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Nuclear Techniques in Food and Agriculture

Soils Newsletter

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Contents

To Our Readers

Opening ceremony of the International Symposium on Managing Land and Water for Climate-Smart Agriculture, 25-29 July 2022.

Time passes quickly and we are already in 2023. Looking back to 2022 especially the last six months, the highlight was the International Symposium on 'Managing Land and Water for Climate-Smart Agriculture' which was successfully held in July, at the Vienna International Centre (VIC). A total of 294 scientists from more than 100 Member States, including technical staff and policymakers, and colleagues from the Food and Agriculture Organization (FAO), participated in-person while another 737 participants attended the sessions virtually. There were 113 oral papers and 161 poster papers presented. These included two special sessions i.e., FAO's Global Soil Laboratory Network GLOSOLAN and AquaCrop – Development and Way Forward. All sessions were actively attended. The Symposium provided the opportunities for exchange of information and knowledge to advance the understanding, collaboration and capabilities to respond to the impact of climate change and rapidly changing global environment and established new initiatives. I want to thank all of you for making the symposium a success.

Two Coordinated Research Projects (CRP) had their mid-term evaluation in the past six months, i.e. CRP D12014 on 'Enhancing Agricultural Resilience and Water Security Using Cosmic-Ray Neutron Technology' and CRP D15019 on 'Remediation of Radioactive Contaminated Agricultural Land'. Both CRPs were approved for continuation. Some interesting work under D15019 looking at the ratio of plant 137Cs to exchangeable 137Cs in soil to explain the variation in 137Cs transferability from soil to plant, is reported in this issue's feature article. More findings from D15019 are reported in the Laboratory R&D section.

A new CRP on 'Assessing the Fate, and Environmental Impact of Plastics in Soil and Crop Ecosystems Using Isotopic Techniques' (D15021) was approved in September and the new CRP will start in Q1-Q2 2023 for five years. More information on the CRP and the application procedures are given in this newsletter.

We are pleased to announce that our submissions to establish a Collaboration Centre with the Liebig Centre at Justus Liebig University Giessen, Germany, and a Practical Arrangement with the Mohammed VI Polytechnic University (UM6P), Morocco, were both approved. The establishment of the Collaboration Centre with the Liebig Centre will allow collaboration in scientific and technical activities, assisting in building capacity (e.g., hosting fellows, analytical support, and hands-on training). The UM6P is a non-profit private university that works towards high level education, applied research and innovation with a focus on Africa. The UM6P seeks mutual collaboration in the areas of education, training and research and development through the peaceful use of nuclear science and technology on climate smart and sustainable agriculture especially fertilizer management.

From the Soil Water Management and Crop Nutrition Laboratory (SWMCNL), interesting work on the decomposition of the antibiotic Sulfamethoxazole (SMX) in soil is currently being implemented. Using 13C-labeled SMX, the preliminary study showed that SMX decomposed faster with the addition of nitrogen, but the decomposition is reduced with high soil water content. It was also found that SMX strongly reduces the heterotrophic carbon respiration in soil.

Further progress has been made in using proximal gamma-ray spectrometry (GRS) for soil texture determination. Using a portable GRS, the field study showed that the spatial activity of 40K concentrations has good correlation with clay and silt content, and hence the potential to be used for soil texture mapping. Further study is needed to ensure this is thoroughly tested.

A new pledge of 250.000 Euro was also announced by the Belgian Government to continue the R&D work in our laboratory, in close collaboration with the Plant Breeding and Genetics Laboratory, under the Peaceful Use Initiative (PUI) project on 'Enhancing Climate Change Adaptation and Disease Resilience in Banana-Coffee Cropping Systems in East Africa'. This will allow to scale and disseminate the developed isotope and related techniques to make banana-coffee production more climate change and disease resilient.

We would like to congratulate Arsenio Toloza who received an IAEA Merit Award in October, in recognition of his excellent work and outstanding contribution to the development of isotope and nuclear techniques in agriculture water management, nuclear emergency response and in mid-infrared spectroscopy for soil property prediction.

We welcome Karynne Abel,who joined the SWMCNL and Plant Breeding and Genetics Laboratory in September, as Team Assistant to both laboratories. We also welcome intern Ayane Kan, who arrived in November from Japan. Ayane will be working in SWMCNL on predicting caesium uptake and dynamics through Mid-Infrared Spectroscopy (MIRS).

We bid farewell to Mr Qu Liang, our Director who retired in October after 17 years of service to the Joint FAO/IAEA Centre. We wish Mr Liang well in his retirement and thank him for his leadership to the Joint Centre. From 1 November until further notice, Mr Thanawat Tiensin, who recently took up the position of Director of the Animal Production and Health Division of FAO, Rome, will also act as Officer in Charge of the Joint FAO/IAEA Centre, with Ms Dongxin Feng taking care of day-to-day matters acting in the role of Director in Vienna.

Finally, I would like to take this opportunity to thank all our readers for their continuous support. Best wishes for a great year ahead!

Lee Heng
Head
Soil and Water Management and Crop Nutrition Section

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Staff News

Karynne Abel (USA) joined the SWMCNL and PBGL in September 2022 as Team Assistant to both labs. Karynne studied philosophy and Spanish, some law, teaching English as a second language, German, and sex education in the United States, Spain and Austria, and she has extensive administrative, paralegal and teaching experience, having most recently worked in Publishing at the IAEA. A Louisiana native and environmentalist, Karynne loves the great outdoors, writing and traveling, and she's happy to live in Vienna since 2010.

Ayane Kan (Japan) joined the SWMCN Laboratory in December 2022 as an intern. Ayane is a master's student at the Graduate School of Agriculture, Hokkaido University in Japan. She has been studying in the field of plant nutrition, especially phosphorus and caesium uptake by white lupin. She will be working under the CRP D1.50.19 project on predicting caesium uptake and dynamics by MIRS. This opportunity of working with specialists in soil mineralogy and modeling will enable her to improve her experimental skills as well as data analysis techniques.

Arsenio Toloza (Philippines) received an IAEA Merit Award in October 2022 from Mr. Liang Qu, recently retired Director of the Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture, in recognition of his excellent work supporting the Soil and Water management and Crop Nutrition Subprogramme. This award is to honour his outstanding contribution to the development of isotope and nuclear techniques in the field of agriculture water management, nuclear emergency response and mid-infrared spectroscopy for soil property prediction.

Feature Articles

The ratio of plant ^{137}Cs to exchangeable ^{137}Cs in soil is a crucial factor in explaining the variation in ^{137}Cs transferability from soil to plant

***Takuro, S.*[1]**

[1]*Graduate School of Agriculure, Hokkaido University, Japan*

In the scope of the Coordinated Research Project (CRP) D15019 on “Remediation of Radioactive Contaminated Agricultural Land”, collaborators from the Hokkaido University, the National Agriculture and Food Research Organization, and Kyoto Prefectural University in Japan published their research findings on how to estimate plant radioactivity using soil exchangeable ^{137}Cs in *The Science of the Total Environment* (https://doi.org/10.1016/j.scitotenv.2022.159208), titled *“The ratio of plant ^{137}Cs to exchangeable ^{137}Cs in soil is a crucial factor in explaining the variation in ^{137}Cs transferability from soil to plant”*.

To mitigate the radioactive cesium transfer from soil to plant after a nuclear accident, the use of transfer factors (TF: radioactivity of plant / radioactivity of soil) has been widely accepted. However, in 2012 – one year after the Fukushima Daiichi Nuclear Power Plant (FDNPP) accident – the Japanese Ministry of Agriculture, Forestry and Fisheries modified this approach. Only TF alone was considered not to be enough to predict the radioactivity in the plant. The same year, as exchangeable potassium ($K_{ex.}$) level was found to play an important role in regulating TF (Kato et al., 2015), it was decided to apply significant amounts of potassium fertilizer to the contaminated agricultural fields. Its impact was positive, and the ratio of the bags of brown rice exceeding the standard limit (100 Bq kg^{-1}) as compared to the total number of investigated bags decreased from 1.5% in 2011 to 0.0007% in 2012. However, based on a large survey of the relationship between $K_{ex.}$ and the TF of rice (Yamamura et al., 2018), there was a clear difference among soils. TF was found to be generally higher in Hama-dori (located in the eastern region of Fukushima prefecture, where most of the highly contaminated area is located) than in Naka-dori (in the middle of Fukushima prefecture).

In 2022, about 2.4% of Fukushima prefecture (ca. 334 km^2) was identified as a Difficult-to-Return Zone (DRZ), and most of the DRZ was in Hama-dori. The re-opening of this area is now in progress, and farmers are aiming to grow crops in soil with a relatively higher transfer factor and higher radioactivity even after the decontamination. Thus, more precise prediction of radioactive cesium transfer from soil to plant is needed.

To achieve this, the research team implemented an experiment with soybean at two different fields, one in Naka-dori and another in Hama-dori. As expected, the relationship between $K_{ex.}$ and TF was different. At the same $K_{ex.}$ level, TF was higher in Hama-dori soil (Fig. 1, left). To explain the difference between soils, the research team looked at the role of exchangeable ^{137}Cs. By introducing the concentration ratio of exchangeable ^{137}Cs (CR-Ex^{137}Cs) instead of TF, the difference among soils was largely reduced (Fig. 1, right).

$$\text{CR-Ex}^{137}\text{Cs} = \frac{^{137}\text{Cs concentration in shoot (Bq kg}^{-1}\text{ DW)}}{\text{Ex }^{137}\text{Cs concentration in soil (Bq kg}^{-1}\text{ DW)}} \quad (1)$$

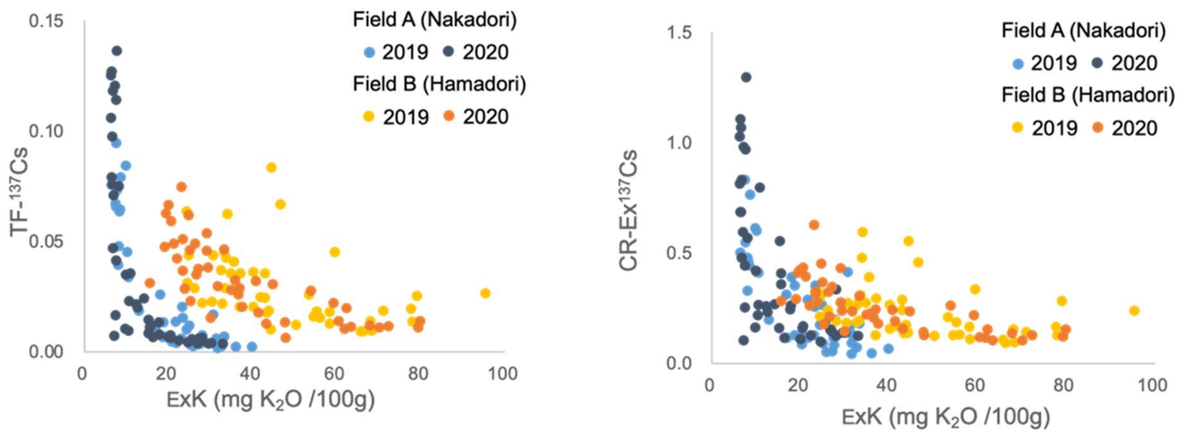

Figure 1. Relationship between exchangeable K and Transfer Factor (TF) of ^{137}Cs and Concentration Ratio (CR) of exchangeable ^{137}Cs between two soils.

The importance of exchangeable ^{137}Cs has been mentioned repeatedly (e.g., Kondo et al., 2015; Yagasaki et al., 2019); however, a clear explanation about its role was not provided. From a physiological point of view, ion uptake by plant roots is strictly regulated by the ionic balance at the root surface, therefore the concentration factor (CF) is a crucial factor to explain how ^{137}Cs is taken up by plant roots with the presence of K (Figure 2).

A disadvantage is that the measurement of soil solution takes time. Especially under upland field conditions, it is not an ideal method to analyze this fraction. Therefore, the research team uses ^{137}Cs and K in the exchangeable fraction of soil to explain the availability of each element for plant uptake. Equation (1) on CR-$^{137}Cs_{Ex.}$ mimics well how soil releases ^{137}Cs to the soil solution like K. We can therefore, with confidence, explain plant ^{137}Cs uptake by exchangeable ^{137}Cs and state that the ratio of plant ^{137}Cs to exchangeable ^{137}Cs is regulated by $K_{ex.}$, because both fractions are representing the availability to supply both ions to the soil solution, where the CF acts principally.

References:

Kato et al. 2015 SSPN, 61, 179-190., Takata et al. 2015 Bull. Natl. Inst. Agric. Sci. SeR., 34, 43-51., Yagasaki et al. 2019 JJSSPN, 90, 123-130., Yamamura et al. 2018 JER, 195, 114–125.

