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Nuclear Techniques in Food and Agriculture

Soils Newsletter

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To Our Readers

Through the interregional technical cooperation project INT5156, the first Cosmic Ray Neutron Sensor was installed in the Himalayas of Nepal by the Tribhuvan University with technical support of Prof. Trenton Franz, USA. (photo credit: Franz, T., 2023)

As in previous years, several of the Soil and Water Management and Crop Nutrition (SWMCN) Laboratory staff, PhD students, interns and fellows presented their R&D work and achievements at the annual European Geosciences Union (EGU) held at the Austrian Center at the end of April 2023. A total of ten oral and poster presentations were presented. The SWMCN Laboratory's work on nitrogen management in agriculture was highlighted in the EGU session 'Field and laboratory experiments in Soil Science, Geomorphology and Hydrology research and teaching'. I thank everyone for their great work at the EGU. You can read more about their presentations in the newsletter.

The EGU week also brought along many Coordinated Research Projects (CRP) participants and visitors to us to discuss new collaboration. One of them is the possible collaboration with the Integrated European Long-Term Ecosystem, critical zone and socio-ecological Research (eLTER) community through SWMCN's European Technical Cooperation Project (TCP) on 'Improving Efficiency in Water and Soil Management'. The eLTER facilitates high impact research and catalyse new insights about the compounded impacts of climate change, biodiversity loss, soil degradation, pollution, and unsustainable resource use on a range of European ecosystems and socio-ecological systems. The idea is to achieve a synergy in building the environmental and agriculture-related data series by merging the eLTER and TCP monitoring sites, as the measurement schemes are complementary. The eLTER network is designed for measuring meteorological data, while the TCP will be measuring soil water content using cosmic ray neutron sensors. Integrating the two data sets will result in great added values for both eLTER and TCP partners.

Some interesting preliminary research on microplastics in agricultural soils was carried out in the SWMCN Laboratory where ^{13}C isotopes were used to track polylactic acid (PLA) degradation under different soil conditions (moisture, fertilizer application) to assess the carbon turnover and its contribution to greenhouse gas emissions.

Three feature articles showing new applications of gamma spectrometry for rapid assessment of soil organic carbon and other properties in agricultural soils, and cosmic ray neutron sensor in support to the eddy covariance flux tower in Congo basin forests, as part of a large campaign to quantify the net ecosystem exchange and water use efficiency of the surrounding lowland tropical forest, as well as on disentangling nitrate pollution sources and its apportionment in a tropical agricultural ecosystem using a multi-stable isotope model.

We are pleased to announce a new Springer book on 'Tracing the Sources and Fate of Contaminants in Agroecosystems Application of Multi-Stable Isotopes' which will be published very shortly.

We would like to welcome Iuliia Dorchenkova from the Russian Federation who just joined the SWMCN Laboratory in May for three months as a new International Centre for Theoretical Physics (ICTP)/IAEA fellow. Iulia will be working on Antimicrobial Resistance (AMR) R&D in agricultural soil, assessing the mineralization rates of ^{13}C-labeled sulfamethoxazole (SMX) using Cavity Ring Down Spectroscopy (CRDS) techniques. Iuliia Dorchenkova is currently working on her PhD thesis on the antibiotic activity of actinobacteria. We wish Iuliia the very best of her fellowship in the laboratory.

We would like to bid farewell to Emil Fulajtar who will be leaving the Agency end of May 2023, after completing seven years of service with the SWMCN Section. Emil has been our newsletter coordinator since he arrived and helped in the update of the SWMCN website. We will miss Emil's great contribution and his friendship, dedication to the Subprogramme. Emil managed many TCPs on soil erosion assessment using fallout radionuclides techniques (^{137}Cs, ^{210}Pb and ^{7}Be) and on the investigation of sediment sources with ^{13}C and ^{15}N stable isotopes. He also managed the CRP on 'Enhancing Agricultural Resilience and Water Security Using Cosmic-Ray Neutron Technology'. Best wishes from all of us, Emil!

The international symposium proceeding papers on 'Managing Soils for Food Security and Climate Change Adaptation and Mitigation' which was held in July 2022 are being compiled. It is hoped that the proceeding will be published in 2024.

This issue of the newsletter will be the last that I will be writing as Section Head, as I will be retiring in October after almost 24 years' rewarding and enriching service with the Joint FAO/IAEA Centre. I would like to thank all of you - my friends and colleagues, current and past, within and outside the IAEA and FAO, for all your support over the past many years when I was working in the Seibersdorf Laboratory, and as a technical officer in the Section and now as the Section Head, in delivering the outputs and outcomes to Member States together. I wish all of you the very best for the future and thank you for the opportunity to learn and work with you.

Lee Heng
Head
Soil and Water Management and
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J. Nakamya	**I. Dorchenkova**		

Staff News

Iuliia Dorchenkova (Russian Federation) is joining the SWMCN Laboratory from 1 May to 30 July as a new ICTP/IAEA fellow. She will participate in research related to Antimicrobial Resistance (AMR) in agricultural soil. Specifically, she will assess the mineralization rates of ^{13}C-labeled sulfamethoxazole (SMX) using CRDS techniques. Iuliia Dorchenkova graduated from Moscow State University with a bachelor's degree in 2018 and a master's degree in 2020 in Soil Science, with honors in both degrees. Since 2020 she has been working on her PhD thesis on the study of the antibiotic activity of actinobacteria and publishing articles , as well asparticipated in Russian and International conferences. . Iuliia has experience as a soil scientist. She worked with soil and ecological researches in many Russian cities: in the Krasnodar Territory, the Republic of Bashkiria and the Republic of Tatarstan. In 2020 Iuliia was working as a biology teacher in Moscow school. Since 2021 she has been working in Moscow State University as an ultratomy engineer in the Electron Microscopy Laboratory.

