (a) soil sampling protocols for field experiments (b) methods for sample preparation of microplastic from soil for isotope ratio analysis, and (c) spectral library of plastics with different ages and history.
- WG2: Isolate polylactic (PLA) degrading bacteria and fungi from soils and conduct incubation study of non-labelled plastics in soils.
- WG3: Monitor the translocation of radio-labelled coated plastics through the soil profile and to crops.
- WG4: Develop/harmonize methods for monitoring (including sampling methods) current plastics in agricultural soils.

Working Group leaders were identified, and all contract holders were assigned to each working group with deadlines. The workplans of individual countries were integrated into the overall workplan of the CRP. The second RCM is scheduled to be held in Q4 of 2025.

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

Technical Officers: M. Zaman and M. Fujisawa

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 and support member states to develop common strategies to mitigate the spread of AM in agricultural systems. Specifically the objectives of this CRP are to:

(1) Develop, evaluate and standardize integrative isotopic and conventional approaches for tracing the sources and persistence of AM and AMR in agricultural systems,

(2) Apply a combination of approaches including isotopic and bioanalytical/molecular biological methods to different agricultural systems for assessing the fate and dynamics of AM and implications for AMR, and

(3) Provide knowledge and guidance for informed decisions that help mitigate the spread of AM and AMR 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 USA), and two technical contract holders (Germany and Australia).

The first RCM was held virtually from 11 to 13 May 2022 with 11 participants (the nine CRP partners and one participant from Food and Agriculture Organization (FAO) and one observer from Germany (Technical University of Munich). The workplans with activities were discussed and developed to achieve the project objectives. For effective implementation of the workplans, four working groups (WGs) were established, namely:

- WG1: Develop synthesis of sulfamethoxazole (SMX) labelled compound that will be used in the glasshouse and field experiments.
- WG2: Develop sampling and analytical (SMX) protocols to be distributed to the partners.
- WG3: Develop glasshouse and field experimental designs, and
- WG4: Develop sampling and analytical protocols related to microbiology/microbial resistance genes.

The second RCM was held from 11 to 15 March 2024 in Vienna, Austria, and the progress to date was presented by each participant. It includes development of synthesis of SMX, development of a set of soil and water sampling and analytical protocols using isotopic techniques, and harmonization of techniques for diagnostics and monitoring of field applied-manure-levelled synthetic antibiotics. It should be mentioned that a new GC-IRMS has been successfully installed in the IAEA SWMCN Laboratory in Seibersdorf, Austria for compound stable isotope analysis of SMX.

Article ‘Novel isotopic Fingerprinting to Assess and Mitigate the Persistence and Transport of Antibiotics and Implications on Antimicrobial Resistance’ was published in the IAEA Nuclear Technology Review 2022. To date, extraction protocols for (1) SMX in soil and plant (lettuce) samples and, (2) DNA extraction and analysis from soil and water samples has been developed and sent to all participants. The CRP is funded mainly through extrabudgetary of US $150 000/year by the FAO. The third RCM will be held in 2026.

Developments at the Soil and Water Management and Crop Nutrition Laboratory

Enabling dryland food security and safety through an interdisciplinary approach to climate-smart agriculture

Vezzone, M.[1], Dercon, G.[1], Vlachou, C.[2], Bhatnagar-Mathur, P.[3]

[1]Soil and Water Management and Crop Nutrition Laboratory, Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture, Seibersdorf, Austria

Climate change presents a multifaceted threat to global food security, exacerbating the existing nutrition crisis through its impacts on agricultural systems. Changes in temperature and precipitation patterns, along with increased CO_2 levels, significantly affect water availability, crop growth, and productivity, thereby impacting water and nutrient use efficiency on farm. These changes often result in diminished crop yields and reduced nutritional quality.

Moreover, studies have shown that climate shifts create favorable conditions for the proliferation of mycotoxin-producing fungi and increase the uptake of heavy metals by crops, leading to contamination of staple foods. This poses a significant risk to human health, particularly in vulnerable populations, and further exacerbates the global nutrition crisis.

Limited information is available on the effects of climate change on dryland crops, even though these regions are often the most vulnerable to the negative impacts of climate change. Millet, cassava and groundnut are exemplary representatives of cereals, root and tuber crops and pulse crops that are crucial for food security.

Additionally, there is a lack of empirical data on crop responses to increased CO_2 levels and multiple stresses, such as elevated temperatures and water scarcity. These interactions can have antagonistic, additive, or synergistic effects, but logistical and infrastructural challenges often constrain relevant experiments. As a result, most projections on climate change impacts rely on models that need validation through empirical data. Multi-factor experiments evaluating sequential stress are crucial for a comprehensive understanding of crop responses to climate change.

To address the complex interplay between water and nutrient use efficiency, nutrition security, and food safety for dryland crops under changing climate, integrated strategies promoting climate-resilient agricultural practices are essential. Such an approach can be realized through the collaboration of the Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture's three laboratories: Plant Breeding and Genetics Laboratory (PBGL), Soil and Water Management and Crop Nutrition Laboratory (SWMCNL), and Food Safety and Control Laboratory (FSCL).