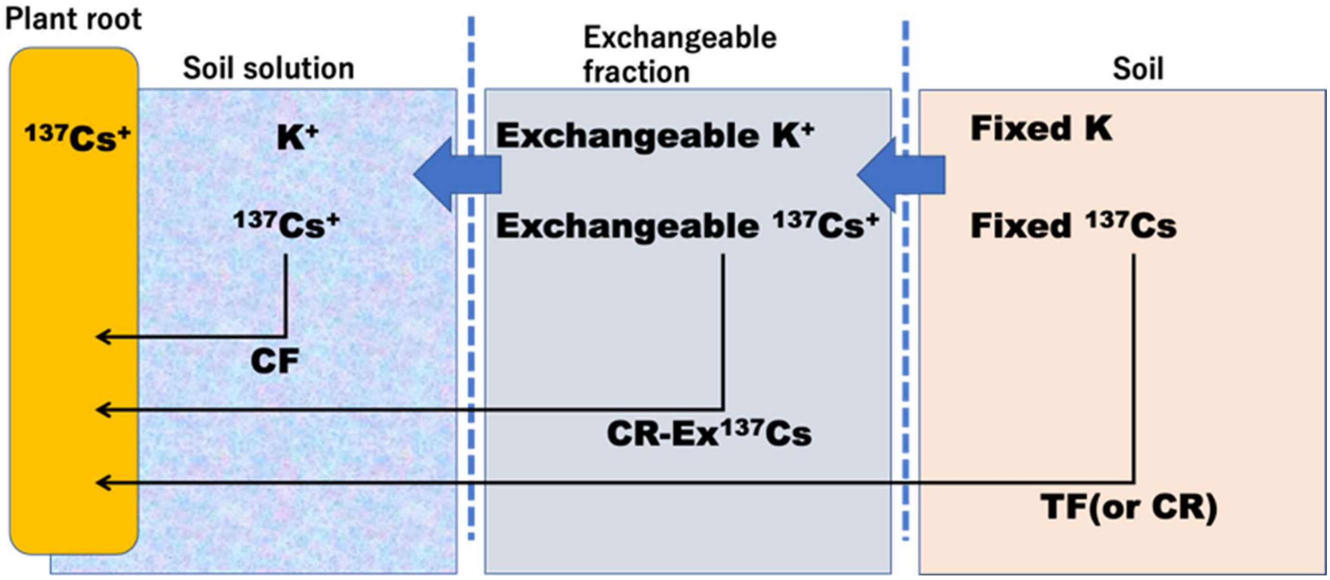

Figure 2. Comparison of three equations of transfer of ^{137}Cs to the soil (soil solution) to the plant. CF: Concentration factor, CR: Concentration ratio, and TF: Transfer factor

Announcements

New CRP
Assessing the Fate, and Environmental Impact of Plastics in Soil and Crop Ecosystems Using Isotopic Techniques (D1.50.21)

Adu-Gyamfi, J.[1] and Meniailo, O.[1]

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

The Soil and Water Management & Crop Nutrition Section has launched a new five-year (2023-2028) Coordinated Research Project (CRP), titled 'Assessing the Fate, and Environmental Impact of Plastics in Soil and Crop Ecosystems Using Isotopic Techniques (D15021). This CRP's first Research Coordination Meeting is expected to take place in early Q2 2023, in Vienna, Austria or virtually.

(a) Use and benefits of plastics

(b) Harm caused by plastics in soil environment

Figure 1. Positive and negative impacts of plastics and microplastics

Background

Plastics (P) are widely used by people, and its production has increased from 1.7 million metric tons in 1950 to 359 million metric tons in 2018. Despite the remarkable benefits of plastics to society, there are increasing concerns associated with the vast amount of plastic entering our environment, where it is degraded to microplastics (MP), particles less than 5 mm in diameter. Most of plastics produced each year ends up in the environment and the soil acts as a log-term sink for these plastic debris before some of them finding its way to the aquatic ecosystem. According to a recent report by the United Nations' Food and Agriculture Organization, the earth's soil may be more saturated with plastic pollution than oceans and an estimated 80% of plastics found in the marine environments are first disposed on land. There is therefore an urgent need for better understanding of the turnover, fate, latest methodology development for sampling and analysis, its environmental impact on soil and crop eco-systems of P and microplastics MP. This CRP aims to assess the fate, dynamics, and impact of microplastics in agricultural soils and ecosystem services using compound-specific stable isotopes (CSSI) and stable isotope Raman micro-spectroscopy (SIRM). The project also aims to assess the rate and identify the environmental drivers of microplastics degradation. The need for this project is pressing because more than 30% of the world's plastic waste is disposed inappropriately, with most of it ultimately ending up in soil. FAO and UNEP consider soil pollution with microplastics an emerging environmental issue with serious consequences for soil carbon turnover and greenhouse gas fluxes. Isotopic methods, proposed in the project, can determine the final products of microplastics decomposition in soil and the environmental conditions optimal for reducing microplastics debris in soil. The CRP will also provide tools and recommendations that will benefit and help Member States' microplastics policies and management strategies and contribute to FAO's Action plan on plastics in agriculture.

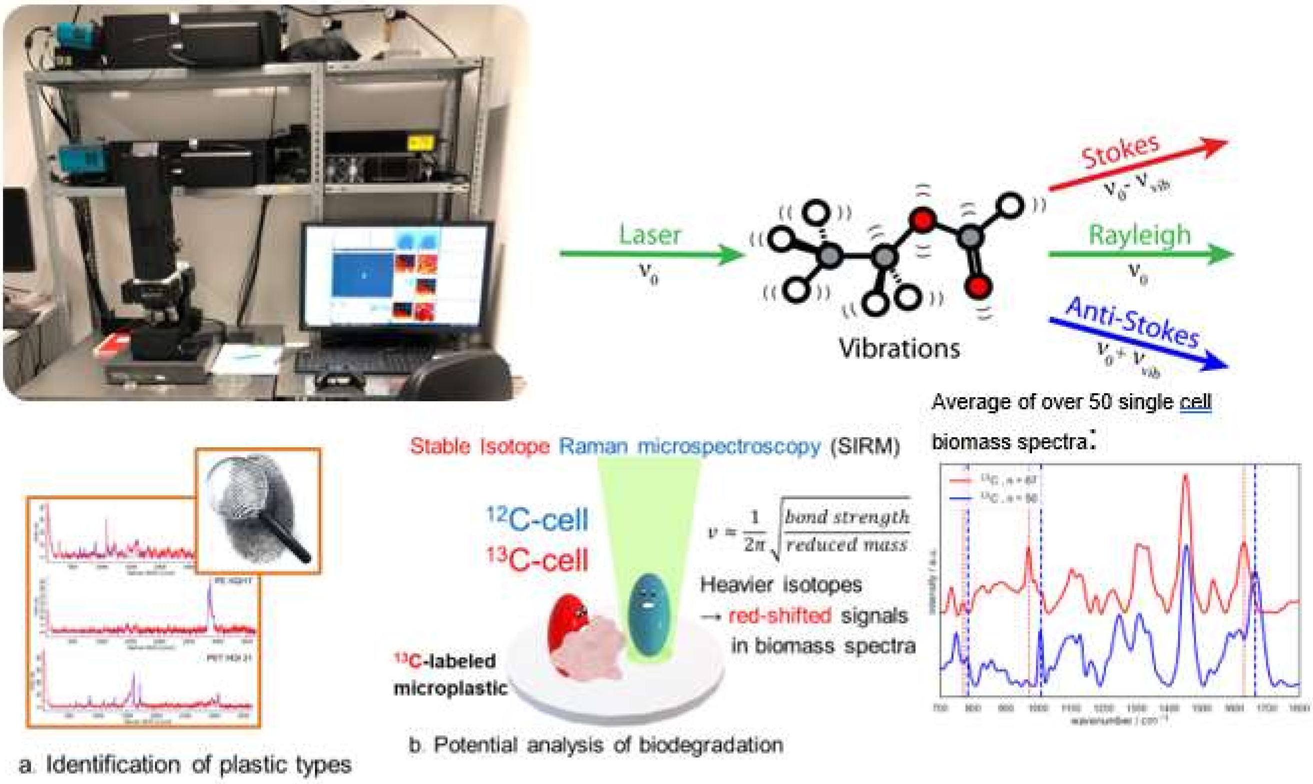

Figure 2. Schematic presentation of stable isotope Raman micro-spectroscopy (SIRM) to trace carbon from microplastics into microbial biomass

CRP Overall Objectives:

(1) To develop guidance for improving the understanding of the fate and impacts of plastics and microplastics in agricultural soils based on nuclear and related techniques

(2) To establish network and coordinating inter-laboratory studies of analytical techniques and data interpretation to support CRP network in developing common strategies to effectively mitigate the plastic pollution of agricultural soils and crops

Specific Research Objectives:

1.1 To develop, evaluate and standardize integrative isotopic and standard approaches for identifying and elucidating the fate of plastics and microplastics in agricultural soils

1.2 To apply the isotopic approaches, in combination with existing methodologies, for assessing the fate and impact of plastics and microplastics in agricultural soils under different environmental conditions

1.3 To provide knowledge and guidance for informed decisions that help minimize the possible negative impacts of plastics and microplastics on soil health and ecosystem services

Further information including submitting an application related to this CRP, can be found here https://www.iaea.org/projects/crp/d15021.

International Symposium on Managing Land and Water for Climate-Smart Agriculture, 25-29 July 2022: Outcome and Overall Summary

The FAO/IAEA International Symposium on Managing Land and Water for Climate-Smart Agriculture was successfully held from 25-29 July 2022 https://www.iaea.org/events/swmcn2022, in IAEA Headquarters in Vienna, Austria. It was a hybrid event, with a total of 106 Member States participated in this symposium in-person, consisting of 294 scientists, technical staff and policymakers, including colleagues from FAO. A total of 737 participants could not make it to Vienna and attended the sessions virtually. Tremendous support was provided by the team members from the SWMCN Section and Laboratory, as well as from the IAEA Conference Services Section to ensure the event was running smoothly. There were 113 oral papers and 161 poster papers presented at the Symposium.

The Symposium comprised 7 Sessions, covering the topics on: plant nutrition and nutrient cycling, soil conservation and land management, agricultural water management, tracing agricultural and industrial pollutants, this includes agricultural pollutants, antimicrobial resistance, agricultural plastics and nuclear emergency and remediation. Other sessions were on greenhouse gas emissions, advances of nuclear-based instrumental and analytical techniques, as well as on nuclear techniques digital technology, GIS, machine learning and modelling. Two special sessions on FAO's Global Soil Laboratory Network (GLOSOLAN) and FAO's AquaCrop – Development and Way Forward were also included on top of the seven sessions. All sessions attracted significant interest from the audience.

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
Azerbaijan	AZB5003	Determining of Radioactive Substances in the Environment with a Focus on Water and Soil	O. Meniailo
Azerbaijan	AZB5004	Strengthening Best Soil, Nutrient, and Water Agricultural Practices for Cotton Production	M. Zaman
Bangladesh	BGD5033	Using Nuclear Techniques in Assessing River Bank Erosion	E. Fulajtar
Belize	BZE5012	Use of Nuclear and Isotopic Techniques for Optimizing Soil-Water-Nutrient Management in Rainfed Agriculture Systems	J. Adu-Gyamfi
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	J. Adu-Gyamfi
Botswana	BOT5024	Improving Selected Legumes and Cereals against Biotic and Abiotic Stresses for Enhanced Food Production and Security	J. Adu-Gyamfi and PBG
Bulgaria	BUL5018	Improving Crop Water Productivity and Nutritional Quality of Orchards	J. Adu-Gyamfi
Burkina Faso	BKF5024	Improving Food Crops through Mutation Breeding and Best Soil and Nutrient Management to Ensure Food Security	J. Adu-Gyamfi 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	L. Heng
Central African Republic	CAF5014	Strengthening Capacity for Enhancing Cassava Production and Quality through Best Soil Nutrient Management Practices	M. Zaman
Chad	CHD5009	Developing Sustainable Water Resources Management through the Use of Nuclear Isotopic Techniques in Drip Irrigation Systems	L. Heng
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	J. Adu-Gyamfi
Costa Rica	COS5035	Building Capacity for the Development of Climate-Smart Agriculture in Rice Farming	M. Zaman
Costa Rica	COS7006	Strengthening National Capacities to Identify Sources of Contamination that Affect Highly Vulnerable Aquifers Using Isotopic and Conventional Techniques	J. Adu-Gyamfi 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	E. Fulajtar
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	E. Fulajtar
Gabon	GAB5004	Improving Soil Fertility Management for Enhanced Maize, Soybean and Groundnut Production	J. Adu-Gyamfi
Ghana	GHA5039	Mainstreaming Nuclear Based Climate Smart Agriculture Technologies into Sustainable Production	L. Heng and PBG
Haiti	HAI5008	Strengthening National Capacities for Enhanced Agricultural Crop Productivity	J. Adu-Gyamfi, E. Fulajtar

Honduras	HON5011	Implementation of Soil, Water and Nutrient Management for Sustainable Coffee Production in Honduras using Nuclear Technologies	E. Fulajtar
Interregional project	INT5156	Building Capacity and Generating Evidence for Climate Change Impacts on Soil, Sediments and Water Resources in Mountainous Regions	G. Dercon
Iran	IRA5015	Enhancing Capacity of National Producers to Achieve Higher Levels of Self-Sufficiency in Key Staple Crops	L. Heng, FEP and PBG
Iraq	IRQ5022	Developing Climate-Smart Irrigation and Nutrient Management Practices to Maximize Water Productivity and Nutrient Use Efficiency at Farm Scale Level Using Nuclear Techniques and Advanced Technology	M. Zaman
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
Madagascar	MAG5026	Enhancing Rice and Maize Productivity through the Use of Improved Lines and Agricultural Practices to Ensure Food Security and Increase Rural Livelihoods	J. Adu-Gyamfi and PBG
Malaysia	MAL5032	Strengthening National Capacity in Improving the Production of Rice and Fodder Crops and Authenticity of Local Honey Using Nuclear and Related Technologies	E. Fulajtar, PBG and APH
Mali	MLI5031	Improving Rice Productivity through Mutation Breeding and Better Soil, Nutrient and Water Management Practices	M. Zaman and PBG
Namibia	NAM5020	Enhancing Staple Crop Yields, Quality, and Drought Tolerance through Broadening Genetic Variation and Better Soil and Water Management Technologies	J. Adu-Gyamfi and PBG
Nicaragua	NIC2002	Strengthening of National Capacities in Energy Planning and Geothermal Resource Assessments through the Application of Isotopic Analytical Methods	E. Fulajtar
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	L. Heng with PBG and SIT
Palestine (T.T.U.T.J.)	PAL5011	Enhancing Food Security via Nuclear Based Approaches	E. Fulajtar
Panama	PAN5002	Strengthening the Operation of the Panama Canal through Erosion and Sediment Transport Analysis using Nucleonic Control System Applications, Radiotracers and FRN and CSSI methodologies	E. Fulajtar
Panama	PAN5028	Improving the Quality of Organic Cocoa Production by Monitoring Heavy Metal Concentration in Soils and Evaluating Crop Water Use Efficiency	J. Adu-Gyamfi
Panama	PAN5029	Strengthening National Capacities to Combat Land Degradation and Improve Soil Productivity Through the Use of Isotope Techniques	E. Fulajtar
Peru	PER5033	Application of Nuclear Techniques for Assessing Soil Erosion and Sedimentation in Mountain Agricultural Catchments	E. Fulajtar
Peru	PER5035	Improving Pasture Production Through Best Soil Nutrient Management to Promote Sustainable Livestock Production in the Highland Region	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	RAF0056	Enhancing Nuclear Science and Technology Capacity Building through Technical Cooperation Among Developing Countries	E. Fulajtar
Regional project Africa	RAF5081	Enhancing Productivity and Climate Resilience in Cassava-Based Systems through Improved Nutrient, Water and Soil Management (AFRA)	M. Zaman and G. Dercon
Regional project Africa	RAF5086	Promoting Sustainable Agriculture under Changing Climatic Conditions Using Nuclear Technology (AFRA) 2022-2023	H. Said Ahmed and L. Heng
Regional project Africa	RAF5090	Supporting Climate Change Adaptation for Communities Through Integrated Soil–Cropping–Livestock Production Systems (AFRA)	M. Zaman and APH
Regional project Asia	RAS5089	Enhancing the Sustainability of Date Palm Production in States Parties through Climate-Smart Irrigation, Nutrient and Best Management Practices (ARASIA)	H. Said Ahmed