Emil Fulajtar (Slovakia), soil scientist based in the SWMCN Section, will be leaving the Agency at end of May 2023, after completing seven years of service with the SWMCN. Emil has been our newsletter coordinator since he arrived, contributing tremendously and ensuring the timely production of the newsletter. Emil has also been helping in the update of the SWMCN website for the past years, another contribution we will surely miss. With the field of expertise in soil science, in particular soil erosion, specializing in erosion assessment through the use of fallout radionuclides (FRN) techniques (^{137}Cs, ^{210}Pb and ^{7}Be) and the investigation of sediment sources with ^{13}C and ^{15}N stable isotopes, Emil managed many TC projects in particular on erosion, as can be seen on the TC project list in the newsletter. Emil is also the project officer for the D12014 CRP on Enhancing Agricultural Resilience and Water Security Using Cosmic-Ray Neutron Technology. In the earlier years, Emil carried out sediment dating using ^{13}C signatures on C_4 crops (such as maize and millet). Emil has a long association with the IAEA firstly through his participation in a CRP D15005 on “Assessment of Soil Erosion through the Use of ^{137}Cs and Related Techniques as a Basis for Soil Conservation, Sustainable Agricultural Production and Environmental Protection”, from 1996-2001, and later as a Technical Officer during a Special Service Agreement contract at SWMCN Section during 2006-2007. Before joining the IAEA, Emil worked as a research worker at the Soil Science and Conservation Research Institute (VUPOP) in Bratislava (1987-2001), later as a Science Officer of Cooperation in Science and Technology (COST) research networking programme at the European Commission (2001-2003) and the European Science Foundation (2003-2005). Mr Fulajtar has been the Head of the Soil Science Department at VUPOP from 2012-2016. He has extensive experience in the management of international research projects associated with agriculture and environment. We wish Emil the very best in his future career development.

Feature Articles

Developments in use of portable gamma spectrometry for rapid assessment of soil organic carbon and other properties in agricultural soils

Blake, W.H.[1], Kalnins,A.[1], Koot, M.[1], Jackson, R.[2], Toloza, A.[3], Said Ahmed, H.[3], Goddard, R.[1], Taylor, A.[1]

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A recent publication in the Journal of Soils and Sediments entitled 'Portable gamma spectrometry for rapid assessment of soil texture, organic carbon and total nitrogen in agricultural soils' by Taylor et al. (2023) demonstrates the new potential for mapping of agricultural soils using proximal gamma spectrometry.

The study was undertaken by scientists at University of Plymouth, UK, in collaboration with the Rural Business School at Duchy College who manage an experimental farm in southwest UK, and colleagues at the Soil and Water Management and Crop Nutrition Laboratory, in the Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture who are also undertaking similar technology trials in parallel (as reported in Soils Newsletter Vol. 45, No. 2, Jan 2023).

As reported in Taylor et al. (2023), the study aimed to evaluate the potential for using a portable gamma sensor (Medusa MS-700) to survey soil health parameters in agricultural fields against a background of growing interest in regenerative farming to enhance soil health, especially the amounts and quality of organic carbon in the soil. There is therefore a particular interest in rapid appraisal of spatial patterns in soil properties to inform farmers of variability in soil health and function within fields and across farms. Such information can support strategic decision making on where to focus regenerative practice efforts for maximum effect especially when resource is limited.

In this study, the capability for a Medusa MS-700 portable gamma spectrometer to evaluate activity concentrations of ^{40}K, ^{238}U, ^{232}Th and ^{137}Cs across agricultural fields was tested (Figure 1). It was hypothesised that the first three radioisotopes, that are geogenic in origin, would provide proxy information on key soil properties relevant to soil health via the interaction of their gamma emissions with soil components. To compare gamma spectrometry signals to soil properties, 90 soil samples were collected for laboratory analysis of soil organic matter (SOM) by loss on ignition (LOI), total C (TC) and N (TN), particle size, moisture content and bulk density. Linear regression was then applied to see if prediction models of soil parameters based upon radionuclide concentrations could be derived as an essential precursor to understanding how spatial pattern in gamma emission could be applied to support on-farm decision making. In this region, ^{137}Cs activity concentrations were largely below useful detection limits for the sensor at the movement rate deployed.

Figure 1. The Medusa MS-700 as deployed in the Taylor et al. (2023) ground-based trial. (photo credit: Kalnins, A., 2022)

The results of the study showed that this new technology has promise in supporting sustainable soil management. There was a notable correlation (Figure 2) between soil parameters and radionuclide concentrations. Relationships showed negative associations between the measured radionuclides and moisture content, LOI, TC and TN, with the strongest relationship seen for ^{40}K (rs >-0.8). As discussed by Taylor et al. (2023), the diluting effect of organic matter in relation to the gamma emitting parent material is a key factor underpinning the use of proximal gamma spectrometry as a tool for rapid evaluation of variability in SOM content. In addition, the attenuating effect of soil moisture on gamma emissions was considered in the study as a key factor which opens up other possibilities in application of this technology. In this study, correlations with soil texture properties (with coefficients <0.7) were generally less strong that those seen of SOM.

Proximal gamma spectrometry has clear potential as a decision support tool. Further work is required to understand better the versatility of this new tool and the specific requirements for successful deployment in a range of agro-climatic conditions and soil types. As discussed by Taylor et al. (2023), there is an excellent potential for rapid detection of soil properties across wide spatial scales to inform targeted measures for regenerative practice and the prediction models from this published exemplar dataset are encouraging. Of course, site-specific validation of sensor data is essential where quantitative information is required but semi-quantitative spatial patterns (e.g. Figure 3) can be of equal or greater value for on-site decision making and helping farmers visualise spatial variability in the health and quality of their soil asset.

Following this successful first trial, the team at University of Plymouth and the Joint FAO/IAEA Soil and Water Management and Crop Nutrition Laboratory are collaborating to expand these trials and lay the foundation for new protocols in applied proximal gamma spectrometry for rapid evaluation of soil health.