The joint PBGL/SWMCNL/FSCL project, *'Ensuring Food Security and Safety by Future-Proofing Dryland Crops under Climate Change',* aims to support Member States in mitigating the impacts of climate change on water and nutrient use efficiency, nutrition, and food safety in key dryland crops (millet, cassava, and groundnut) through nuclear and isotopic techniques. These techniques are valuable for elucidating the nexus between resource use efficiency, food safety, and security under climate change scenarios.

Currently in the feasibility phase, the project focuses on advancing technical foundations by strengthening existing methodologies, extending results from relevant R&D projects, and identifying new applications of nuclear and related techniques. These efforts aim to enhance genetics, optimize resource utilization, improve nutrition, and ensure food and feed safety under simulated high temperatures, elevated CO_2 levels, and drought conditions. Additionally, the initiative seeks to develop a global network to investigate climate change effects on food and nutritional security of dryland crops, and to develop mitigation and future readiness strategies.

A virtual workshop will be held in October 2024 to identify research gaps and needs, with the goal of preparing a comprehensive and long-term R&D project on the safety and security of dryland crops in the context of climate change. Through this interdisciplinary project, FAO/IAEA R&D and analytical capabilities will be enhanced to support Least Developed Countries (LDCs) in mitigating the effects of climate change on global nutrition.

Sharing SWMCNL's research progress at the 2024 European Geosciences Union (EGU) General Assembly in Vienna, Austria

Vlasimsky, M.[1]

[1]*Soil and Water Management & Crop Nutrition Laboratory (SWMCNL), Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture, Department of Nuclear Sciences and Applications, International Atomic Energy Agency, Vienna, Austria*

Photo 1. The SWMCN participants at EGU24 (Jane Omenda not pictured but present).

From 14 to 19 April 2024, the European Geosciences Union (EGU) General Assembly welcomed 20,931 registered attendees, of which 18,838 made their way to Vienna from 116 countries, while 2,593 joined online from 109 countries. In total 18,895 presentations, through 938 sessions, were given in this unique opportunity for scientific sharing and global networking. The SWMCN Section and Laboratory's activities were reported in 11 presentations (eight in person, three virtual) covering a wide range of topics including prediction of soil moisture using machine learning, prediction of soil texture using gamma ray sensing, mid-infrared spectroscopy for crop nutrition analysis, incubation experiments to inform climate smart management, incubation experiment looking at microplastics in soil, and use of stable isotopes for nutrient and water use in wheat and coffee. Two staff members, one ITCP-STEP fellow (virtual), two PUI PhD Fellows, two PhD students, two Marie Skłodowska-Curie fellows, three interns, and one visiting expert attended the conference to share their research work performed in the past year. Of the 13 attendees representing SWMCN (of which one is not pictured, and one attended virtually), 11 were female and two were male.

Details of contributions from the SWMCN Section and Laboratory can be found in the publication list at the end of this Newsletter while more information regarding EGU 2024 can be found at: http://www.egu2024.eu. The EGU General Assembly reconvenes at the ACV in Vienna & online as EGU25, 27 April–2 May 2025.

Predicting Carbon-13 ($\delta^{13}C$) signatures as an Indicator of intrinsic Water Use Efficiency (WUEi) in Cassava using Mid-Infrared Spectroscopy (MIRS)

Darboe, S.[1], Vlasimsky, M.[1], Heiling, M.[1], Van Laere, J.[1,5,6], Resch, C.[1], Selvaraj, M.G.[2], Becerra, L.A.[3], Drapal, M.[4], Perez, L.[4], Fraser, P.[4], Osoro, D.[1], Dercon, G.[1]

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The screening of intrinsic water use efficiency in plants can be based on the stable carbon isotope ($\delta^{13}C$) signatures in leaves, which reflect an interplay between soil water availability and drought stress in plants. Isotope Ratio Mass Spectrometry (IRMS) is the traditional and most accurate method for measuring $\delta^{13}C$ signature in plants. However, for large numbers of samples, more affordable and accessible alternatives need to be identified.

To address this need, the SWMCNL assessed the use of Mid-Infrared Spectroscopy (MIRS). Cassava, a staple crop in many developing countries, is the focal point for this study. The research aims to use MIRS to predict $\delta^{13}C$ signatures in cassava leaves, establishing correlations between MIR spectral features and reference $\delta^{13}C$ data obtained through IRMS of leaf material.

More than 700 cassava leaf samples from Colombia, Tanzania and DR Congo were supplied by our research partners, the International Centre for Tropical Agriculture (CIAT) and Royal Holloway University of London, and analysed by the SWMCNL in Seibersdorf for their $\delta^{13}C$ signature and MIR spectrum (range 4000 cm^{-1} – 650 cm^{-1}). The dataset was characterised by a representative range of $\delta^{13}C$ values, between -30 to -21‰, showing the representativeness of the dataset. After mathematical pre-processing of the MIR spectra (baseline correction, standard normal variate and Savitzky Golay), Partial Least-Squares Regression (PLSR) was used to develop a robust prediction model. The model's prediction performance, assessed through accepted statistical metrics such as R^2, Root Mean Square Error (RMSE) and Ratio of Performance to Deviation (RPD), sheds light on the potential of MIRS for Carbon-13 prediction as an indicator of intrinsic water use efficiency.