Regional Project Asia	RAS5091	Assessing and Mitigating Agro-Contaminants to Improve Water Quality and Soil Productivity in Catchments Using Integrated Isotopic Approaches	J. Adu-Gyamfi
Regional project Asia	RAS5093	Strengthening Climate Smart Rice Production towards Sustainability and Regional Food Security through Nuclear and Modern Techniques	M. Zaman and L. Heng
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 and Pacific	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. Zaman with PBG and FEP
Regional project Europe	RER5028	Improving Efficiency in Water and Soil Management	E. Fulajtar
Regional project Latin America	RLA5077	Enhancing Livelihood through Improving Water Use Efficiency Associated with Adaptation Strategies and Climate Change Mitigation in Agriculture (ARCAL CLVIII)	L. Heng
Regional project Latin America	RLA5084	Developing Human Resources and Building Capacity of Member States in the Application of Nuclear Technology to Agriculture	J. Adu-Gyamfi, PBG and FEP
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)	J. Adu-Gyamfi
Rwanda	RWA5001	Improving Cassava Resilience to Drought and Waterlogging Stress through Mutation Breeding and Nutrient, Soil and Water Management Techniques	M. Zaman and PBG
Saint Vincent & the Grenadines	SVT0001	Building National Capacity in Nuclear Technology Applications	J. Adu-Gyamfi, NAHU and NAPC
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	L. Heng
Sierra Leone	SIL5021	Improving Productivity of Rice and Cassava to Contribute to Food Security	M. Zaman and PBG
Slovenia	SLO5005	Strengthening Agricultural Land Use and Management to Reduce Emerging Contaminants and Improve Water Quality	J. Adu-Gyamfi
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	E. Fulajtar
Togo	TOG5004	Improving the Productivity of Crops and Agricultural Practices through Radiation Induced Mutation Techniques	E. Fulajtar
Zimbabwe	ZIM5026	Improving Soil Quality for Optimizing Selected Cereal and Legume Productivity in Smallholder Farms	J. Adu-Gyamfi

Forthcoming Events

FAO/IAEA Events

First Research Coordination Meeting of CRP D15021 'Assessing the Fate, and Environmental Impact of Plastics in Soil and Crop Ecosystems Using Isotopic Techniques, Q2 2023 in Vienna, Austria or virtual.

Project Officers: J. Adu-Gyamfi and O.Meniailo

Final Research Coordination Meeting of CRP D15018 'Multiple Isotope Fingerprints to Identify Sources and Transport of Agro-Contaminants, October 2023, Vienna, Austria.

Project Officer: J. Adu-Gyamfi

NON-FAO/IAEA Events

European Geosciences Union (EGU), 23–28 April 2023, Vienna, Austria and online: https://www.egu23.eu/

Past Events

FAO/IAEA Events

Regional Training Course on the Use of Cosmic-Ray Neutron Sensor (CRNS) for Area-Wide Soil Moisture Monitoring (RAF5086: 'Promoting Sustainable Agriculture under Changing Climatic Conditions Using Nuclear Technology), 18-22 July 2022 (Seibersdorf)

Technical officer: H. Said

Fifteen Member States from Africa participated in the regional training course on the use of Cosmic-Ray Neutron Sensor (CRNS) technology for area-wide soil moisture monitoring, under the new regional project RAF5086 on 'Promoting Sustainable Agriculture under Changing Climatic Conditions Using Nuclear Technology (AFRA)'. This regional training course, held at the SWMCN laboratory in Seibersdorf, consisted of lectures and practical exercises on the installation and calibration of the CRNS, data processing and designing field experiments for better use of this advanced nuclear technology for agricultural water management.

Participants of RAF5086 Regional Training Course

Coordinated Research Projects

Project Number	Ongoing CRPs	Project Officer
D12014	Enhancing Agricultural Resilience and Water Security Using Cosmic-Ray Neutron Technology	E. Fulajtar and H. Said Ahmed
D15018	Multiple Isotope Fingerprints to Identify Sources and Transport of Agro-Contaminants	J. Adu-Gyamfi and L. Heng
D15019	Remediation of Radioactive Contaminated Agricultural Land	G. Dercon and L. Heng
D15020	Developing Climate-Smart Agricultural Practices for Mitigation of Greenhouse Gases	M. Zaman and L. Heng
D15021	Assessing the Fate, and Environmental Impact of Plastics in Soil and Crop Ecosystems Using Isotopic Techniques	J. Adu-Gyamfi and O. Meniailo
D15022	Isotopic Techniques to Assess the Fate of Antimicrobials and Implications for Antimicrobial Resistance in Agricultural Systems	J. Adu-Gyamfi and L. Heng

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

Project Officers: E. Fulajtar and H. Said Ahmed

This CRP (2019 to 2024) is aimed on testing the potential of using a cosmic ray neutron sensor (CRNS) and gamma ray sensor (GRS) for agriculture and environment protection, especially on irrigation scheduling and management of extreme weather events. CRNS provides soil moisture data at a large scale and in real time, which has a great value for land and 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 modelling for improving agricultural water management and its resilience; and (3) Develop approaches using CRNS and GRS for long-term soil moisture monitoring in agroecosystems. The final output of the CRP will be a set of methods and guidelines applicable in irrigation scheduling, flood prediction and drought management.

This CRP was approved in March 2019. It involves eleven partners: with five research contract holders (two from Brazil, two from China and one from Mexico), two research agreement holders (Denmark and UK) and four technical contract holders (Italy, Netherlands, Spain and USA).

The first Research Coordination Meeting was held on 26-30 August 2019, at the IAEA in Vienna, Austria. The major results of this meeting were: (1) reviewing the state of the art research on the use of CRNS and GRS for soil moisture assessment; (2) developing a detailed individual work plan and updating the overall workplan of the CRP; (3) establishing specific cooperation activities between the project partners. In autumn 2019 the installations of CRNS and their calibration began at selected study sites of project partners and the stationary soil moisture measurements began. The project started about half year before the problems with traveling emerged in spring 2020 due to COVID-19. At that time all partners had established already some CRNS monitoring sites and the first soil moisture time series were collected.

In winter 2019 and spring 2020 the first results of the CRP were published in international scientific journals and as oral presentations and posters at the online EGU General Assembly (4-8 May 2020 in Vienna). These publications presented 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 the field work limitations emerged due to travel restrictions, lockdowns and home office. Soil moisture monitoring was interrupted at some sites. Also the installation of CRNS and GRS at some sites were delayed. Nevertheless, in late summer and autumn the measurements and installations of new sites continued and the major activities were successfully implemented and already in its first year the CRP brought significant scientific achievements:

- Proposing algorithm for filtering the noise and smoothening the signal of neutron counts;
- Developing approach for estimation of rainfall from soil water content data obtained by CRNS;
- Testing the procedure for estimating rooting depth soil moisture distribution from CRNS data.

These results were published in three research papers in international scientific journals and two oral presentations presented at the 6th International COSMOS Workshop on 8-10 October in Heidelberg, Germany.

The Second Research Coordination Meeting was held virtually from 7 - 11 June 2021. Main achievement of this meeting was initiating the preparation of the methodological guideline. The time during the lockdowns and home office periods was exploited very efficiency for writing a number of publications and also preparing inputs for the major guideline which will be major output of the project. The draft manuscript is almost ready now and it will be submitted in winter 2022/23.

In autumn 2021 the work on testing GRS for soil moisture management began and the achievement is on the testing of the newly constructed CRNS (FINAPP Probe) in comparison with traditionally used CRNS (Hydroinnova). The most important methodological achievements presented in this guideline are: neutron signal noise filtering, CRSPy tool (neutrone counts processing using Python language), agriculture soil moisture products (rooth zone depth estimation and precipitation estimation) and approach using CRNS for remote sensing soil moisture products (SENTINEL, ASCAT) validation. Apart from that the results were presented at 2021 IEEE International Workshop: Metrology for Agriculture and Forestry, 3-5 November 2021 or 2022?.

In autumn 2022 the mid term evaluation of CRP was successfully done and the first major output of CRP was completed. It is a manuscript of guidelines for CRNS data processing and developing added value products. The manuscript will be submitted to Springer in early 2023.

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

Project Officers: J. Adu-Gyamfi and L. Heng

This five-year CRP (2018-2022) aims 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 are used to achieve the objectives including 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 compound specific stable isotope (CSSI)-based monitoring approach for evaluating in-situ degradation, transport, transformation, and fate of pesticides.

The second RCM of this CRP was held virtually from 1–4 March 2021. The mid-term review for the project was submitted on 8 September 2021 and was approved by the CCRA with a further extension of the CRP till 31 December 2023 (at no additional cost) to enable the participants complete the work on the respective research projects. The CRP achieved two of the three specific objectives namely to (1) develop, evaluate and standardize an integrative isotope approach for identifying and apportioning sources of contaminants in agro-ecosystems, (2) apply the combined approach to different agro-ecosystems to control contaminants. During last two years, the CRP proposes to focus on the third specific objective “to provide guidelines and decision trees for adapting and applying the toolbox” and furthermore to develop appropriate remediation strategies to reduce the environmental risk.

The third RCM was held virtually on 18-20 May 2022. Some of the main issues discussed were:

(1) A collaboration with the Mekong River Commission (MRC) on monitoring the source and transport of agro-contaminants along the Mekong transboundary river in the following countries: Laos, Thailand, Cambodia and Viet Nam. The CRP plans to perform a sampling campaign along the MRC established 48 sites on the Mekong River for isotope analyses. A similar collaboration between IAEA and the Joint Danube survey in Europe to apply stable isotopes to monitor nitrate from tributaries to the mainstem of the transboundary Danube River was successfully achieved and published (https://www.nature.com/articles/s41598-022-06224-5.pdf).

(2) A Publication “Tracing the Sources and Fate of Contaminants in Agroecosystems: Applications of Multi Stable Isotopes and Related Technologies” that will serve as a toolbox that provides guidelines and decision trees, planned for Q3 2023.

The achievements from the CRP to-date include:

(1) A publication in Springer on ‘Oxygen Isotopes of Inorganic Phosphate in Environmental Samples: Purification and Analysis’(https://link.springer.com/book/10.1007/978-3-030-97497-8) containing protocols for source identification and apportion of phosphate P to distinguish between P from agriculture and sewerage disposal causing eutrophication.

(2) A special issue on Agro-contaminants sources, transformation, and transport in agroecosystems (2021) was published in Agriculture, Ecosystems & Environment Journal (Elsevier) https://www.sciencedirect.com/journal/agriculture-ecosystems-and-environment/special-issue/101RHMH9Z15.

(3) The CSIA ($\delta^{13}C$ and $\delta^{15}N$) for assessing the fate of pesticides successfully tested in the field. A new passive sampler for detecting pesticide isotope signature developed and tested in India.

(4) $\delta^{34}S(SO_4)$ and $\delta^{18}O(SO_4)$ for partitioning different sources of pollutants from household waste and from

mining areas in the catchment tested [Nambeelup Brook, W. Australia].

(5) Combined use of ($\delta^{18}O$ and $\delta^{2}H$) and FRN-based sedimentary geochronology was used to assess the contribution of sediment source apportion to pollution [UK, Tanzania, China and Chile].

(6) A success story from Viet Nam "Nuclear Techniques and Improved Resource Management Help Reduce Pollution in Viet Nam's Nhue River (https://www.iaea.org/newscenter/news/nuclear-techniques-and-improved-resource-management-help-reduce-pollution-in-viet-nams-nhue-river) and 2 journal articles were published.

(7) A publication on field validation and applications of the protocols in specific countries----Case Studies is planned for October 2023.

The Final RCM is planned for October 2023 in Vienna, Austria.