Reference:

Taylor, A., Kalnins, A., Koot, M., Jackson, R., Toloza, A., Said Ahmed, H., Goddard, R., Blake, W.H. 2023. Portable gamma spectrometry for rapid assessment of soil texture, organic carbon and total nitrogen in agricultural soils. Journal of Soils Sediments. doi.org/10.1007/s11368-023-03488-w

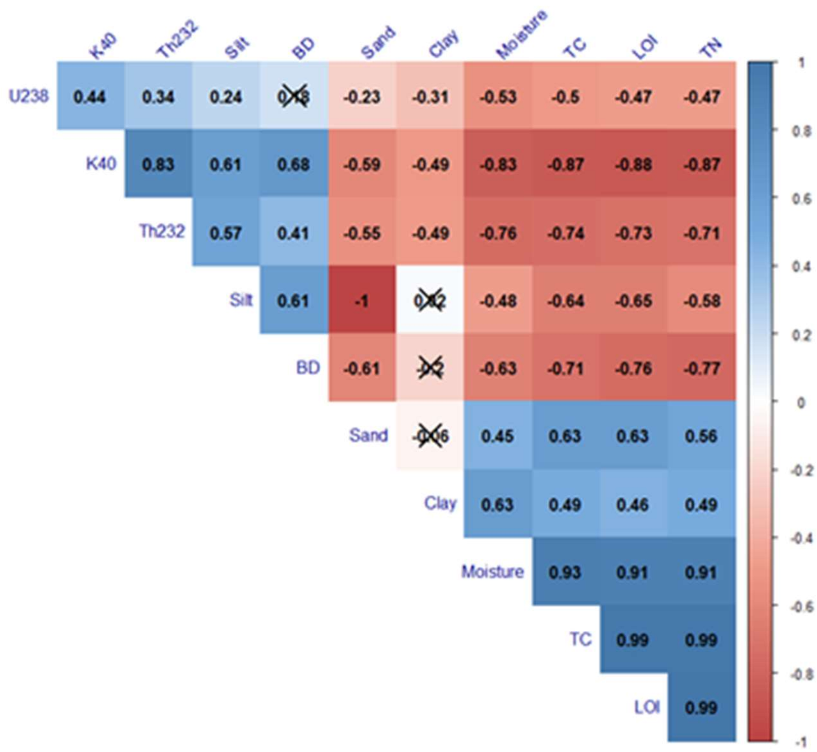

Figure 2. Spearman's Rank correlation matrix with correlation coefficient (rs) values shown. All values significant (p<0.05) except for those crossed through (from Taylor et al., 2023)

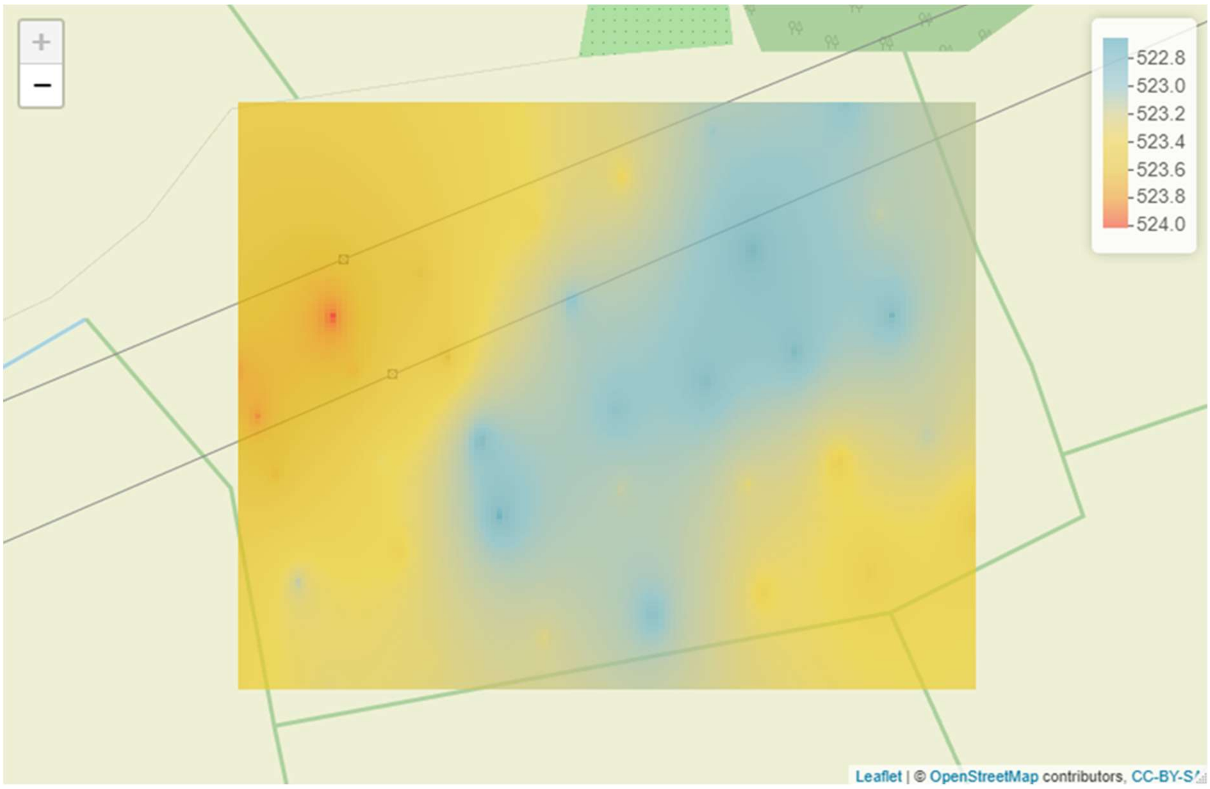

Figure 3. Example of spatial patterns in K-40 activity concentrations as estimated by proximal gamma a spectrometry in an agricultural field, southwest UK (unpublished data, University of Plymouth)

Cosmic ray neutron sensor in support to the first eddy covariance flux tower in Congo basin forests

Daelman, R., Lefevre, L., Kimbesa, F., Mbifo, J., Boon, G., Sibret, T., Meunier, F., Verbeeck, H., Bauters, M., Boeckx, P.

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The rainforest of the Congo Basin is the largest tropical rainforest in the world, next to the Amazon. With almost 200 M ha of humid forest, this region plays a critical role in the regional water cycle, the global carbon cycle and the continental greenhouse gas balance. Despite its importance, the region remains poorly studied and the knowledge of the ecology of the Congo Basin forests lags far behind that of the Amazon or the rainforests of Asia. The lack of observation data does not only limit our understanding of the current climate in this region but is also a major hurdle in projecting future climate change impact for these forests.

On the right bank of the Congo River, ca. 100 km northwest of Kisangani, the very first eddy covariance (EC) tower of the Congo basin has been installed by Ghent University. The EC tower is part of the CongoFlux climate site, installed in the INERA research center in Yangambi (0°48’52.0” N, 24°30’08.9” E), in the heart of the Congo Basin.