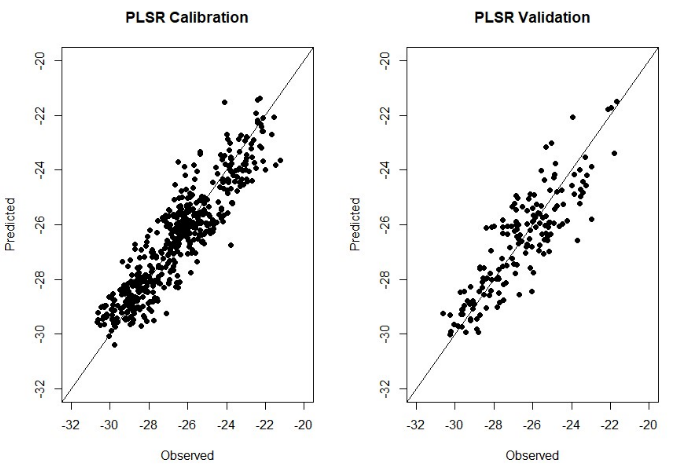

FIG.1. Partial Least-Squares Regression model accuracy (75% of the dataset (n= 514) was used for calibration and the remaining 25% (n= 171) for the validation of the model) for predicting carbon-13 ($\delta^{13}C$) signatures as an indicator of drought stress in cassava using Mid-Infrared Spectroscopy (MIRS).

The model results show a strong 1:1 correlation between the predicted and observed dataset (Fig.1). The accuracy measures of PLSR for the calibration and validation shows the RMSE = 0.84 and 0.94, respectively with the R^2 = 87% and RPD = 2.78 for calibration, and 77% and RPD = 2.1 for the validation. This indicates that PLSR model has potential in establishing a correlation between MIRS and reference $\delta^{13}C$ signatures in cassava. More data from the Kenyan Plant Village project are now being added for further validation and improving the prediction quality.

Harmonizing soil extraction methodologies for conventional and biodegradable microplastics

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The extensive use of plastics in agriculture has undeniably delivered substantial agronomic and economic benefits. However, plastic waste pollution has emerged as a latent menace to soil quality and plant growth within agroecosystems. Recently, negotiations for the United Nations Plastics Treaty have been underway, aiming to establish a legally binding international agreement to address plastic pollution, including the prevention and reduction of plastic pollution in terrestrial environments, particularly agricultural soils. This treaty encourages research into the environmental impacts of microplastics on soil health and ecosystem dynamics. Identifying accumulation zones, hotspots, and sectors most affected by existing plastic soil pollution is crucial for developing effective management strategies and regulatory policies.

Conventional petroleum-based plastics and their residues are considered hazardous materials, leading to increased interest in bio-based and biodegradable plastics (BPs) as sustainable alternatives. However, concerns have been raised regarding the higher generation rate of microplastics (MPs) from biodegradable plastic mulch, the potential ecotoxicity of additives and leachates, and excessive GHG emissions. These concerns underscore the necessity for rigorous monitoring of the impacts of BPs.

Previous investigations of MPs in soils have employed various sampling strategies and extraction methodologies, resulting in considerable data variability and making direct comparison challenging. Therefore, developing harmonized and practical microplastic monitoring and extraction methods is essential for accurately quantifying, comparing, and assessing global soil MP contamination. While methodological studies on MP extraction from soils exist, few include biodegradable plastics. Consequently, the efficiency and applicability of previous extraction methods are questionable for BPs.

The SWMCNL aims to develop harmonized methods for MP extraction from agricultural soil for both conventional and biodegradable MPs. A series of experiments are designed under CRP D15021 on 'Assessing the Fate and Environmental Impact of Plastics in Soil and Crop Ecosystems Using Isotopic Techniques.' At SWMCNL, widely used plastics such as Polypropylene (PP), Polyethylene (PE), Polyethylene Terephthalate (PET), Polyvinyl Chloride (PVC), and synthetic rubber from tires are selected as conventional plastics, and Polylactic Acid (PLA) and Polybutylene Adipate Terephthalate (PBAT) as biodegradable plastics. MP spikes were produced, using a blender, with readily available materials, encompassing diverse morphologies, including fibers, fragments, beads, films, flakes, and rubbers (Fig.1). The MP sizes ranged from 500 to 1000 μm and will be subjected to a series of experimental extraction procedures over the coming year. The experiments include trials on selecting chemical reagents for organic matter removal and density flotation, and the sequence and frequency of these procedures.

Initial observations indicate that under the standard drying temperature of 50 °C and the use of ethanol, biodegradable plastics, especially PBAT, showed a high degree of deformation and aggregation. This suggests the necessity for adjustments to the extraction protocols. The extraction procedures will be refined based on these observations and recovery rates to optimize the laboratory extraction of microplastics from both traditional and biodegradable plastics used in agricultural applications. This study will contribute to the harmonization of MP extraction methodologies.