Remediation of Radioactive Contaminated Agricultural Land (D15019)

Project Officers: G. Dercon and L. Heng

Innovative monitoring and prediction techniques present a unique solution to enhancing the readiness and capabilities of societies for optimizing the remediation of agricultural areas affected by large scale nuclear accidents. In this CRP, new field, laboratory and machine-learning modelling tools will be developed, tested and validated for predicting and monitoring the fate of radionuclide uptake by crops and related dynamics at the landscape level, with the emphasis on those under-explored environments and related main crop categories. Laboratory, greenhouse and field-based research using stable caesium and strontium isotopes in combination with integrated time and space dependent modelling and machine learning will be used to predict radiocaesium and radiostrontium crop uptake and movement in the case of a large-scale nuclear accident affecting food and agriculture. Operation research will be applied to guide the use of remediation techniques at landscape level (i.e. selection, optimization and prioritization). Protocols will be developed and adapted for innovative spatio-temporal decision support systems for remediation of agricultural land, based on machine learning and operations research integrated with Geographic Information System (GIS) techniques. The overall objective is to enhance readiness and capabilities of societies for optimizing remediation of agricultural areas affected by large scale nuclear accidents through innovative monitoring, decision making and prediction techniques. The specific objectives are (1) to combine experimental studies with field monitoring and modelling to understand and predict the role of environmental conditions on radiocaesium and radiostrontium transfer in the food chains and their dynamics at landscape level in particular for (1) under-explored agro-ecological environments such as arid, tropical and monsoonal climates, and (2) to customize the remedial options in agriculture to these under-explored agro-ecological environments and to adapt and develop innovative decision support systems for optimizing remediation of agricultural lands affected by nuclear accidents, based on machine learning and operations research techniques. Eleven countries participate in this CRP: eight research contract holders from Belarus, Chile, Morocco, P. R. China (three institutions), Russia, Ukraine; two technical contract holders from France and Macedonia; and six agreement holders from Belgium (two institutions), Japan (three institutions) and India. The CRP D15019 was developed as a follow up to CRP D15015. It was formulated based on recommendations from a consultants' meeting held at the IAEA, Vienna, 20–22 February 2019. Expert consultants from Belgium, Japan, Ukraine and Russia noted that the importance of optimization of remediation based on monitoring and prediction of the fate of radiocaesium and radiostrontium in agriculture is essential for returning the affected territories to normal environmental conditions. The First RCM was held on 21–24 October 2019. During this meeting the objectives and experimental plans of the national research projects were discussed and adjusted to be in line with the objectives and work plan of the CRP. Common guidelines for implementing the national project activities and collaboration networks were established. The second RCM was held online on 4-8 October 2021, which was combined with the NARO-FAO/IAEA International Joint Symposium on "Remediation of Radioactive Contamination in Agriculture: Next Steps and Way Forward" (4 October 2021). This meeting showed the significant progress in all fields of the project and based on these advances individual and project work plans were revised and adjusted where needed.

Since the beginning of the CRP a series of laboratory experiments has been carried on improving remediation of radioactive contamination in farmland. The CRP team aims to develop new isotope techniques to better understand the dynamics of radiocaesium and radiostrontium in the soil. Significant steps have now been made for stable isotope techniques that allow stable caesium and stable strontium to mimic the behaviour of their radioisotope equivalents. Further progress has also been achieved in the application of advanced mathematical approaches for improving the prediction of soil properties based on Mid-Infrared Spectroscopy and enhancing the decision making for the optimization of remediation of radioactively contaminated agricultural soils. Decision-support tools are being developed to improve strategies for remediation of radioactive contamination in agriculture. In June 2022, mid-term progress of the CRP was reviewed, and first CRP results were presented at the FAO/IAEA International Symposium on Managing Land and Water for Climate-Smart Agriculture held in July 2022. The final RCM is planned for 2024.

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

Project Officers: M. Zaman and L. Heng

Climate Change due to continued increased anthropogenic emission of greenhouse gases (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 (CO2), methane (CH4), and nitrous oxide (N2O) 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 N2O and CH4, which predominantly originate from agriculture. Based on the outputs of the previous CRP (D15016), climate-smart agricultural practices are a promising tool to enhance crop production with lower environmental footprints. However, more quantitative data on the effect of soil processes (e.g. carbon- and nitrogen-dynamics) on emissions of GHGs in relation to land-use changes are urgently needed. This new CRP as phase-2 was started with the objective to develop and validate climate-smart agricultural practices, based on isotopic and related techniques, to increase soil carbon (C) sequestration, mitigate GHG emissions (N2O, CH4, CO2) and limit gaseous losses of ammonia (NH3) and dinitrogen (N2) from agricultural ecosystems, with the aim to enhance agricultural productivity and sustainability. After the 1st RCM in 8-12 February 2021, all CRP participants have started establishing field trials to develop and validate climate-smart agricultural practices, to increase soil C sequestration, mitigate emissions of GHG and NH3 from agricultural ecosystems, to enhance agricultural productivity and sustainability. The Technical University of Madrid developed and validated a novel field method of ammonia volatilisation which is capable of measuring ammonia emission at field scale (one hectare). They also developed a robust method of C budgeting tool for estimating C footprint of cropping systems and shared this knowledge via on-line training with CRP CSIs from Argentina, Brazil, Bangladesh, Costa Rica, Ethiopia, and Viet Nam. Field results from Brazil indicated that mixed planting of legumes with pasture had a positive effect on pasture production, quality of animal feed, gain of live weight of animals, BNF, low emission of ammonia and N2O and C storage. Bangladesh for the first time identified microbial process of N2O production using 15N tracing technique and published the results in a refereed scientific journal. Field studies from China provided important insights into the effects of applying biochar, urease, and nitrification inhibitors on NH3 emissions from a rice paddy field and these results were published in a refereed scientific journal.

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

Project Officers: J. Adu-Gyamfi and O.Meniailo

Plastic use has increased from 1.7 million in 1950 to 359 million metric tons in 2018. However, despite its benefits to society, most plastics end up on land and in the soil (long-term sink), degrading into microplastics (diameter < 5mm) before entering the marine environment. Soil plastic pollution is especially acute in many parts of the world and the earth's soil is more saturated with plastic and microplastic than oceans. and 80% of them found in the marine environments are first disposed on land. This five-year CRP (2023-2028) has the overall objectives to (1) develop guidance for improving the understanding of the fate and impacts of plastics and microplastics in agricultural soils based on nuclear and related techniques, and (2) establish network and coordinating inter-laboratory studies of analytical techniques to support CRP network in developing common strategies to effectively mitigate the plastic pollution of agricultural soils and crops. The specific objectives 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 approaches, in combination with existing methodologies, 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. The request for submission of proposals (technical, research and agreement) are in progress. A draft technical document on the "Role of nuclear and related techniques on the fate, degradation, and impacts of plastics and microplastics on soil ecosystem and environment" is also in progress. The first research coordination meeting (RCM) is planned for Q2 2023 in Vienna, Austria or virtually.

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

Project Officers: J. Adu-Gyamfi and L. Heng

This five-year CRP (2021-2026) has the overall objective to develop guidance for improving the understanding of the fate, dynamics and persistence of AM and AMR in agricultural systems based on nuclear and related techniques and support MS to develop common strategies to mitigate the spread of AM in agricultural systems. The specific objectives are (1) to develop, evaluate and standardize integrative isotopic and conventional approaches for tracing the sources and persistence of AM and AMR in agricultural systems, (2) to apply a combination of approaches of isotopic and bioanalytical/molecular biological methods to different agricultural systems for assessing the fate and dynamics of AM and implications for AMR, and (3) to provide knowledge and guidance for informed decisions that help mitigate the spread of AM and AMR in agricultural systems. Nine member states are participating in this CRP including four research contract holders from Brazil, China, South Africa, and Viet Nam, three agreement holders from China, Norway, and USA, and two technical contract holders from Germany and Australia.

The first research coordination meeting (RCM) was held virtually on 11–13 May 2022. The purpose of the meeting was to discuss workplans and activities with meeting participants and to develop an overall workplan to realize the project objectives. Eleven participants including the nine research contract, agreement, and technical contract holders, one participant from FAO and one observer from Germany (Technical University of Munich). For effective implementation of the workplans, four working groups (WGs) were established. These are (1) WG1 on synthesis of sulfamethoxazole (SMX) labelled compound that will be used in the glasshouse and field experiments, (2) WG2 to develop sampling and analytical (SMX) protocols to be distributed to the partners, (3) WG3 to develop glasshouse and field experimental designs, and (4) WG4 to develop sampling and analytical protocols related to microbiology/microbial resistance genes. The coordinators of all the 4 WGs made their presentations to elucidate their implementation plans. There were discussions with the participant from FAO on possibilities for collaboration on FAO's Strategy and initiative in AMR. A submission "Novel isotopic Fingerprinting to Assess and Mitigate the Persistence and Transport of Antibiotics and Implications on Antimicrobial Resistance" was published in Nuclear Technology Review 2022.

Developments at the Soil and Water Management and Crop Nutrition Laboratory

Proximal gamma-ray spectrometry for soil texture determination

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Under climate change and increasing agricultural demand, soil resources are under severe pressure. Soils are essential for the proper functioning of agricultural ecosystems. Therefore, special attention should be given to soil management to ensure sufficient and sustainable food production.

Soil texture mapping with a traditional soil sampling approach is labor-intensive and expensive (including soil sampling and laboratory analyses). Having a proximal sensing technique to accurately map soil texture would be a big step forward, in particular at a sufficiently detailed spatial scale for soil management purposes.

For the development of such proximal sensing techniques, the SWMCN Laboratory uses the Hydrological Open-Air Laboratory (HOAL) in Petzenkirchen (Lower Austria) to evaluates the suitability of the Gamma-Ray Sensor (GRS) to determine the texture of the topsoil.

Figure 1. Medusa MS-350 portable GRS

Figure 2. Soil sampling and natural gamma-radiation (^{40}K, ^{238}U, and ^{232}Th) measurement using mobile Gamma-ray sensor. model MS 350 in Petzenkirchen, Austria.

A Medusa MS-350 portable GRS (Figure 1) was used to measure the spatial activity concentrations (Bq/kg) of ^{40}K (potassium), ^{238}U (uranium), and ^{232}Th (thorium) over 20 points across the fields. These activity concentrations were then characterized against soil texture parameters of interest such as silt, clay, and sand. In total 200 soil samples (10 soil samples for each of the 20 points) were taken in the Petzenkirchen experimental fields for soil texture determination, in combination with ^{40}K, ^{238}U, and ^{232}Th natural gamma-radiation measurements using mobile Gamma Ray Spectrometry (Figure 2).

As shown in Figure 3, the best correlation could be observed between ^{40}K radionuclide concentrations and clay ($R^2 = 0.51$) and silt ($R^2 = 0.46$), respectively. Thus, spatial monitoring of ^{40}K with mobile GRS can be used for spatial determination of clay and silt. However, correlations with other radionuclides concentrations such as ^{238}U and ^{232}Th were weak with R^2 coefficients less than 0.16.

These results demonstrate the potential of monitoring ^{40}K concentrations by a portable gamma sensor for soil texture mapping in agricultural land. Further studies are required to verify the applicability of this model to different soil types to enable the use of this nuclear technology for soil texture determination with high spatial resolution.

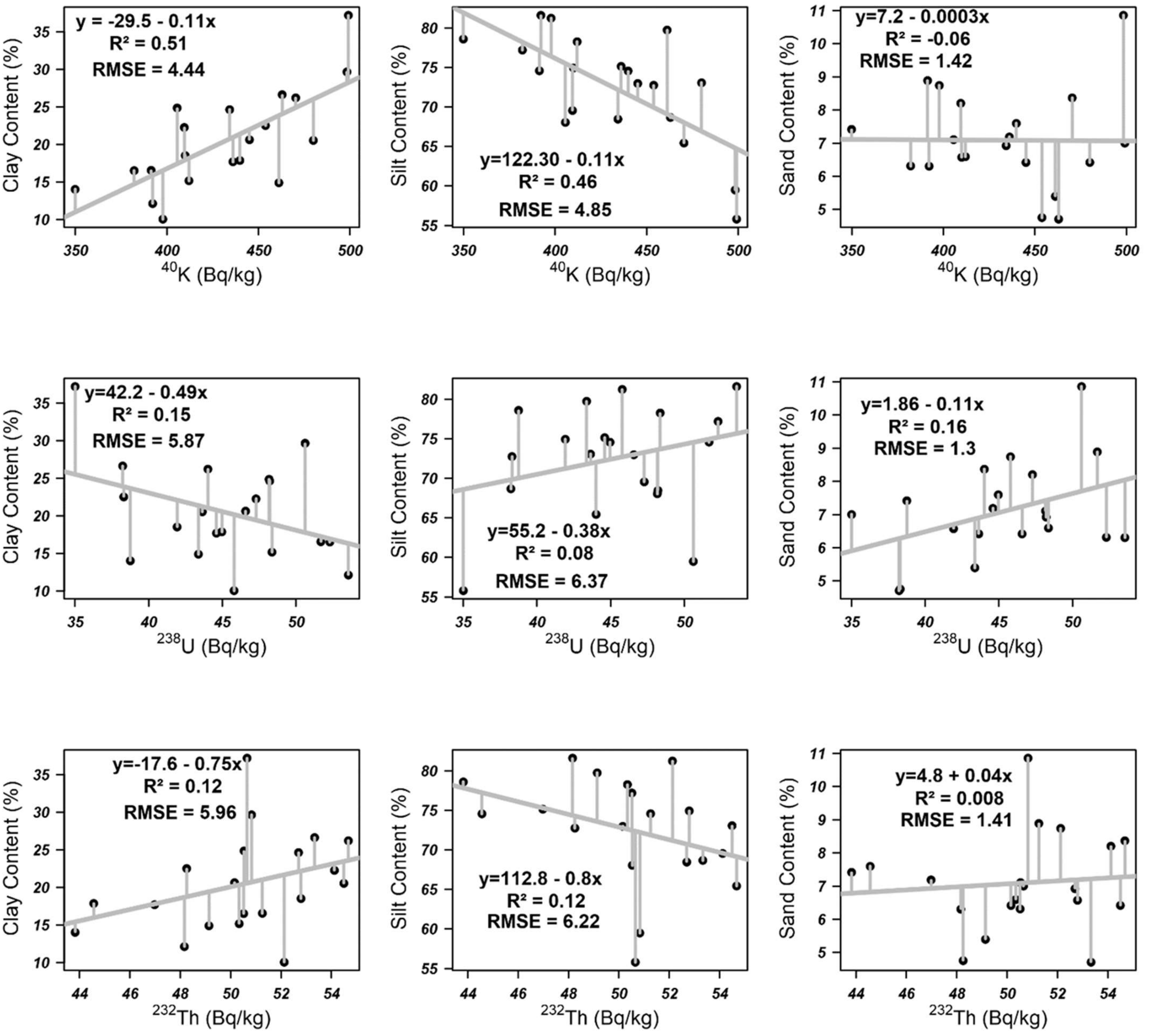

Figure 3. Correlation between the activity concentrations (Bq/kg) of ^{40}K, ^{238}U, ^{232}Th and soil texture (silt, clay and sand)

Decomposition of antibiotic Sulfamethoxazole in soil is accelerated by nitrogen addition and reduced by soil moisture content

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The use of antibiotics in livestock farming and the application of manure (Binh et al., 2008) or sludge as soil fertilizer (Krzemiński et al., 2020) are some of the main drivers making agricultural soils a significant source of Antimicrobial Resistance (AMR) (FAO and IAEA, 2019). The amount of time that antibiotics reside in soil is critically important for AMR appearance (Ouyang et al,, 2019), therefore the rate of decomposition and environmental conditions favouring the degradation of antibiotics should be investigated. Under the FAO/IAEA Coordinated Research Project (CRP) on 'Isotopic Techniques to Assess the Fate of Antimicrobials and Implications for Antimicrobial Resistance in Agricultural Systems' (D15022), the SWMCNL team assesses how nitrogen and water addition affects the mineralization of sulfamethoxazole (SMX) as a model antibiotic.