The CongoFlux EC tower measures the land-atmosphere exchange of CO_2 and H_2O, allowing to quantify the net ecosystem exchange (NEE) and the water use efficiency (WUE) of the surrounding lowland tropical forest. The NEE is the sum of the ecosystem respiration (Reco > 0) and the gross primary production (GPP ≤ 0). The latter separate components are more useful for Earth system modeling purposes than NEE, as they provide more information about the underlying processes of the net CO_2 flux. The partitioning of NEE into GPP and Reco is therefore an important step in the EC data processing and already various methods to handle this partitioning have been developed. Several techniques estimate respiration as a function of temperature, fitted with nighttime flux data. However, during the night in tropical forests, the temperature range is small, and the quality of flux data is low due to insufficient turbulence, which limits the applicability of these methods.

Figure 1. Cosmic ray neutron sensor CRS 2000/B (Hydroinnova LLC) (photo credit: Daelman, R., 2023)

Recently neural networks are being trained to partition the NEE, using micrometeorological variables like incoming shortwave radiation, vapor pressure deficit and soil water content as input data. Especially soil water dynamics can be an important factor to include as input data, as a large contribution of respiration (mainly during the night) comes from soil respiration, directly influenced by soil water and temperature. Several soil moisture sensors are placed around the EC tower, but they only monitor small areas, which makes it hard to obtain an area-averaged soil water content that is representative for the footprint of the EC tower.

Figure 2. Cosmic ray neutron sensor with two moderated and two bare sensors. (photo credit: Daelman, R., 2023)

To this end a cosmic ray neutron sensor (CRNS) has been installed in the footprint of the EC tower. The CRNS relates cosmic ray neutron intensity to water content, resulting in an area-averaged soil water content. In essence the CRNS is a hydrogen detector as hydrogen is the main element that slows down fast neutrons. Large hydrogen pools in the surrounding of the CRNS will therefore lower this neutron counting rate. This counting rate also decreases with latitude. The precision of the CRNS is mainly in function of the counting rate which means that the error in soil water content will increase with decreasing counting rates. To compensate for the low latitude and the large hydrogen pool in biomass and soil at the CongoFlux site, counting rate was increased by placing two moderated detectors instead of one. Furthermore, two bare detectors are included in the set-up.

To calibrate the measurements two large-scale sampling campaigns were carried out in March 2023. In each campaign soil samples were taken from six depths, on three different distances from the CRNS along six directions, resulting in 108 soil samples per campaign. The soil samples were placed in ziplock bags and dried and weighed within one week from the sampling day. The average soil water content is calculated as a depth and distance weighted average of the volumetric water content of the 108 collected soil samples. Regular recalibration does not seem to be necessary as the largest hydrogen pool like biomass, soil organic carbon and lattice water will remain relatively constant over time at the CongoFlux site. A small follow-up calibration is planned next year to see if this statement hold.

Figure 3. The CongoFlux Eddy Covariance tower installed in Yangambi, DR Congo (0°48’52.0” N, 24°30’08.9” E).
(photo credit: Sibret, T., 2020)

Disentangling nitrate pollution sources and apportionment in a tropical agricultural ecosystem using a multi-stable isotope model

Saka, D.[1,4], Adu-Gyamfi, J.[2], Skrzypek, G.[3], Ofosu Antwi, E.[4], Heng, L.[2], Torres- Martínez, J. A[5].

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 # Published in Environmental Pollution 328 (2023), funded through FAO/IAEA CRP D15018 research contract 121589:
https://www.sciencedirect.com/science/article/abs/pii/S0269749123005912

Due to the extensive use of N fertilizers to meet agricultural demand, nitrate (NO_3^-) concentrations have increased in many surface and groundwater systems. This has repercussions for human health and environmental sustainability as it impacts the quality of water sources. This study aims to (1) assess NO_3^- concentration and its spatial distribution using hydrochemical and multivariate statistical analysis, (2) disentangle NO_3^- sources and transformation pathways using stable isotopes ($\delta^{15}N_{NO3}$, $\delta^{18}O_{NO3}$), and (3) estimate the proportional contribution of the major NO_3^- sources to surface water and groundwater in the Densu River Basin (DRB) of Ghana using the Bayesian Mixing Model in R (MixSIAR). The study area and the hydrochemical data and water grouping is shown in Figure 1. Samples for $\delta^{18}O_{H20}$ and $\delta^{2}H_{H2O}$ were measured using a Liquid-Water Isotope Analyser (Model 908-008-2000) and $\delta^{15}N_{NO3}$ and $\delta^{18}O_{NO3}$ were determined using the denitrifying bacteria (*Pseudomonas auroeofaciens*) method and was analysed using an isotope ratio mass spectrometer. The MixSIAR Model was used to estimate the contribution of each nitrate pollution source to surface and groundwater in the study area.

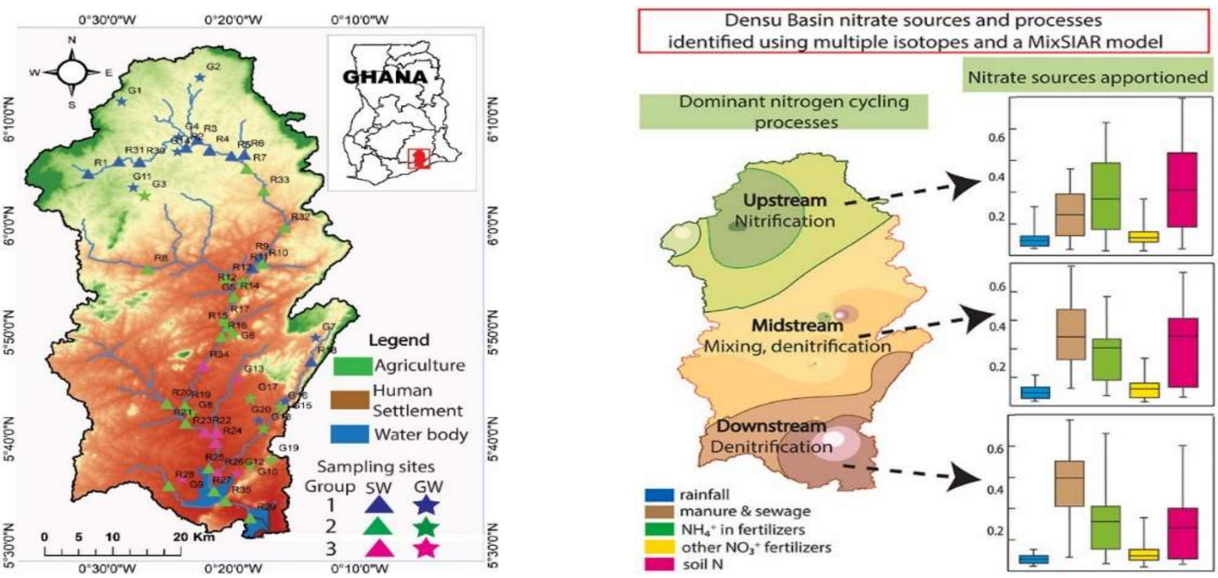


Figure 1. Study area, land use map of the Densu River Basin Ghana (left), and hydrochemical data and water grouping (right)