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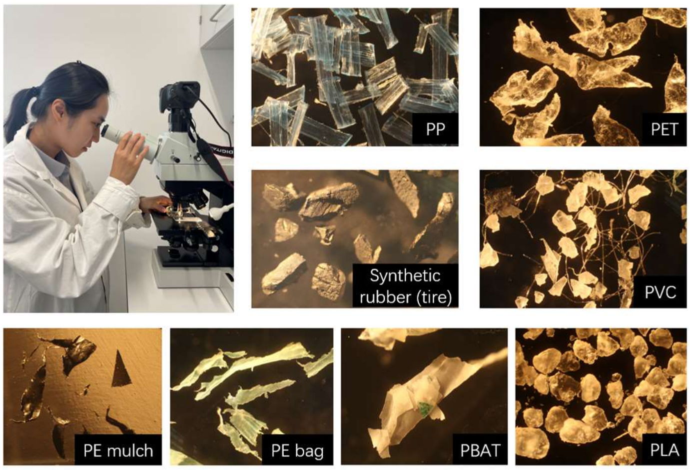

FIG.1. Produced microplastic spikes for the SWMCNL experiments.

Soil particle size distribution mapping through the use of gamma-ray spectrometry in combination with integral suspension pressure techniques

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Characterizing soil texture is crucial for sustainable soil water and nutrient management. Soil texture significantly affects water availability, nutrient cycling, erosion prevention, carbon storage, and overall soil health and quality. Traditional methods for soil texture characterization and mapping are labor-intensive, which has led to the development of alternative techniques.

The study at the SWMCNL aimed to predict the spatial distribution of soil texture using Gamma Ray Spectrometry (GRS). This method was calibrated through laboratory analysis of soil particle size distribution using the integral suspension pressure (ISP) method.

FIG.2. Gamma Ray Spectrometry field measurement in Petzenkirchen, Austria.

To achieve this objective, GRS data were collected in 2023 over an area of 3.65 hectares in the Hydrological Open-Air Laboratory (HOAL) in Petzenkirchen, Lower Austria, (see Figures 1 and 2). Additionally, for the IPS based determination of soil texture, 14 locations within this area were sampled at two different depths, with up to three replicates per location, resulting in 54 soil samples. The 2012 soil texture mapping results were also utilized for checking the quality of the soil texture analyses.

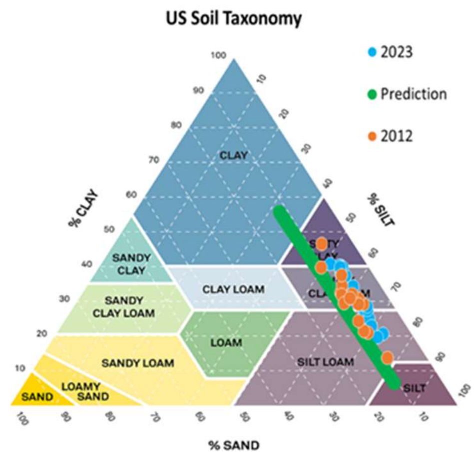
For the 54 samples from the HOAL, the PARIO system was used to analyze soil particle distribution through the Integral Suspension Pressure (ISP) method. This method utilizes Stokes' law to calculate particle size distribution based on changes in suspension pressure and temperature (Durner and Iden, 2021). Suspension pressure and temperature changes are measured at 10-second intervals following the chemical and physical dispersion of soil samples, which includes pre-treatment steps such as the removal of organic matter and soluble salts, as well as the determination of sample dry weight.

The analysis of soil texture from the 2023 soil sampling, conducted using the PARIO system, revealed a predominant silty clay loam structure, with no significant difference from the results obtained in 2012 (Fig.2a). These findings suggest that the soil texture data from 2012 remains relevant.

In addition to soil sampling for laboratory-based analysis of soil particle size distribution, field measurements were conducted using GRS to measure the spatial activity concentrations (Bq.kg^{-1}) of ^{40}K (potassium), ^{238}U (uranium), and ^{232}Th (thorium) across the field (Fig.2). The radionuclide concentrations measured using GRS were correlated with soil texture data through an R-based linear regression correlation model and mapped using QGIS.

In this study, mapping the concentration of radionuclides and particle size distribution, based on the 14 soil sample location, shows that ^{238}U and ^{232}Th exhibit similar patterns, comparable to the distribution of silt and clay particles, but different from that of ^{40}K (Fig.2b). This discrepancy could be attributed to the fact that the measurement of ^{40}K concentration can be affected or attenuated by soil moisture.

2a)



2b)

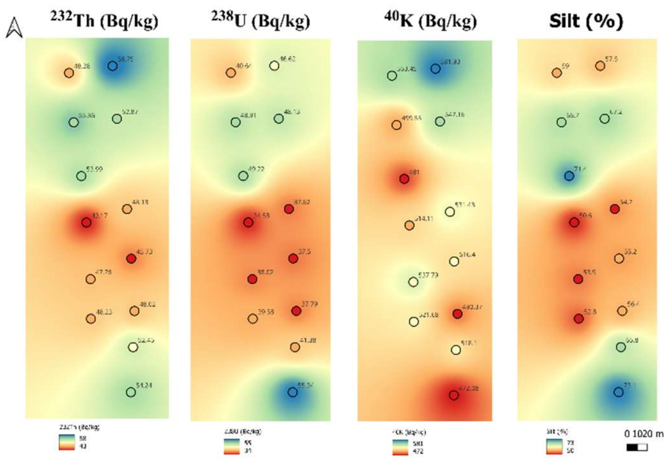


FIG.3a. Soil textural classification based on model results.; b. Comparing soil radionuclide concentrations measured with GRS vs silt concentration.