In this study, which will last four months, carbon poor soil (from Grabenegg) is incubated in 100 mL jars, amended with $^{13}C_6$-labeled sulfamethoxazole (20 mg/kg soil), with or without nitrogen (N) added (NH4NO3 at 150 mg N.kg^{-1}) or moisture elevated (from 40% to 100% of Water Filled Pore Space). Jars were hermetically sealed, then 30 mL of headspace gas samples have been collected every three to five days for analysis of 13C composition and concentrations of CO2 and CH4 by the cavity ring-down spectroscopy (CRDS) laser isotope analyzer Picarro 2201-i.

We expect that by following 13C incorporation into CO2 and CH4 we should be able to distinguish the relative contribution of soil organic matter and SMX to the fluxes of both greenhouse gases. At the time of writing, we are in the initial phase (the first 17 days). So far, there is no 13C signal in CH4, nevertheless the 13C signal in CO2 is well distinguishable (Figure 1) despite the very low rate of SMX application. It can be observed that the highest 13C enrichment is found in the treatment with the nitrogen addition suggesting that SMX mineralization is N limited. Applying N fertilizer in SMX polluted soils would increase SMX mineralization rates, reducing SMX concentration and the level of AMR. If these findings are further confirmed over the next 4 months, this is potentially information to share with all Member States experiencing high pollution of agricultural soil with Sulfamethoxazole.

It is also important to notice that the addition of water reduced the rate of SMX mineralization, which is demonstrated by the low 13C incorporation into CO2 for the high soil moisture treatment (Figure 1). This suggests that SMX mineralization is most likely an aerobic process, which requires molecular oxygen (O2) and is inhibited by O2 deficiency. This also means that the application of manure, wastewater and sludge with high SMX to water saturated soils (rice paddies) is especially dangerous since the SMX will be very slowly degraded, amplifying AMR.

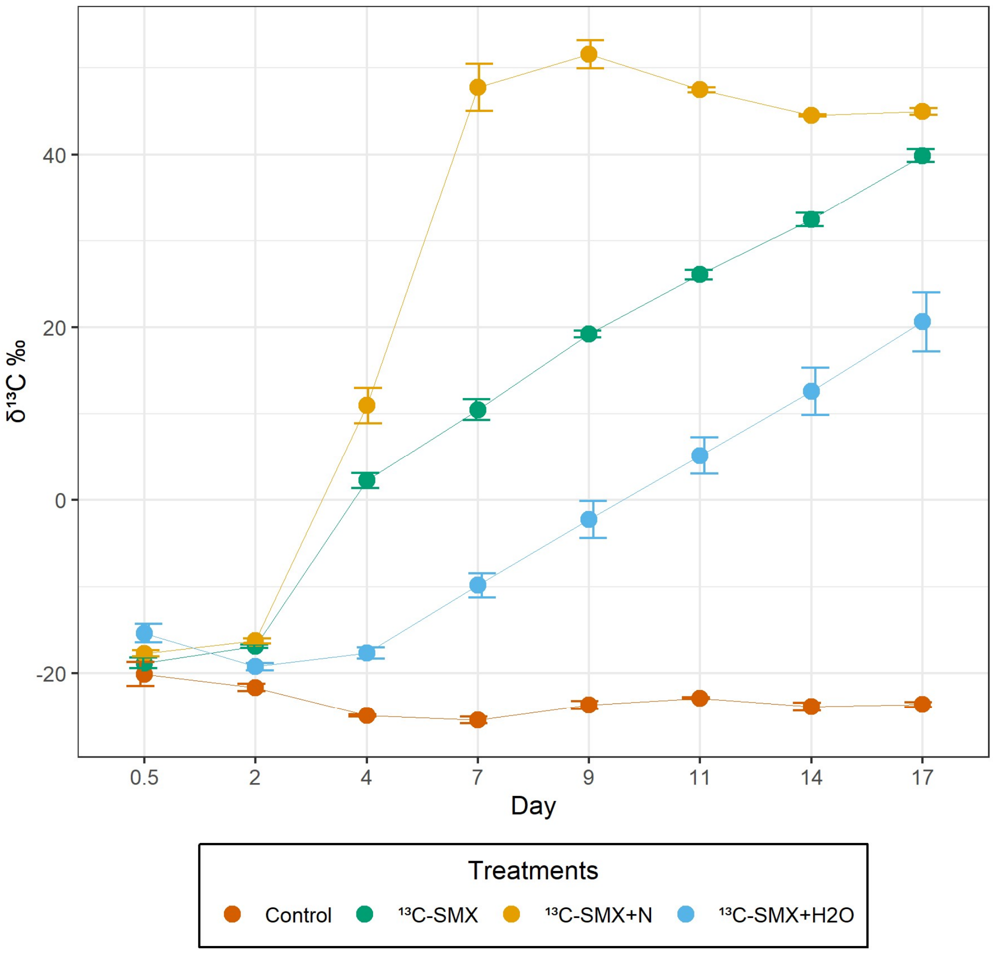

Figure 1. Dynamics of ^{13}C incorporation into CO_2 during the soil incubation experiment with application of $^{13}C_6$-labeled sulfamethoxazole (green), SMX and nitrogen (orange) and SMX and water (blue). (N=3, mean ± SE).

In conclusion, the application of $^{13}C_6$-labeled SMX provides important insights about the influence of environmental factors on SMX mineralization in soils. Through this study, the effects of nitrogen and water addition on SMX degradation are being shown for the first time, which can help Member States develop measures to reduce SMX pollution in agricultural soils and hence reduce the spread of AMR.

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Antibiotic Sulfamethoxazole (SMX) strongly reduces heterotrophic C respiration in soils

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Agricultural soils are increasingly polluted by antibiotics, and this makes them a source of antimicrobial resistance (AMR). However, antibiotics may also change microbial community in soils, altering microbiological processes. The recently initiated FAO/IAEA Coordinated Research Project (CRP) D15022 on *'Isotopic Techniques to Assess the Fate of Antimicrobials and Implications for Antimicrobial Resistance in Agricultural Systems'* targets sulfamethoxazole (SMX) as a model antibiotic. Given the knowledge gap on how SMX affects soil microbial community, and in particular soil carbon (C) cycling, we conducted an experiment to investigate how different concentrations of SMX alter soil heterotrophic respiration (C mineralization).

We collected soils rich and poor in soil organic carbon from Seibersdorf and Grabenegg, respectively. After the samples were sieved at 2 mm, we incubated 80g of soil in 100mL jars at room temperature for 30 days. The SMX was added at day 1, at six rates (0; 0.01; 0.1; 1; 10 and 100 mg.kg^{-1}) in water solution. Soil moisture was kept constant at 45% of soil water-filled pore space throughout the incubation experiment. The flux of CO_2 and isotopic composition of carbon in respired CO_2 were determined with a Picarro 2201-i laser isotope analyzer using Keeling plots.

For this, 100mL jars were placed in 1L jars, hermetically closed. These 1L jars were then connected through tubes to the laser isotope analyzer via a multiplexer and small sample introduction module (SSIM). Eight samples were run at once (Figure 1). Air samples (20mL) were taken from each jar every 72 min. Running five to six sampling cycles we received correspondingly 5-6 data points on accumulated CO2 concentrations and depleted ^{13}C-CO_2 values, sufficient for the Keeling plots.

Figure 1. Automatic measurements of CO_2 flux and ^{13}C-CO_2

Further, during the 30 days of incubation, the CO_2 flux was determined eleven times. Based on these measurements, the total amount of CO_2 emitted from the soils over the entire incubation was estimated. The amount of emitted CO_2 from the control soils (without SMX) was taken as reference (i.e.100%), the cumulative CO_2 flux from all other treatments were then estimated as a fraction of this reference (Figure 2).

In general, SMX concentration negatively affected the CO_2 production rate. The negative effect was larger with a higher SMX concentration. The inhibitory effect of SMX followed a logarithmic function, after excluding outliers. The fitted equations may be used to predict how much the microbial activity is inhibited, if the concentration of SMX in soil is known. Upon confirmation with more diverse soils and tested under field conditions, such equations may be transferable to Member States. It was also observed in our study that when the toxicant concentration increases, the toxic effect declines at some specific concentrations or even a stimulation of CO_2 production could be found. In fact, three concentrations (10 mg/kg for Seibersdorf, and 0.1 and 1 mg/kg for Grabenegg) resulted either in a smaller decrease or an increase of CO_2 production (considered as the above-mentioned outliers, shown in Figure 2). This observed increase can be related to the following processes: (1) It may be concentration-dependent AMR, (2) SMX may act as a C source, but the most likely explanation is (3) inhibiting bacteria, it may reduce the competition, allowing for other microbial groups to proliferate and so actively decompose soil organic matter.

Overall, the incubation experiment with different concentrations of SMX provides important insights on the toxicological effects of SMX on soil microbial life and the soil C cycle in agricultural soils. The derived equations are useful to predict the inhibitory effect of SMX on microbial activity, if the concentration of the pollutant is known, and to estimate priming effects related to soil organic matter dynamics.

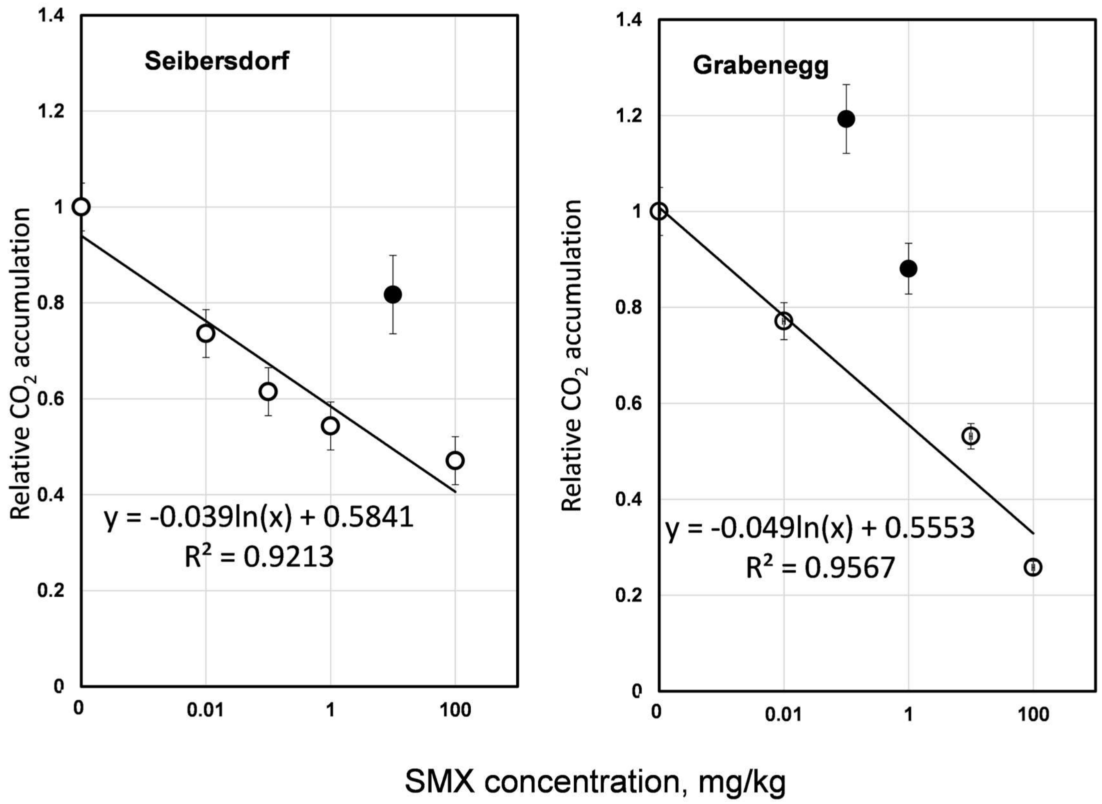

Figure 2. The effect of SMX at different concentrations on soil C respiration. (N=3, Mean ± Standard Error). White bullets are values taken for fitting the logarithmic equation; black bullets were not considered for modelling.

Understanding the interaction between maize water use efficiency and nutrient uptake in irrigated cropping systems, a basis for predicting and improving Zambia's productivity in a changing climate

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Food security is a growing concern for the population in Zambia, and more so with the negative effects that climate change and reduced rainfall have on crop production. It is therefore important to be able to understand crop production trends so that mitigation measures can be put in place if the expected production does not follow the increasing demand for food.

To predict maize crop production trends for Zambia, the FAO's AquaCrop model is used in this study, carried out under the ICTP/IAEA Sandwich Training Educational Programme (STEP). AquaCrop is a crop growth model developed by FAO's Land and Water Division to address crop response to water and assess the effect of the rainfall and irrigation and their management on crop production.

AquaCrop simulates the yield response of herbaceous crops to water and is particularly well suited to conditions in which water is a key limiting factor in crop production. AquaCrop balances accuracy, simplicity and robustness.

To ensure its wide applicability, it uses only a small number of explicit parameters and mostly intuitive input variables that can be determined using simple methods (https://www.fao.org/aquacrop/en/).