Results:

Waters in the studied catchment have variable concentrations of Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-, SO_4^{2-}, PO_4^{3-}, NO_3^-. The hierarchical cluster analysis (HCA) dendrograms reveal that surface water and groundwater samples can be clustered into three distinct groups. Group 1 consisted of sampling sites located in the pristine upstream zones of the study area. The river's middle course sampling sites are mostly clustered in Group 2. Six river points comprise Group 3, all located downstream of the Densu River before the river discharges into the Weija Lake. Surface water $\delta^{15}N_{NO3}$ values ranged from 2.5‰ to 19.8‰ and $\delta^{18}O_{NO3}$ ranged from -3.8‰ to 11.5‰. Groundwater had $\delta^{15}N_{NO3}$ ranging from 5.4‰ to 38.9‰ and $\delta^{18}O_{NO3}$ values between -2.7‰ and 19.3‰) (Figure 2).

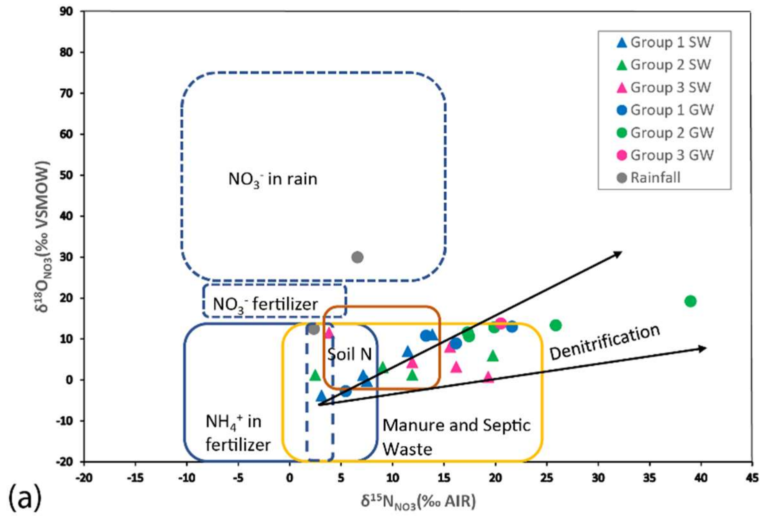


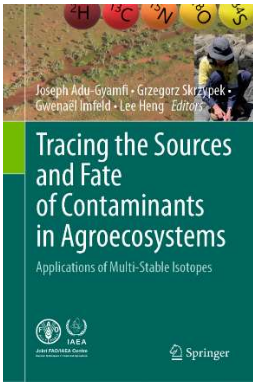
Figure 2. Plot of $\delta^{15}N_{NO3}$ and $\delta^{18}O_{NO3}$ showing the primary NO_3^- sources for surface water, groundwater, and rainfall samples.

Conclusions:

This study applied hydrochemical and statistical analysis to classify surface water and groundwater in the Densu Basin into three groups, which reflect the different land uses. Multiple stable isotopes ($\delta^{15}N_{NO3}$, $\delta^{18}O_{NO3}$ and $\delta^{18}O_{H2O}$) were used to disentangle five major nitrate sources. Nitrification was observed upstream, while denitrification was the leading biogeochemical process in the transition zone to downstream groundwater. However, widespread manure/sewage contamination of groundwater in the basin offsets the expected reduction in NO_3^- concentration by denitrification. Mixing of sources from the various tributaries contributed to the $\delta^{15}N_{NO3}$ and NO_3^- composition of the Densu River, resulting in relatively low NO_3^- levels midstream and an increase downstream. The MixSIAR model estimated NO_3^- fertilizers and soil N as main NO_3^- sources in the river upstream, where agriculture is the major land use activity. From midstream to downstream, manure/sewage emerge as the prominent NO_3^- source in the river, also reflecting the transition to peri-urban and urban land use. This study highlights the successful use of multiple isotope models with hydrochemical and statistical analysis for tracing NO_3^- sources and processes. The findings of this study would be useful particularly for water resources managers in the Densu Basin and for researchers in agricultural water management.

Announcements

Open Access new Springer book "Tracing the Sources and Fate of Contaminants in Agroecosystems Application of Multi-Stable Isotopes"



Pollution originating from agriculture, domestic water waste, mining sites, sediment and soil erosion, and other sources has a direct negative impact on human health and water, food, and natural environment quality. Solutes such as nutrients, fertilizers, pesticides, or their by-products disperse through natural ecosystem contaminating streams, rivers, lakes, and groundwater aquifers. Pollutants frequently increase downstream, and many agro-ecosystems are contaminated by multiple pollution sources, but traditional techniques based on chemical concentrations do not allow evaluation of the relative contributions from different sources. Complementarily to conventional monitoring, more advanced multi-tracer approaches are required. Stable isotope compositions of nitrates δ(15N)NO3, δ(18O)NO3, water δ(2H)H2O, δ(18O)H2O, sulphates δ(34S)SO4, δ(18O)SO4, phosphates δ(18O)PO4 and carbon δ(13CPOM or DIC) combined with advanced hydrochemical methods and models over the last couple of decades have become important methods in forensic investigations of water quality. There is also a need for method standardisation and the formulation of a scientific toolbox that assembles all the sampling and analytical techniques useful for identifying sources and transport of agro-pollutants for better understanding, managing, and improving soil, crop, surface, and groundwater quality.