Results from the model indicate a significant negative correlation ($R = -0.79$, $p = 0.0013$, $R^2 = 0.62$) between clay content and the ratio of ^{238}U to ^{232}Th concentrations, and a positive correlation ($R = 0.81$, $p = 0.00077$, $R^2 = 0.66$) between silt content and the ratio of ^{238}U to ^{232}Th concentrations. The correlation with ^{40}K concentration was not significant. Therefore, as a future recommendation, soil moisture should be included as an independent variable in the model since it influences the attenuation of ^{40}K. Additionally, more sampling is necessary to gather additional data for enhancing model performance, particularly for training and validation.

In conclusion, spatial monitoring of ^{238}U, ^{232}Th, and ^{40}K radionuclides using mobile GRS has the potential for the spatial determination of clay and silt. However, further analysis is essential to compare and validate these results with a more extensive dataset that includes additional soil texture data. The area-wide soil texture mapping conducted in 2012 will be used to further refine the modeling approach. Comprehensive analysis and validation are required to verify the robustness of this model and to understand how to transition from site-specific to more generic soil texture prediction modeling based on GRS.

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Optimizing Agricultural Resilience in Ethiopia: Integrating Cosmic Ray Neutron Sensors (CRNS) and Remote Sensing for Enhanced Soil Moisture Monitoring

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Climate change presents significant challenges to Ethiopia's agricultural sector, particularly in water scarcity and extreme weather events. Irrigation water requirements are projected to increase by 70–90% by 2050, which will intensify pressure on available water resources (Garrote et al., 2015; Kreins et al., 2015). In the Awash River basin, farmers experience both floods during the rainy season and water stress in the dry season, underscoring the urgent need for effective water management strategies.

Soil moisture monitoring is a crucial tool for helping farmers optimize irrigation practices and mitigate water-related risks. By providing real-time insights into soil water conditions, irrigation system managers, farmer organizations, and farmers can make informed decisions on water distribution, irrigation timing, and quantity. This approach prevents crop water stress and optimizes the use of water resources. Despite its potential benefits, the adoption of soil moisture maps for irrigation management decision-making in Ethiopia remains limited due to spatial resolution constraints.

High-resolution soil moisture mapping holds promise in addressing these challenges, offering detailed insights into soil water dynamics across large areas. By identifying and monitoring irrigated areas, these maps facilitate improved water management practices, particularly in regions facing water scarcity.

In collaboration with the Ethiopian Institute of Agricultural Research in Addis Ababa, the SWMCNL is investigating how high-resolution soil moisture information, developed through the integration of CRNS Technology and remote sensing imagery, can be leveraged to establish baseline data for agricultural water management and optimize the management of large-scale irrigation systems, primarily for wheat production. This involves developing a comprehensive model that incorporates local climate data, soil properties, crop water requirements, and real-time soil moisture information. The research aims to minimize the risk of production loss in the Awash and Rift Valley basins (Fig.1 and 2).

In conclusion, integrating soil moisture monitoring initiatives holds potential for enhancing agricultural resilience in Ethiopia. By supporting farmers in optimizing their irrigation management systems using real-time information at the landscape level, these efforts will contribute to sustainable land and water use management and food security in the region.

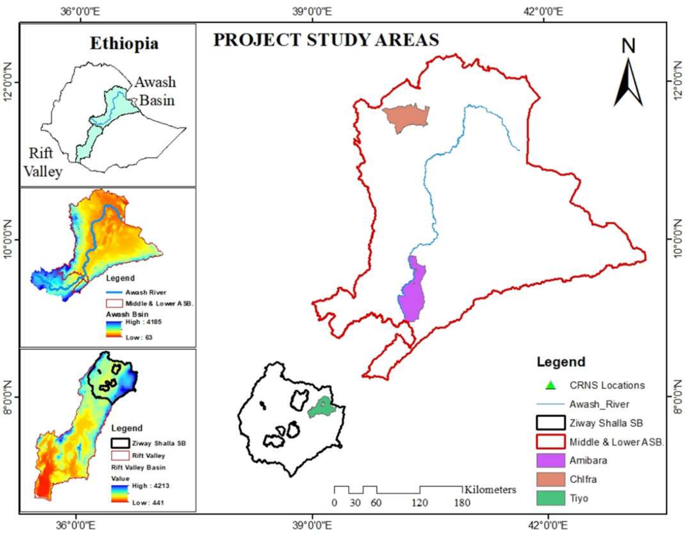

FIG.1. Location of the project study area in the Awash and Rift Valley basin of Ethiopia.

Photo 1. Field data collection in the experimental areas of the project study area in the Awash and Rift Valley Basin.