As explained in our previous Newsletter (Vol. 44 No. 2 Jan 2022), a field experiment was implemented by the STEP fellow at the Mount Makulu Central Research Station of Chilanga in Zambia as part of her PhD study, looking at the nitrogen response of maize under different water management practices. The main aim of this research is to identify optimal and sustainable water and nitrogen application for maximizing maize production in irrigated crop systems. Maize was planted at three nitrogen and three irrigation levels. The resulting crop growth and yield data are now being used in AquaCrop, firstly to validate the model's performance in the Zambian context, and secondly to run different nutrient and water management scenarios to improve crop productivity.

To calbrate the AquaCrop model, only the 100% ET water level and the highest nitrogen level (140 Kg N/ha) were considered in this study. Further, the following datasets were collected:

i) Above-ground biomass at five growth stages throughout the growing season;

ii) Aerial photos using an airborne optical camera to measure plant canopy cover. One square meter (1 m^2) was marked in the field and the picture was taken. These were then analysed in image J to calculate the green canopy cover (Figure 1);

iii) Soil characteristics, such as initial soil moisture (at planting time), water holding capacity and texture, measured to be used as inputs for the model;

iv) Weather data;

v) Yield (both grain and biomass).

This information is now being put into the AquaCrop model, and we are checking how well it performs to predict the observed above-ground biomass, green canopy cover, soil moisture and yield. Preliminary results for green canopy cover showed that the model simulates the canopy cover over the growing season well (Figure 2). However, the model predicts a yield of 6.0 ton/ha, higher than the measured yield of 4.9 ton/ha. Refining inputs further will be required to produce a better representation of yield by carrying out further analyses of the soil's physical parameters.

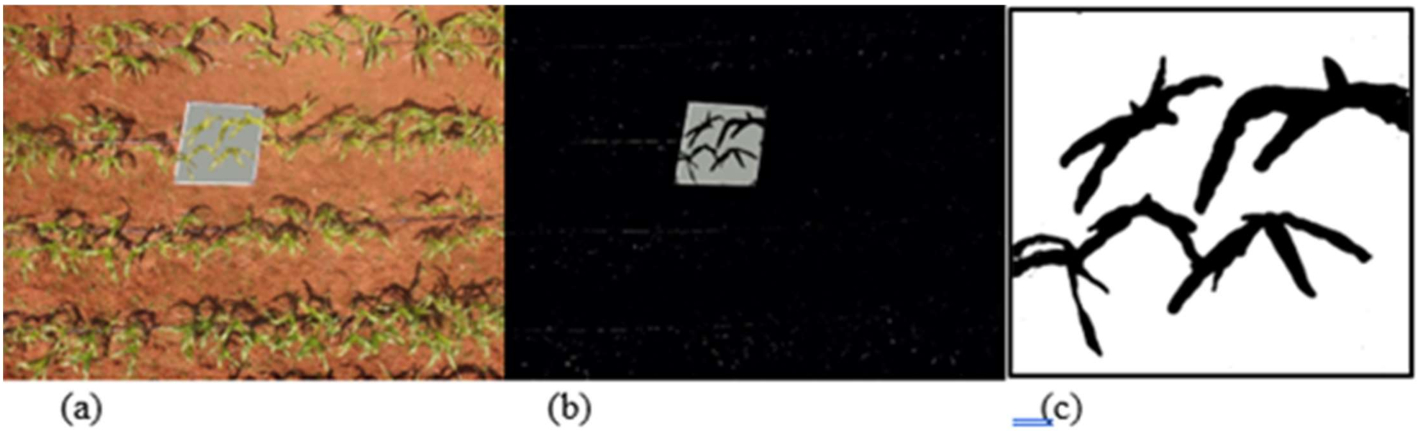
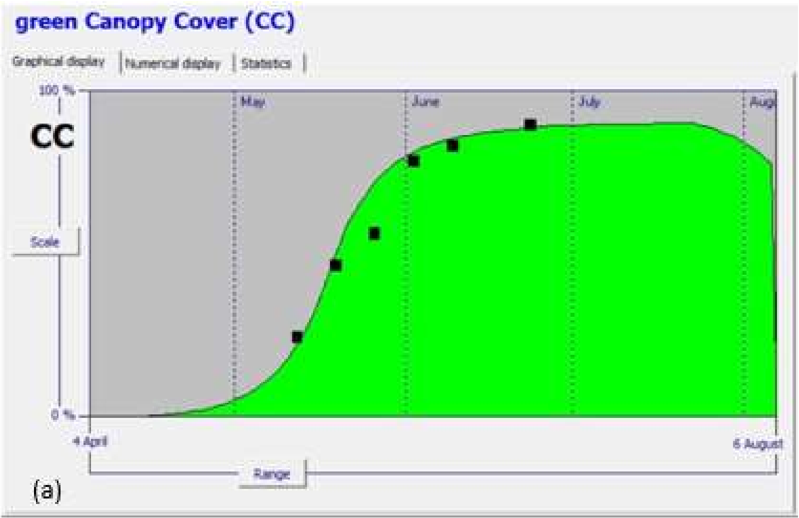


Figure 1. (a), (b) and (c): Processing aerial photos for image analysis for cover crop.



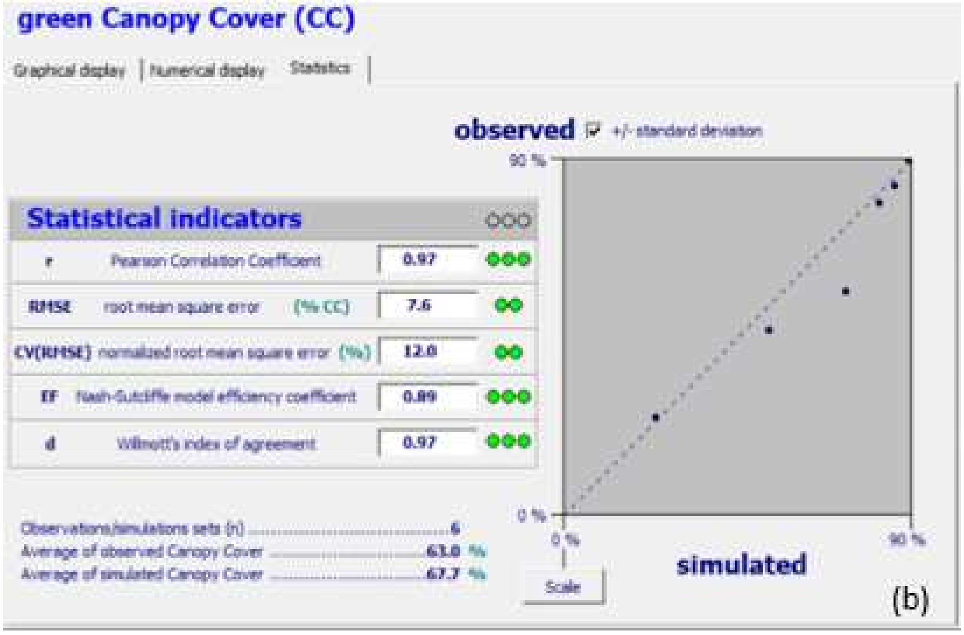


Figure 2. Simulation results of green canopy cover: (a) graphical display, and (b) statistical indicators.

After this validation, we will analyse based on the long-term dataset (30 years) how maize crop production may be expected to evolve, and how irrigation (and nitrogen) management in combination with agronomic measures such as planting time may help to mitigate the impacts of climate change.

Influence of NH4^{+} fertilisation and clay mineral amendments on Cs^{+} in soil solution

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The dynamics of the nuclear fission product radiocaesium (RC) in the soil-plant continuum are strongly influenced by soil mineralogy. Clay minerals, such as 2:1 hyllosilicates and zeolites, can cause the immobilisation of RC in soils due to their negative surface charges. On the other hand, competing cations, such as ammonium (NH4+), may induce the desorption of RC from the exchange sites of clay minerals and therefore increase the risk of RC plant uptake. Under CRP D15019 on “Remediation of Radioactive Contaminated Agricultural Land”, an incubation experiment for a duration of five weeks was carried out at the SWMCNL aiming to elucidate the effect of NH4+ fertilisation on Cs+ in soil solution in five different soil types (Andosol, Cambisol, Gleysol, Chernozem and Podzol), with distinct clay mineralogy. One soil (allophanic Andosol) with low RC interception potential (RIP) was additionally treated with clay amendments such as smectite, vermiculite and zeolite, and this at an application rate of 10 and 40 t ha^{-1}. The RC uptake for ryegrass (lollium perenne) was calculated by means of the empirical equation given by Smolders et al. (1997). The results showed that NH4+ induced RC desorption depends on the soil´s clay mineralogy. More precisely, the presence of 2:1 clay minerals (mica, vermiculite) caused relatively smaller RC desorption due to exchange sites that are highly RC selective. In contrast, 2:1:1 (chlorite), 1:1 (kaolinite/halloysite) and amorphous (allophane) clay minerals are less RC selective and were hence associated with stronger RC desorption. Moreover, the clay mineral applications reduced the solution RC concentration in the following order: vermiculite > zeolite > smectite and 40 t ha-1 > 10 t ha^{-1} for each mineral. Solution NH4+ concentrations decreased with time due to nitrification processes and most likely fixation in the 2:1 clay mineral structure, which led to decreasing solution RC concentrations.

Table 1. Effect of the NH4+ fertiliser treatment on the calculated RC uptake of ryegrass. Green down-facing arrows indicate a decreased and red up-facing arrows an increased calculated RC uptake of ryegrass after the fertilisation treatment. The arrow size indicates absolute changes < 100 (↓), > 100 & < 500 (↓) and > 500 (↓)

Day	Chernozem	Podzol	Cambisol	Gleysol	Andosol
1	-	↑	↓	↓	↑
8	↓	=	↑	↓	↑
22	↑	↓	↓	↑	↓
36	↓	↓	↓	↑	↓

Table 2: Effect of clay mineral amendments in reducing the RC uptake of ryegrass relative to the control (allophanic Andosol). Red up-facing arrows indicate a relative increase and green-down facing arrows a relative decrease. The arrow size indicates relative changes < 2 (↑), >2 & < 100 (↑) and > 100 (↑).

Day	Smectite (10 t ha^{-1})		Smectite (40 t ha^{-1})		Vermiculite (10 t ha^{-1})		Vermiculite (40 t ha^{-1})		Zeolite (10 t ha^{-1})		Zeolite (40 t ha^{-1})	
	NF	F	NF	F	NF	F	NF	F	NF	F	NF	F
1	↑	↑	↑	↑	↑	↓	↓	↑	↑	↓	↑	↑
8	↑	↑	↑	↑	↓	↓	↓	↓	↑	↑	↑	↑
22	↑	↓	↑	↑	↓	↓	↓	↓	↑	↑	↑	↑
36	↑	↑	↑	↑	↓	↓	↓	↓	↑	↑	↑	↑

Contrary to our expectations, the calculated RC uptake of ryegrass was, in nearly 60% of the investigated conditions (soils without clay mineral amendments), reduced by NH4+ fertilisation (Table 1). This result could be attributed to the increased solution of K+ concentrations, which resulted in a reduction of the RC concentration factor (CF), defined as RCplant/RCsolution. As these results contradict earlier studies that empirically determined the RC plant uptake after NH4+ fertilisation, we explain the phenomenon by high abundance of K+ shortly after the NH4+ fertilisation and, later, K+ exhaustion causing a strong increase of the RC CF (Lasat et al., 1997;

Dushenkov et al., 1999; Paasikallio and Sormunen-Cristian, 2002; Ioannides et al., 2003; Sun et al., 2019).

Moreover, the calculated RC uptake was predominantly increased by the zeolite and smectite amendments but decreased by the vermiculite amendments relative to the control without any amendments (Table 2). As all minerals were K+ depleted prior to their application, solution K+ concentration decreased, and the RC concentration factor increased. This effect exceeded the effect of reduced solution RC concentrations, particularly in the zeolite amended soils, as zeolite (Clinoptilolite) is a highly K+ selective clay mineral. Earlier assumptions that zeolite amendments are helpful due to K+ release from the mineral could therefore not be confirmed in this study (Fujimura et al., 2013; Yamaguchi et al., 2019). In contrast, the strong reduction in solution RC concentration exceeded the effect of the increased RC CF in the vermiculite amended soils. However, the preparation of the vermiculite used in this study is cost intensive and therefore of less practical relevance. Summarising, NH4+ fertilisation includes the risk of RC desorption but needs to be considered in the context of solution K+ concentrations dynamics, while clay mineral amendments are helpful in reducing the solution RC concentration. However, potential solution K+ reductions need to be considered.

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What can a mountain in Kenya tell us about the effect of weathering on radiocesium bioavailability in soils?

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In September 2022, Margot Vanheukelom travelled to Kenya to collect soil samples for the next experiment in her PhD project, linked to the CRP D15019 on "Remediation of Radioactive Contaminated Agricultural Land". The aim was to collect soils that have a similar parent rock but represent different stages of weathering and, as such, differences in soil mineralogy that can affect the bioavailability of radiocesium. A sequence of soils collected at different altitudes is called a toposequence. Toposequences on a volcanic mountain has often been used in soil science to study soil weathering. In this scenario, the effect of weathering could be studied on the bioavailability of radiocaesium in soils.

In practice, sampling the soils was challenging. In four days, at least 10 kg of soil had to be collected from four locations on the mountain flank of Mount Elgon at altitude intervals of 250-300 m and at four locations on farms in the valley, around Kitale, with the objective to find soils with contrasting properties, so that the role of weathering becomes clear (Figure 1). For the first part of the sampling, the team had to be escorted by forest rangers. Equipped with a shovel, bags and GPS, the team set out to find the sampling locations. The first sample at 2400 m a.s.l. was taken along a dirt road that was easily accessible by vehicle. However, for the next locations, the team had to go on foot through a dense forest without walking trail to collect the remaining 30 kg of soil. As the journey was far and the team was hampered by vegetation and afternoon rains, the team had to return after sampling at 2650 m and 2900 m altitude. On the way down, the vehicle got stuck in the mud leaving the team return only by midnight.