The toolbox integrates multiple isotope tracers that provide information on the origins and pathways of multiple pollutants through agro-ecosystems, thereby providing more accurate guidance on mitigations. The objective of this book is to present protocols, methodologies, and standard operating procedures (SOPs) used for the identification of sources, transport, and fate of agro-contaminants and illustrate them with several case studies of successful applications. This book is structured into eight chapters covering (i) an overview of the book's content, (ii) guidelines for designing water sampling programmes, (iii) the use of mixing models applicable to tracers for water pollution studies, (iv) compound-specific isotope analyses to investigate pesticide degradation in agricultural catchments, (v) the use of stable oxygen isotope composition of phosphate to investigate phosphorous in soil-plant continuum, (vi) the use of stable sulphur isotopes to disentangle agro-pollutants from other contaminants, (vii) nuclear tools used in sediment source apportionment, and (viii) the conclusions and perspectives forward. The book offers up-to-date information, and we hope it will be a great source of information for students, researchers, and policymakers.

Looking for more participants for the WEPAL proficiency test

Proficiency Tests are an important tool for external quality control and provide confidence in the analytical performance of laboratories. The University of Wageningen, the Netherlands, organizes Proficiency Tests on ^{15}N and ^{13}C isotopic abundance in plant materials, the participation fee for one round per year for selected participants is covered by the IAEA. The Wageningen Evaluating Programs for Analytical Laboratories (WEPAL, http://www.wepal.nl) is accredited for the organization of Inter-laboratory Studies by the Dutch Accreditation Council.

The SWMCN Laboratory is currently looking for more stable isotope laboratories, who want to participate in one round of this yearly Proficiency Test free of charge. The applications are treated according to the principle "first come, first served", laboratories from developing countries are encouraged to apply.

Please send your application with a brief description of your stable isotope laboratory to Mr Christian Resch, ch.resch@iaea.org.

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 and L. Heng
Azerbaijan	AZB5004	Strengthening Best Soil, Nutrient, and Water Agricultural Practices for Cotton Production	M. Zaman
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
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 / J. Adu-Gyamfi
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 / J. Adu-Gyamfi
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 / M. Zaman
Honduras	HON5011	Implementation of Soil, Water and Nutrient Management for Sustainable Coffee Production in Honduras using Nuclear Technologies	E. Fulajtar / M. Zaman

Interregional project	INT5156	Building Capacity and Generating Evidence for Climate Change Impacts on Soil, Sediments and Water Resources in Mountainous Regions	G. Dercon
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	MAL5033	Strengthening national capacity in food and animal feed for food safety and security	L. Heng and FSC
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 / M. Zaman
Pakistan	PAK5053	Strengthening and Enhancing National Capabilities for the Development of Climate Smart Crops, Improvement in Animal Productivity and Management of Soil, Water, and Nutrient Resources Using Nuclear and Related Techniques	L. Heng with PBG and SIT
Palestine (T.T.U.T.J.)	PAL5011	Enhancing Food Security via Nuclear Based Approaches	E. Fulajtar / M. Zaman
Panama	PAN1002	Strengthening the Operation of the Panama Canal through Erosion and Sediment Transport Analysis using Nucleonic Control System Applications, Radiotracers and FRN and CSSI methodologies	E. Fulajtar / J. Adu-Gyamfi
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 / J. Adu-Gyamfi
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 / L. Heng
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	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 / 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 / L. Heng
Togo	TOG5004	Improving the Productivity of Crops and Agricultural Practices through Radiation Induced Mutation Techniques	E. Fulajtar / J. Adu-Gyamfi
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, 3-7 July 2023, Vienna, Austria. Hybrid.

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, 9-13 October 2023, Virtual.

Project Officer: J. Adu-Gyamfi

Other Events

COP28: United Nations Climate Change Conference, 30 Nov – 12 Dec 2023, Dubai, UAE.

Past Events

FAO/IAEA Events

Regional Training Course on Irrigation and Nutrient Management in Date Palm Cultivation under TC project RAS5089 (Enhancing the Sustainability of Date Palm Production in States Parties through Climate-Smart Irrigation, Nutrient and Best Management Practices), 6-11 November 2022 Kuwait

Technical Officer: H. Said

Eleven scientists from Jordan, Kuwait and Saudi Arabia participated in the regional training course on irrigation and nutrient management in date palm cultivation under the regional TC project RAS5089, held at the Kuwait Institute for Scientific Research (KISR). The training consisted of lectures, demonstrations, and field visits on different aspects of climate-smart irrigation management (based on evapo-transpiration calculation). Further, ^{15}N techniques were discussed to enhance nitrogen use efficiency.

Participants of RAS5089 Regional Training Course on Irrigation and Nutrient Management in Date Palm Cultivation
(photo credit: Said Ahmed, H., 2022)

Regional Training Course on High-resolution soil moisture monitoring using Cosmic Ray Neutron Sensor and remote sensing digital technology under RAF5086 (Promoting Sustainable Agriculture under Changing Climatic Conditions Using Nuclear Technology), 21-25 November 2022, Rabat, Morocco.

Technical Officer: H. Said

Twenty-two participants from fifteen African Member States participated in the training course on high-resolution soil moisture monitoring through combining nuclear and digital technology, held at the Centre National De L'énergie, Des Sciences Et Techniques Nucleaires (CNESTEN) in Rabat, Morocco. The training consisted of lectures on how to develop and use a high-resolution soil moisture map based on Cosmic Ray Neutron Sensor (CRNS) and remote sensing imagery (Sentinel) information.

Participants of RAF5086 Regional Training Course High-resolution soil moisture monitoring using Cosmic Ray Neutron Sensor and remote sensing digital technology
(photo credit: Said Ahmed, H., 2022)

Coordinated Research Projects

Project Number	Ongoing CRPs	Project Officer
D12014	Enhancing Agricultural Resilience and Water Security Using Cosmic-Ray Neutron Technology	E. Fulajtar, L. Heng 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 use of 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:

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 guidelines. The time during the lockdowns and home office periods was exploited very efficiently for writing a number of publications and also preparing inputs for the first volume of CRNS guidelines which will be major output of the project. The draft manuscript was submitted in January 2023. Meanwhile the work on testing GRS for soil moisture management began in autumn 2021. Another achievement is testing the FINAPP Probe (newly constructed CRNS device which does not need Helium) and comparing its results with traditionally used CRNS (Hydroinnova).