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Effects of selected agricultural management practices on sorghum yield and intrinsic water use efficiency using carbon isotope discrimination in upper Eastern Kenya

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In April 2024, the research findings from this PhD study, guided by the SWMCNL, were presented at the EGU24 conference in Vienna. The objective of the study is to provide research-based evidence on the possible synergistic effects of integrating soil and water conservation practices with soil fertility inputs on sorghum performance and water use efficiency in the drylands of Kenya.

Limited fertilizer use, due to constrained availability and affordability, and low and erratic rainfall are major factors contributing to sustainable sorghum productivity in most sub-Saharan African (SSA) countries. Thus, effective use of limited water and nitrogen supply is essential in these environments. One possible way to close the yield gap of sorghum in dry areas is to increase the water use efficiency of the crops, thereby reducing water stress. Enhancing rainwater infiltration into the root zone is an important strategy to achieve this.

In 2019, a long-term field experimental trial was established in the drylands of Tharaka-Nithi County, Kenya. We evaluated the effects of selected soil and water conservation practices under low and high fertilizer application on sorghum yield performance and its agronomic and intrinsic water use efficiency using stable carbon isotope techniques. Keeping all other conditions constant across the different plots and over the years, such as soil and water conservation practices and fertilizer inputs, stable carbon isotope techniques allow assessment of how these practices mitigate drought stress annually, characterized by extremely variable yearly patterns, ranging from nearly 300 mm to 700 mm of precipitation in one cropping season. Additionally, the long-term nature and the complex micro-topography of the fields caused by practices such as tied ridges would not permit the use of soil water sensors for these assessments.

The experimental trial adopted a Randomized Complete Block Design with three levels of nitrogen fertilization (120 kg N ha^{-1}, 60 kg N ha^{-1}, and 30 kg N ha^{-1}) with four replications. We evaluated four soil and water conservation technologies (minimum tillage, mulching, tied ridges, and managing beneficial interactions in legume intercrops (MBILI)) along with a control (farmers' practice). So far, the trial has consisted of nine seasons, or five years of on-station assessment with sorghum as the test crop planted during the long rainy seasons (March to July) and short rainy seasons (October to February). Carbon-13 signatures were measured for five out of nine seasons in the grains, representing water availability conditions during the post-flowering period, the driest part of the cropping seasons. Data were subjected to analysis of variance (ANOVA) using SAS version 9.4, and means were separated using the Tukey-Kramer Honest Significant Difference Test ($p \leq 0.05$).

The highest sorghum grain yield (4.85 Mg ha^{-1}) and agronomic water use efficiency (1.17 kg m^{-3}) were observed under the minimum tillage treatment (Fig. 1). The grain $\delta^{13}C$ varied significantly ($p = 0.0001$) across the seasons. The $\delta^{13}C$ values ranged from -13.14 to -11.86‰ for the sorghum grain, indicating high and low water stress conditions respectively. Minimum tillage generally showed the lowest water stress across the seasons. The best overall treatment combination for improving sorghum yield was minimum tillage with mulch at 120 kg N ha^{-1} of combined goat manure and mineral fertilizer. Our findings demonstrate that using minimum tillage with organic and inorganic fertility inputs can bridge the yield gaps in Kenya, depending on the water availability during the cropping seasons. This study is pioneering in its use of stable isotope carbon techniques in long-term trials to analyze the impact of soil and water conservation practices on crop performance and water stress in dryland areas.

The project has been supported through the ICTP/IAEA Sandwich Training Educational Programme (STEP). For more information, visit the ICTP/IAEA STEP website (ICTP/IAEA Sandwich Training Education Programme | ICTP).

EGU24 Abstract can be found at ohttps://meetingorganizer.copernicus.org/EGU24/EGU24-3544.html:

Omenda, J., Kiboi, M., Ngetich, F., Dercon, G., Mucheru-Muna, M., Mugwe, J., Hami, S. A., Kaburu, F., Nettey, S. N. A., Mugendi, D., Merckx, R., and Diels, J.: Sorghum water use efficiency and yield variations discerned by 13C isotopic technique under managed agricultural practices in Upper Eastern Kenya, EGU General Assembly 2024, Vienna, Austria, 14 to 19 Apr 2024, EGU24-3544, https://doi.org/10.5194/egusphere-egu24-3544, 2024.