The next day, continued with the aim, the team put the walking boots and rain jackets back on for another climb to take the final sample at 3200 m altitude. For the second part of the sampling, the team drove to farms in Trans Nzoia district to collect arable soils. The team had to explain the project aims to farmers and ask where the typical weathered tropical soils could be found. Finally, the soils had to be air-dried and packed for transport so that on the last day Margot could take the soil samples in her luggage to Belgium.

In addition to the soil series in Kenya, similar sequences have been collected in Chile, France, Guatemala, the Philippines, Spain and Vietnam. The soil properties are being measured and a selection of soils will be used in a pot experiment where the soil is spiked with ^{137}Cs and two potassium fertilizer scenarios are compared (no K vs. with K). Ryegrass will be grown on the soils for 30 days so that the ^{137}Cs soil-to-plant transfer factors can be determined. The outcome will reveal the role of the soil weathering stage on the ^{137}Cs bioavailability. All such work would improve predictions of the ^{137}Cs soil-plant transfer used for emergency preparedness and the recovery phase in case of nuclear power plant accidents.

The sampling campaign was made possible by the funding from the Belgian Nuclear Research Centre (SCK-CEN) and the collaboration of the University of Eldoret (UoE) in Kenya and the University of Leuven (KU Leuven) in Belgium. It would never have gone so smoothly without the help of Dr. Abigael Otinga, Dr. Ruth Njoroge and Ms. Mary Nekesa of UoE and Prof. Roel Merckx of KU Leuven.

Figure 1. Sampling at Mount Elgon (from left to right Cambisol, Nitisol, Nitisol)

Figure 2. Sampling in farms around Kitale (from left to right Gleysol, Vertisol, Ferralsol) in the Trans Nzoia district, Kenya.

Reducing the impact of decontamination efforts on downstream ecosystems in large-scale nuclear emergencies affecting food and agriculture

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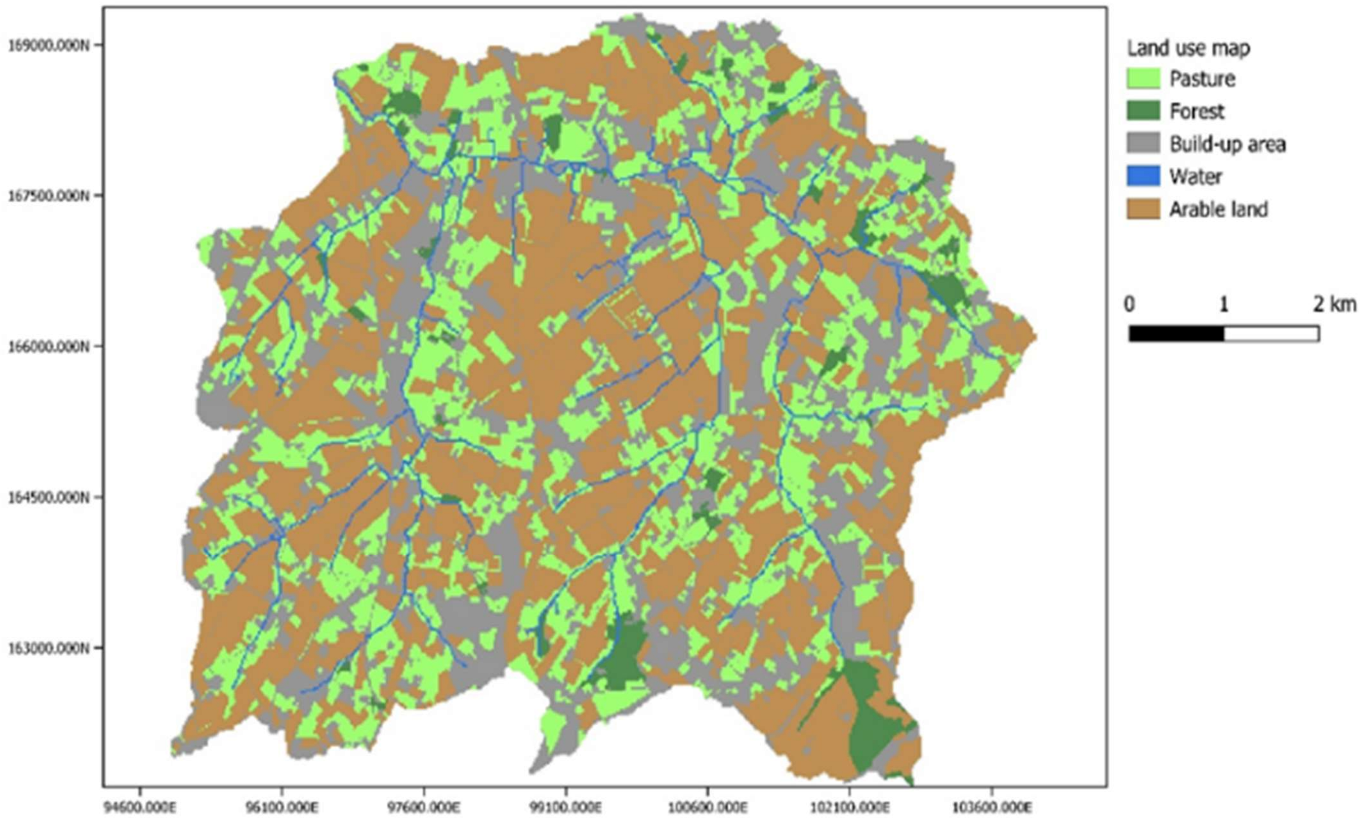
In the areas affected by the Fukushima Daiichi and Chernobyl nuclear power plant accidents, government-led decontamination efforts reduced the radiation risk, yet its long-term downstream impacts remain unclear (Bin et al., 2022). Because a major part of the deposited radiocaesium on the ground will become tightly fixed to the clay particles, subsequent migration with suspended sediments into the river system will affect downstream areas (Qin et al., 2012; Yoshimura et al., 2015). Many studies have reported radiocaesium wash-off resulting from soil erosion in Fukushima (Evrard et al., 2015; Onda et al., 2020) and Chernobyl (Konoplev et al., 2021). Bin et al (2022) demonstrated that upstream decontamination efforts caused persistently excessive suspended sediment loads downstream. Rapid vegetation recovery can shorten the duration of such unsustainable results and assessing the off-site impact should therefore be included in the remediation process. A Cellular Automata Based Heuristic Solution Method for Minimizing Flow (CAMF) was adapted to consider not only the quantity but also the Cs-137 concentration of the transported sediments. Through the collaboration between the partners of the CRP D15019 on "Remediation of Radioactive Contaminated Agricultural Land", it became possible to use data acquired in the region affected by the Fukushima Daiichi nuclear power plant accident to help develop and test these models. Using an iterative workflow, the model will identify areas with the highest contribution of radiocaesium wash-off to the outlet. This information, as seen in Figure 1, can be provided to decision makers for improving the sustainability of remediation actions. This model will be further integrated with the on-site decision support system (OREFA) developed under CRP D15019, where it can help improve the efficient allocation of resources for remediation of agricultural regions.



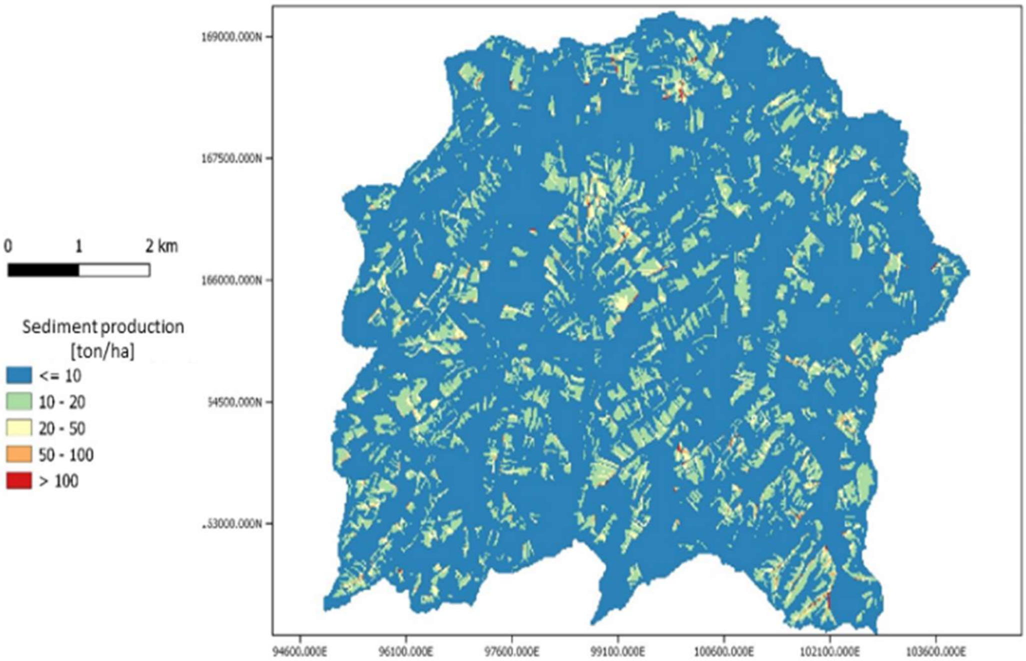


Figure 1. Identification of priority areas for remediation decisions based on the production of sediments (right) and land use (left) in the Maarkebeek catchment after a hypothetical accident.

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Validating banana drought stress proxies on-farm in the Kilimanjaro region of Tanzania

Vantyghem

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Research under the PUI (Peaceful Uses Initiative) project on ‘Enhancing climate change adaptation and disease resilience in banana-coffee cropping systems’ in East Africa, funded by Belgium, has indicated that stable carbon isotopes ($\delta^{13}C$) and leaf temperature can be used to detect drought stress in banana. This was determined during greenhouse experiments and in controlled field experiments. The next step in the project was to test the robustness of these drought stress measurement methods on-farm. Smallholder farms typically greatly vary in terms of soil fertility, water availability, which are all factors that could potentially affect $\delta^{13}C$ and leaf temperature, so their implication as a proxy for stress under farm conditions is far from evident.

Leaf temperature and $\delta^{13}C$ of the phloem sap were measured in 10 farms in the Kilimanjaro region, Tanzania. Measurements took place during the dry season. Twenty-seven plants (both mother and daughter plants) were sampled in three plots per farm, which varied in water availability. Phloem sap was collected in the morning, while leaf temperature was measured at noon. Furthermore, data were collected on tree shading within the farm and overall cloudiness.

We found that leaf temperature and $\delta^{13}C$ in the phloem sap clearly correlated over the variable farm environments, although only under sunny conditions (Figure 1). The presence of clouds prevents the leaves from warming up, resulting in no variability in leaf temperature. Moreover, we found that shadiness within the farm was the main driver of variability in both parameters and thus, drought stress. Parts of the farm where banana plants were completely shaded by trees were the least stressed. Intercropping of banana with trees is a commonly applied strategy in this highland area. Our research confirms that this strategy might be very beneficial when insufficient irrigation water is available. This is already the case fairly often and climate change is only expected to make water supplies even less reliable.

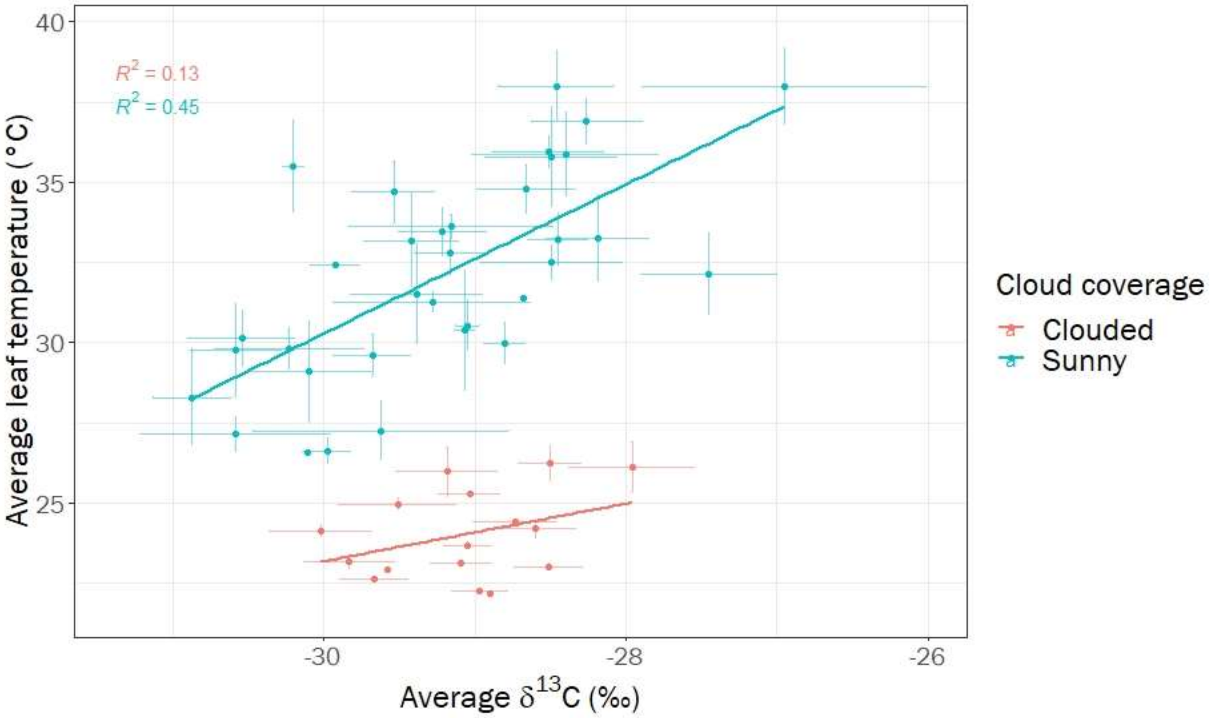

Figure 1. Relation between leaf temperature and $\delta^{13}C$ in phloem sap in plots with different water availability in 10 farms (n = 9) under clouded and sunny conditions.