In January 2023 the mid-term evaluation of CRP was successfully done. The main achievements of CRP are summarized as follows:

- Developing CRNS data processing tools
    - The CRNS Excel Spreadsheet for small data sets processing
    - The crspy software tool for large data sets processing (software tool designed in Python programming language)
    - The algorithm for neutron count signal smoothening by noise filtering
- Testing new soil moisture monitoring techniques
    - The new CRNS equipment (FINAPP) which does not need Helium
- Developing agriculture added value soil moisture products
    - The algorithm for root zone soil moisture estimation
    - The algorithm for rainfall estimation from CRNS data
- Approach using CRNS data for validating the remote sensing (Sentinel-1) soil moisture products and constructing high resolution soil moisture maps

The achieved result were published in number of publications:

- In total 23 research papers were published in international scientific journals.
- The significant progress in methodological development of CRNS technology were summarized in CRNS guidelines: “Cosmic-Ray Neutron Sensing: Applications in Agricultural Water Management” (Springer).

The Final meeting is planned for spring 2024.

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 (δ18O, δ2H, δ13C, δ15N, δ13C-DIC, δ15N-NO3, δ18O-NO3, δ18Op, δ34S) 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:

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).

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:

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.

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.

The CSIA (δ13C and δ15N) 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.

δ34S(SO4) and δ18O(SO4) for partitioning different sources of pollutants from household waste and from mining areas in the catchment tested [Nambeelup Brook, W. Australia].

Combined use of (δ18O and δ2H) and FRN-based sedimentary geochronology was used to assess the contribution of sediment source apportion to pollution [UK, Tanzania, China and Chile].

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.

An article "Simple extraction methods for pesticide compound-specific isotope analysis from environmental samples" has been published (https://doi.org/10.1016/j.mex.2022.101880)

A Special Issue on "Multi Isotope fingerprints to identify sources and fate of agro-contaminants on water quality in the environment" in the Journal of Environmental Research is planned for December 2023.

The Final RCM is planned for 9-13 October 2023 will held virtually.

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 preliminary results on predicting cesium dynamics and uptake using Mid-Infrared, which was carried in 2023 at the SWMCN Laboratory, was presented at the EGU2023 in Vienna (See Figure 1). The final RCM is planned for 2024.

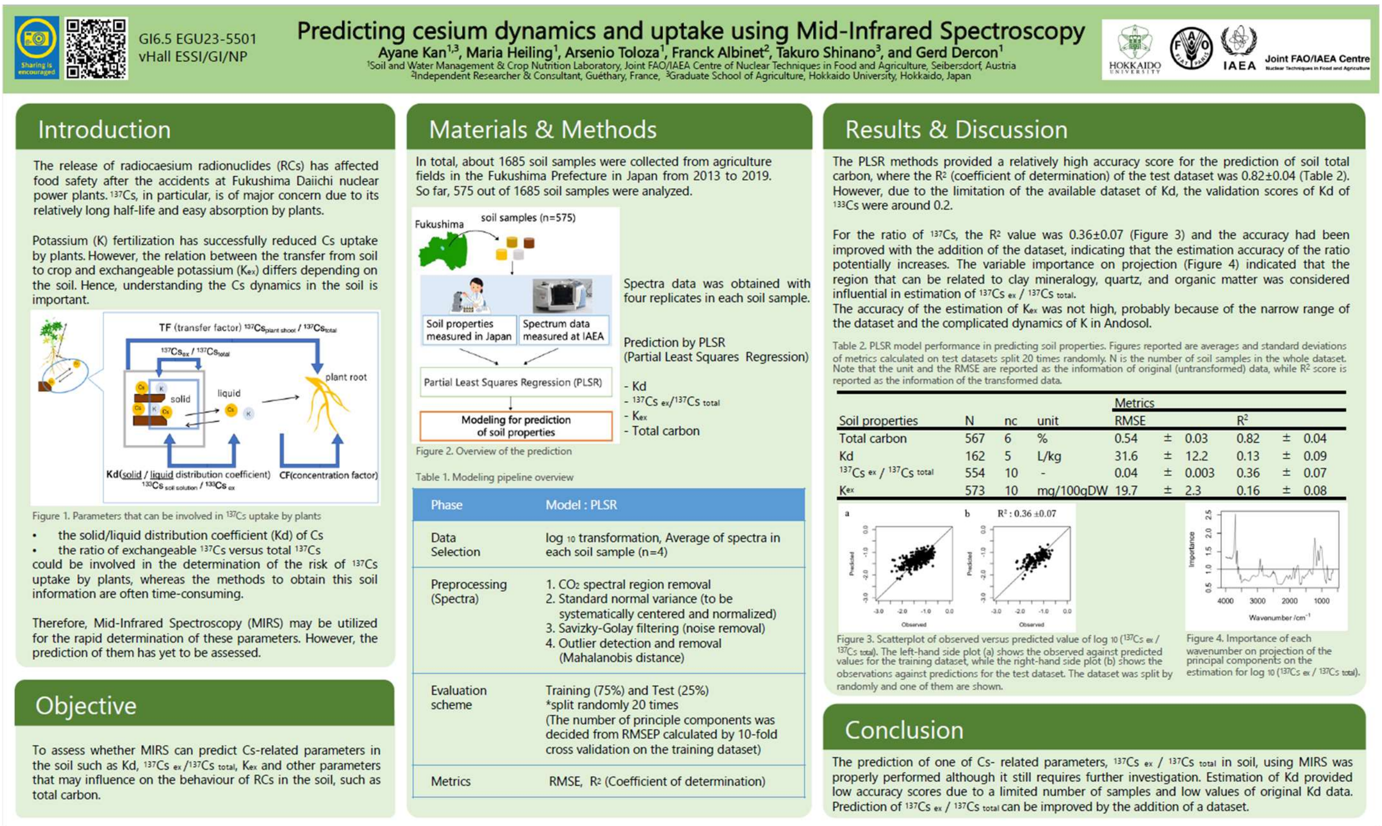


Figure 1. Poster presentation on predicting cesium dynamics and uptake using Mid-Infrared Spectroscopy at EGU2023, Vienna.