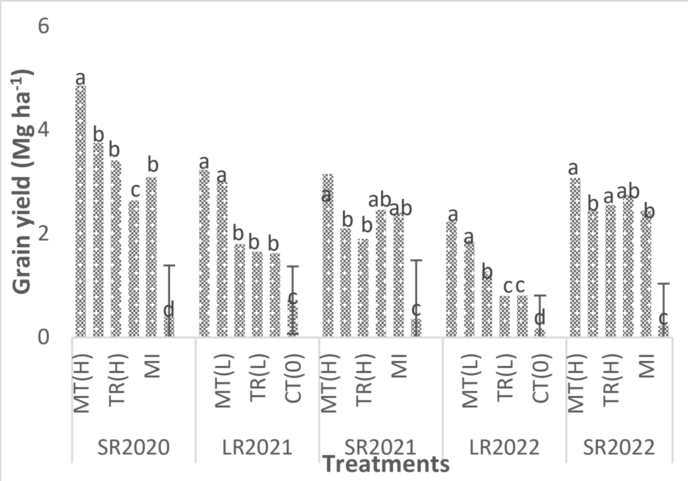

FIG.1. Treatment effect on sorghum grain yield for five seasons (Short rain season (SR) and long rain season (LR) for 2020 (only short rainy season data are available), 2021 and 2022 in Tharaka South sub-County; Treatments: MT(H)= Manure + Fertilizer (High) + minimum tillage with residue, MT(L)= Manure + Fertilizer (Low) + minimum tillage with crop residue, TR(H)=Manure Fertilizer (High) + Tied ridging, TR(L)= Manure + Fertilizer (Low) + Tied ridging, MI= MBILI intercrop, CT (0) = Control. Means with different letters indicate statistical differences (p = 0.05) with Tukey HSD. The error bars indicate the hsd value for comparing treatments within the same cropping season.

Moving toward new fronts of research & development on nuclear techniques for agricultural water and soil management

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In the context of R&D on agricultural water and soil management, the SWMCN Laboratory has initiated new research and development activities. These activities integrate CRNS, stationary GRS, and satellite imagery data to map and assess the effects of soil tillage systems and crop rotation on soil moisture and fertility dynamics over time and space.

For this purpose, the research leverages an existing long-term experimental setup established in 1996 at the experimental farm of the University of Natural Resources and Life Sciences (BOKU) in Raasdorf, Lower Austria, near Vienna (Neugschwandtner et al., 2022) (Figure 1). Covering a total area of approximately 6 hectares with plots measuring 12 by 40 meters, the setup includes four distinct soil tillage systems: (i) Mould-board ploughing, (ii) No-till, (iii) Deep conservation tillage, and (iv) Low conservation tillage. Currently, it involves two crop rotations: winter wheat with sugar beet, and winter wheat with maize.

By integrating these advanced technologies, the study aims to provide a comprehensive understanding of soil moisture dynamics over time and across various setups of the long-term experiment. These insights are vital for developing effective strategies to optimize water and soil management, thereby promoting sustainable and climate change resilient agricultural practices for the future.

Additionally, within this experimental framework, the SWMCNL team will test the combined use of CRNS and GRS for mapping soil moisture and properties in a heterogeneous landscape with diverse land uses. This approach aims to enhance soil monitoring technology for agricultural water and soil management, particularly in smallholder farming systems globally. The ability to accurately monitor soil moisture and soil health in diverse agricultural settings can significantly improve soil and water management practices and crop yield predictions.

FIG.1. Setup and installation of CRNS at the long-term experimental farm of the University of Natural Resources and Life Sciences (BOKU), Raasdorf, Austria.

References:

Neugschwandtner, R.W.,Száková, J., Pachtrog, V., Tlustoš, P., Kulhánek, M., Cˇerný, J., Kaul, H.-P., Wagentristl, H., Moitzi, G., Euteneuer, P. Exchangeable and Plant-Available Macronutrients in a Long-Term Tillage and Crop Rotation Experiment after 15 Years. Plants 2022, 11, 565. https://doi.org/10.3390/plants11040565.

Assessing the Impact of Long-Term Soil Incubation with Antibiotics on Sulfamethoxazole Decomposition Using Stable Isotopes

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While extensive research has been conducted to understand AMR in human and animal health, its impact on soil and water ecosystems remains comparatively unexplored. The effects of antibiotics on soil microorganisms have received relatively little attention, and studies often yield contradictory results. In particular, sulfonamides such as sulfamethoxazole (SMX), a commonly used antibiotic found in significant soil concentrations, raise questions about their persistence, fate, and environmental effects.

Previous soil incubation experiments conducted at the SWMCNL demonstrated the influence of nitrogen and phosphorus fertilizers on SMX decomposition. Studying the impact of phosphorus is significant, as there is limited literature available on how it affects SMX mineralization. The total amount of bacteria after one month of incubation soil with SMX decreased from $7.4*10^6$ CFU/g to $3.9*10^6$ CFU/g. The addition of nitrogen and phosphorus fertilizer increased the number of bacteria to $2.8*10^8$ and $1.3*10^8$ CFU/g respectively. The high number of prokaryotes after the incubation with antibiotics may indicate the sustainability of microbial communities and could be a factor of the antibiotic resistance spreading.

To further study the relationship between the sulfonamide degradation and the microbiological diversity, a follow-up experiment was conducted. It aims to assess the impact of long-term incubation of soil with antibiotic on the development of antibiotic-resistant communities and their subsequent ability to decompose SMX. Samples of two soil types were prepared: Chernozem soil from Seibersdorf (Austria) and Cambisol soil from Grabenegg (Austria). Non-labelled SMX (1 mg/kg) was added to these soil samples over varying incubation periods: one year, six months, three months, one month, and one week. Additionally, a dose of fully ^{13}C-labeled SMX (10 mg/kg) will be introduced prior to measurements using a laser CRDS analyzer, to quantify CO_2 and CH_4 fluxes to estimate the extent of SMX decomposition.