Counteracting drought effects in cassava production systems: An update on the CIALCA activities at SWMCNL

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Climate change is a driver of agricultural shifts around the globe. Due to an increase in dry spell frequency and temperatures in Central-Africa, various crops will lose their importance, while others will become more suitable. In Central-Africa, cassava is one of those crops that will gain importance. It is generally believed that this crop can still achieve considerable yields on nutrient poor soils and under drought. However, yield losses of up to 70% have been found in cassava, more severely when the drought happened during the first four months after planting. This increases the importance of the search for agronomical practices to improve water use efficiency in cassava cropping systems.

The SWMCN Laboratory has been working previously with cassava in controlled greenhouse experiments, researching how drought, fertilizer application and variety selection are reflected in isotopic signatures (C-13 and O-18, proxies for water use efficiency and stomatal conductance respectively). As a follow up, the work was taken to the field, more specifically to the Democratic Republic of Congo. In collaboration with IITA under the CIALCA project, cassava fields were planted under supervision of Fidèle Barhebwa in Walungu, Uvira and Bunyakiri, to assess effects of fertilizer application (control vs NPK) and weeding time and frequency on water use efficiency (Figure 1).

Figure 1. Measuring stomatal conductance and related parameters

At 4 months after planting, morphological as well as physiological parameters of the plants were measured in multiple repetitions, spread over the different locations. Leaf samples were taken and isotopic composition of bulk, soluble sugars and cellulose are being measured by Isotope Ratio Mass Spectrometry in the SWMCN Laboratory in Seibersdorf. Preliminary results of isotopic analyses can be found in Figure 2.

Figure 2. Field work on study site in Walungu, DR Congo.

Fertilizer application significantly increased the $\delta^{13}C$ ($p < 0.05$) in both bulk and soluble sugars of samples from Uvira, while the same, but insignificant trend was found in Bunyakiri. This means that applying fertilizer increased the intrinsic water use efficiency of the plants. Trends between different leaf levels are different for bulk (upward trend towards the upper leaf) and sugars (increase towards middle leaf and stagnation or decrease towards upper leaf). This shows that other information is stored in the isotopic signal of both materials. Further steps will be to link isotopic information with yields, morphological and physiological parameters, to understand cassava's response to fertilizer application.

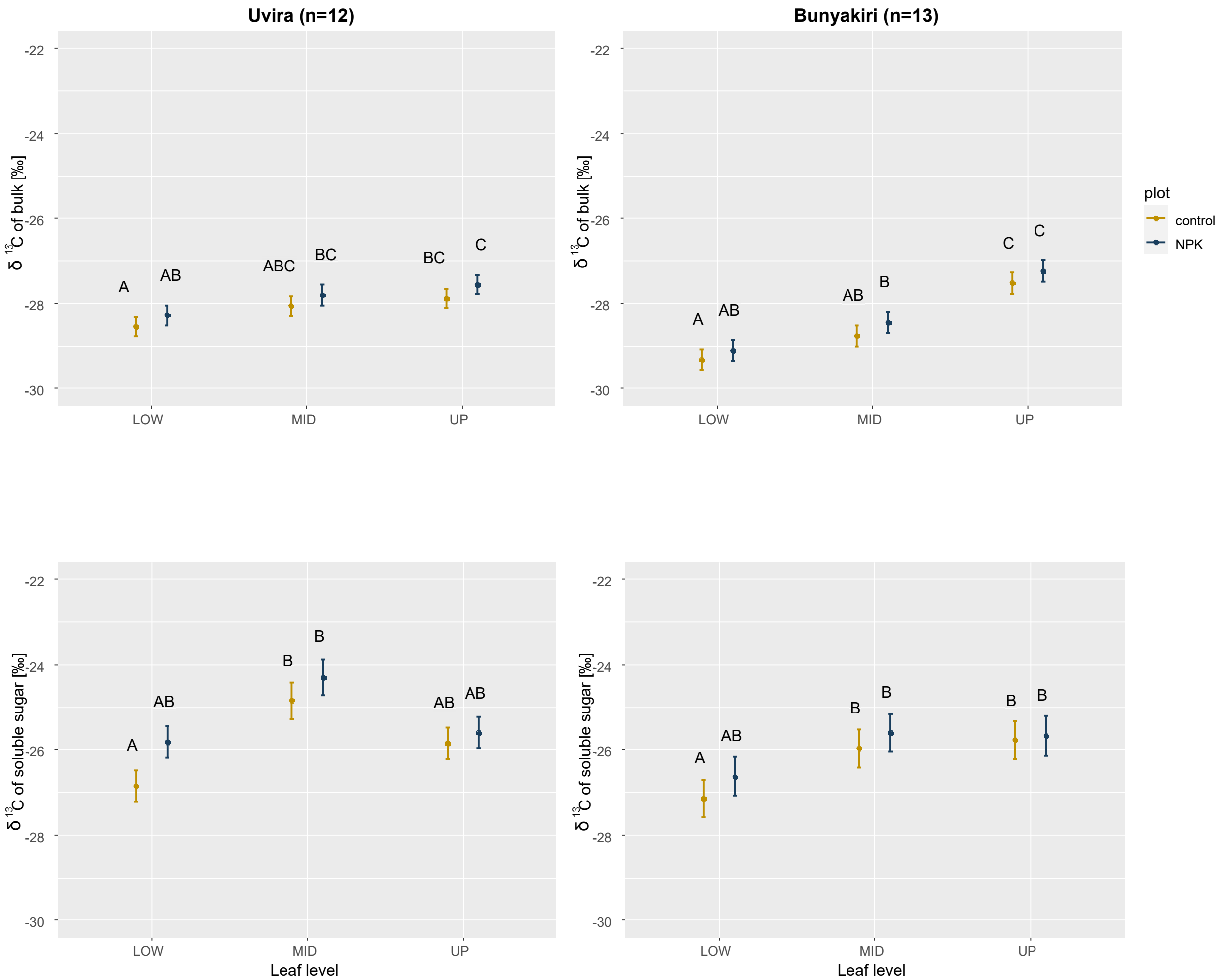

Figure 2. Isotopic composition (δ¹³C) of cassava leaves from the field work in Uvira and Bunyakiri. Leaves from the lower level, middle level and upper level were analyzed for isotopic composition in bulk (upper two panels) and extracted soluble sugars (lower two panels). Each dot represent the means of 12 (Uvira) or 13 (Bunyakiri) samples, while error bars represent standard errors. Yellow color represents control plots, while blue color represents plots that received NPK fertilization. Different letters per panel show significant ($p<0.05$) difference between the groups, based on anova followed by tukey HSD

Effect of urease inhibitor and biofertilizer on wheat production

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Agricultural production must increase by 50% to support about 9 billion people by 2050 (Alexandratos and Bruinsma, 2012). Previous studies showed that integrated crop-soil management strategies can improve cereal yield by 30% without increasing nitrogen (N) use (Chen et al., 2014). Sustainable agricultural practices can help reach this point by improving resource use efficiency.

In the spring of 2022, a field experiment was established at the experimental station of the University of Natural Resources and Life Sciences (BOKU), located at Groß-Enzersdorf in the east of Vienna, to determine the effect of urease inhibitors and biofertilizers on wheat production (Figure 1). A randomized complete block design including five treatments and four replicates was used in this study. Each main plot was 9 by 9 meters, and a buffer zone of 1.5 meters was implemented between each of the individual main plots. The treatments were: T_1 (control treatment - without N fertilizer), T_2 (Urea only), T_3 (Urea+Urease Inhibitor (UI)), T_4 (Urea+Biofertilizer), T_5

(Urea+UI+Biofertilizer). All treatments received 50 kg N ha^{-1} at tillering stage (GS 31), except T_1. In this study N-(n-butyl) thiophosphoric triamide (nBTPT) or "Agrotain" was used as UI and *Azotobacter chroococcum* or "AZOTOHELP" was used as biofertilizer.

Figure 1. Spring wheat in Groß-Enzersdorf (Vienna)

To determine wheat yield (grain and straw), a 1.5 by 8 meter area was harvested in each main plot (9 by 9 meters) (Figure 1). To measure other parameters including the number of tillers per square meter, 1000-grain weight (g), plant height (cm), spike length (cm) and numbers of grains per spike, a 1m-by-1m area was harvested within each main plot for all treatments.

The highest grain and straw yields were observed in the T_5 treatment (Urea+UI+Biofertilizer), with a grain yield of about 20, 11, 8% higher, compared to the T_2 (Urea), T_3 (Urea+UI) and T_4 (Urea+Biofertilizer) treatments, respectively. A significant difference between the T_2 and T_5 treatments could be observed with regards to grain and straw yields. However, the yields of the T_3 and T_4 treatments were not significantly different from both T_2 and T_5 treatments. There was also no significant difference in grain and straw yields and other parameters between the Urea+UI and Urea+Biofertilizer treatments. The number of grains per spike and the weight of 1000-grain in the Urea+UI+Biofertilizer treatment (T_5) showed an increase of about 20 and 11%, respectively, compared to the Urea treatment (T_2), but these increases were not significant. Plant height in treatments that received N fertilizer was not affected by fertilization treatments, but spike length was affected (Figure 2).

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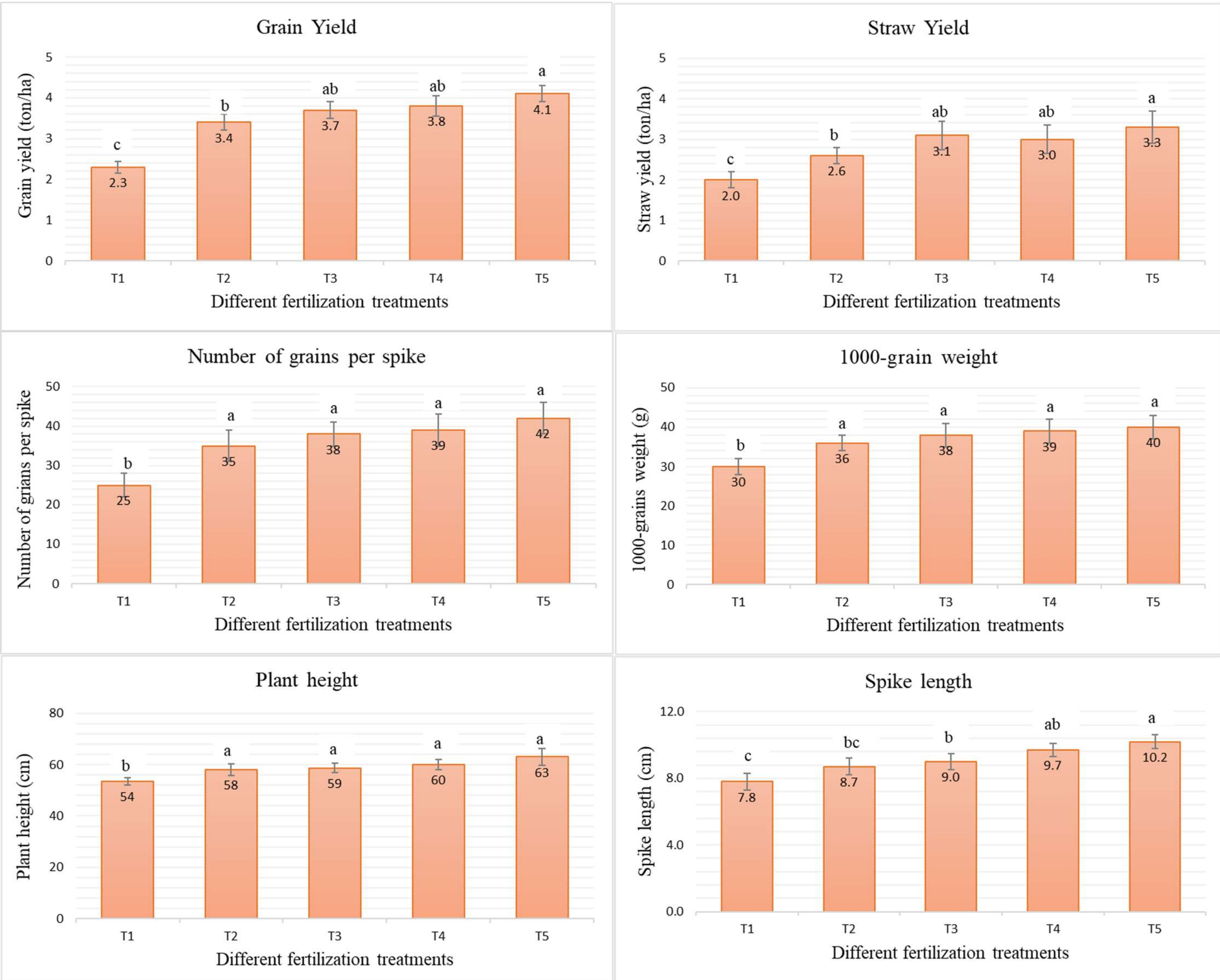

*Figure 2. The effect of different fertilization treatments (T_1: control treatment; T_2: Urea; T_3: Urea+UI; T_4: Urea+Biofertilizer; T_5: Urea+UI+Biofertilizer) on grain and straw yields, number of grains per spike, 1000-grain weight, plant height, and spike length. The vertical bars indicate the standard deviation. A mean comparison between fertilization treatments from Tukey's HSD-test indicates a significant difference at $p<0.05$. The same letters indicate groups that were not significantly different from one another. * UI: Urease Inhibitor*

Analytical Services

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In 2022, the SWMCN Laboratory analysed 9496 samples for stable isotopes and 73 samples for radionuclides. Most analyses were carried out for supporting Research and Development activities at the SWMCNL focused on the design of affordable isotope and nuclear techniques to improve soil and water management in climate-smart agriculture, to support soil conservation measures and combat soil erosion.

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Websites and Links

- Soil and Water Management and Crop Nutrition Section: https://www.iaea.org/topics/land-and-water-management
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