The hypothesis of this decomposition experiment is that during the long incubation of soil with antibiotics the taxonomic structure of microorganism community will change and the dominant group of microorganisms will develop antibiotic tolerance. Labelled ^{13}C-SMX will be used identify the microbial community shifts using Phospholipid Fatty Acids (PLFA) and Next-Generation Sequencing (NGS).

This comprehensive approach integrates molecular techniques with ecological assessments to elucidate the dynamics of antibiotic-induced changes in soil microbial communities and their implications for SMX degradation and antibiotic resistance dissemination.

Integrating Multi-Disciplinary Approaches to Combat Antimicrobial Resistance (AMR) in Agrifood Systems towards One Health

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Antimicrobial agents, such as antibiotics, are essential in treating bacterial and other infections and diseases in both humans and animals. However, their widespread misuse and application of poor-quality antimicrobials, has led to AMR, which has been recognized as a critical threat to public health and requires joint efforts such as the quadripartite One Health Approach.

This major concern necessitates a coordinated approach involving various disciplines and sectors to assess and mitigate its negative impacts. To help control AMR, subprogrammes of the Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture use nuclear and isotopic techniques in combination with biotechnology to study AMR in agricultural systems (Fig.1 and 2 show examples of soil and pig farms). Their goal is to help improve food safety and public health across these interconnected domains.

FIG.1(left). Using stable carbon isotope (^{13}C) to study AMR in soil; FIG.2 (right). Collecting bioaerosol samples from at a pig farm.

To tackle this multifaced issue, the Joint FAO/IAEA Centre has launched CRPs and specific training programmes, collaborating in a cohesive and interdisciplinary manner to help develop integrated approaches, spanning from plant, food safety, animal and environmental health topics related to AMR.

Specifically, efforts are targeting: (i) AMR and antimicrobial resistance genes characterization and surveillance programmes; (ii) antimicrobial residue testing and monitoring programmes: (iii) the evaluation of novel alternatives to antimicrobial growth promoters in animal diets: (iv) the investigation of the fate and dynamics of antimicrobials in agricultural systems: and (v) the correlation between the presence of resistance and their genes.

The collaboration extends to developing rapid and accurate infection diagnostic technologies, detection methods for antimicrobial agents, effective vaccines, and good husbandry practices to reduce the need of antimicrobials.

FIG.3. FAO/IAEA manuals of analytical methods and standard operating procedures available for the detection of antimicrobial agents.

Using a multidisciplinary collaborative approach, the Joint FAO/IAEA Centre continues to contribute to the development of sustainable and specific laboratory support for AMR control by providing targeted nuclear and isotopic techniques alongside biotechnology approaches. The centre is also helping to raise awareness among Member States of the importance of existing programmes on AMR implemented in collaboration with World Health Organization (WHO), United Nations Environment Programme (UNEP), and the World Organization for Animal Health (WOAH).

The work of the Joint FAO/IAEA Centre relevant to AMR started in 2009 focusing on the development and validation of analytical methods to detect, quantify and confirm the presence of antimicrobial agents. Further work followed through CRPs on 'Integrated Radiometric and Complementary Techniques for Mixed Contaminants and Residues in Foods' (CRP D52041, 2017–2023).

Dedicated laboratory manuals were prepared and are currently available in combination with a database of analytical methods, the Food Contaminant and Residue Information System (FCRIS) (see Fig.3 and 4).

FIG.4. The Food Contaminant and Residue Information System (FCRIS) is hosted on the iaea.org web pages link.

Current CRPs on or relevant to AMR include:

- D15022 'Isotopic Techniques to Assess the Fate of Antimicrobials and Implications for Antimicrobial Resistance in Agricultural Systems' (2021–2026).
- D32043 'Innovative Nuclear and Related Molecular Approaches for Detection and Characterization of Antimicrobial Resistance in Animal Production Environment' (2023–2028).
- D52043 'Depletion of Veterinary Pharmaceuticals and Radiometric Analysis of their Residues in Animal Matrices' (2021–2026).
- D52044 'Nuclear Techniques to Support Risk Assessment of Biotoxins and Pathogen Detection in Food and Related Matrices' (2022–2027).

Leveraging on these initiatives and diverse strengths within, the Joint FAO/IAEA Centre is taking steps to further align itself to multi-disciplinary One Health approaches in combating AMR in Members States.

This will require multisectoral collaboration and engagement addressing the health of humans, animals, plants, food and feed, as well as the environment. Through the expanded work on AMR, the Joint FAO/IAEA Centre is committed to initiating new and strengthening existing partnerships to contribute to the shared global vision of One Health.

The way forward will include, but not limited to, expanding current CRPs on AMR, and developing new CRPs to include cross-cutting research, and capacity building through peaceful uses initiatives where, multiple stakeholders can play a significant role in knowledge and innovation co-creation. This work is also relevant to the Atoms4Food Initiative.

Analytical Services

Christian Resch, Reinhard Pucher, Arsenio Toloza

In 2023, 9170 samples were analysed for stable isotopes and 150 samples were measured for fallout radionuclides in the SWMCN Laboratory. Most analyses were carried out supporting Research and Development activities focused on the design of affordable isotope and nuclear techniques to improve soil and water management in climate-smart agriculture.

Publications

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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
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