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. The objectives of this CRP are to develop and validate climate-smart agricultural (CSA) practices, based on isotopic and related techniques, to increase soil carbon (C) sequestration, mitigate GHG emissions and limit gaseous losses of ammonia (NH3) and dinitrogen (N2) from agricultural ecosystems, with the aim to enhance agricultural productivity and sustainability. Results from field trials provided significant insights on factors influencing emissions of GHGs, NH3 volatilisation, C sequestration and crop productivity. The Technical University of Madrid developed and validated a novel field method to measure NH3 volatilisation 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 participants. Field results from Brazil reported that mixed planting of legumes with pasture increased pasture and livestock productivity, improved animal feed quality, reduced emission of NH3 and N2O (37% reduction) and increased C sequestration (10 Mg C ha-1 in 0 to 30 cm). Bangladesh for the first time identified microbial process of N2O production using 15N tracing technique and CSA for increased rice production with lower environmental footprints. Field studies from China provided important insights on 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. In a field study, Ethiopian scientists reported that the combined use of compost and mineral fertilisers at smallholder farms increased soil fertility, nitrogen use efficiency, and maize yields and reduced GHG emissions compared to chemical fertiliser application. In another field study, researchers in Ethiopia reported that agroforestry practices and on-site charcoal production enhanced soil fertility and soil C sequestration. Researchers in Viet Nam developed CSA practices which led to reduced emissions of GHGs and NH3 volatilisation as well as increased C sequestration. Justus Liebig University developed an automatic system with Cavity Ring Down Spectroscopy (CRDS) to measure GHGs and their isotopic signatures.

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. Six member states are participating in this CRP including five research contract holders from Brazil, China, Ghana, Kuwait, and two technical contract holders from Germany. The first research coordination meeting (RCM) to discuss workplans with the participants and to develop an overall workplan to establish the project's objectives is planned for 3 to 6 July 2023 in Vienna, Austria. All the research and technical holders including one observer each from the IAEA Marine Environment Laboratories in Monaco, FAO in Rome, China (Chinese Academy of Sciences), and Germany (Technical University of Munich) are expected to participate in the RCM.

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. To date, extraction protocols for (1) SMX in soil and plant (lettuce) samples and, (2) DNA extraction and analysis from soil and water samples has been developed and sent to all participants who will also receive synthesized SMX labelled-13C compound for field trials in July 2023. The second RCM will be held in China during Q2 2024.

Developments at the Soil and Water Management and Crop Nutrition Laboratory

Sharing SWMCNL's research progress at the 2023 European Geosciences Union (EGU) General Assembly in Vienna, Austria

Dercon, G.[1.]

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Mathilde Vantyghem presenting results from the 13C labeling experiment in banana during the "Carbon allocation in plants and ecosystems" session at EGU

From 23-28 April, the EGU23 General Assembly welcomed 18,831 registered attendees, of which 15,453 made their way to Vienna from 107 countries and 3,378 joined online from 105 countries. In total 16,357 presentations, through 938 sessions, were given in this unique opportunity for scientific sharing and global networking. The SWMCN Section and Laboratory's activities were reported in presentations covering topics in area-wide soil moisture monitoring, climate resilient crop production, remediation of radioactive contamination of agricultural land and isotope approaches to tracing pollutants. Three staff members, one PhD student, two interns, and one fellow attended the conference to share their research work performed in the past years. The SWMCNL's work on nitrogen management in agriculture was highlighted in the EGU session SSS11.3 on 'Field and laboratory experiments in Soil Science, Geomorphology and Hydrology research and teaching'. Details of contributions from the SWMCN Section and Laboratory can be found in the publication list at the end of this Newsletter while more information regarding EGU 2023 can be found at: http://www.egu2023.eu. The EGU General Assembly reconvenes at the ACV in Vienna & online as EGU24, 14–19 April 2024.

Enhancing Wetland Conservation Efforts through High Resolution Soil Moisture monitoring using C-Band Sentinel and Cosmic Ray Neutron Sensor in the Andes of Bolivia

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In the Andes region of Bolivia (Potosi), wetlands form unique ecosystems that provide a range of vital ecological services, including water regulation, biodiversity conservation, and carbon sequestration. However, climate change is having a significant impact on these ecosystems highlighting the need for effective conservation efforts. One approach to enhance wetland conservation is through the use of advanced monitoring technologies such as high-resolution soil moisture monitoring using Cosmic Ray

Neutron Sensor technology integrated with C-Band Sentinel satellite imagery.

C-Band Sentinel is satellite imagery used for a wide range of applications, including land and water management in agriculture. In wetlands, C-Band Sentinel data can be used for soil moisture monitoring.

The Cosmic Ray Neutron Sensor (CRNS) technology used to estimate soil moisture (SM) content at the landscape level (up to 20 to 30 ha). This technology has proven to be a valid, robust technology able to support decision making in agricultural water management. Additionally, the CRNS technology fills the critical gap between satellites and point-scale ground sensors. By doing so, it allows for the calibration of microwave earth observation satellites data and improve the accuracy of water content data estimated by remote sensing (Said et al., 2021).

Therefore, under the IAEA TC INT5056 on “Building Capacity and Generating Evidence for Climate Change Impacts on Soil, Sediments and Water Resources in Mountainous Regions”, the SWMCN laboratory worked with the Universidad Mayor de San Andrés (UMS) in Bolivia on high-resolution soil moisture mapping by combining CRNS data and remote sensing data (C-Band Sentinel 1).

In the Bolivian Andes, close to the capital La Paz, a CRNS and a low-cost weather station were installed in the Huayna Potosi watershed, above 4000 m a.s.l. (the highest CRNS in the world). This watershed is essential for providing drinking and irrigation water for the region of El Alto-La Paz (Figure 1).

The soil moisture information produced by the CRNS will be used as part of an early warning system on drought and flooding prediction for the cities of El Alto and La Paz. Besides its use in the planned early warning system, the real-time high-resolution soil moisture map (Figure 2) can be used to monitor wetland areas and provide more comprehensive understanding of wetland ecosystems and dynamics, how they are changing over time. This information is crucial to identify areas of wetland ecosystems that are under stress and to develop targeted conservation strategies helping to ensure their long-term sustainability and resilience in the face of ongoing climate threats.

Reference:

Said, H., Mbaye, M., Heng, L. K., Fulajtar, E., Weltin, G., Franz, T., Dercon, G., Strauss, P., Rab, G., Saud Al-Menaia, H., Ndiaye, M. (2021) High-resolution soil moisture mapping through the use of Cosmic-Ray Neutron Sensor and Sentinel-1 data for temperate and semi-arid environments. EGU General Assembly 2021. Abstract EGU21-9688. https://doi.org/10.5194/egusphere-egu21-9688.

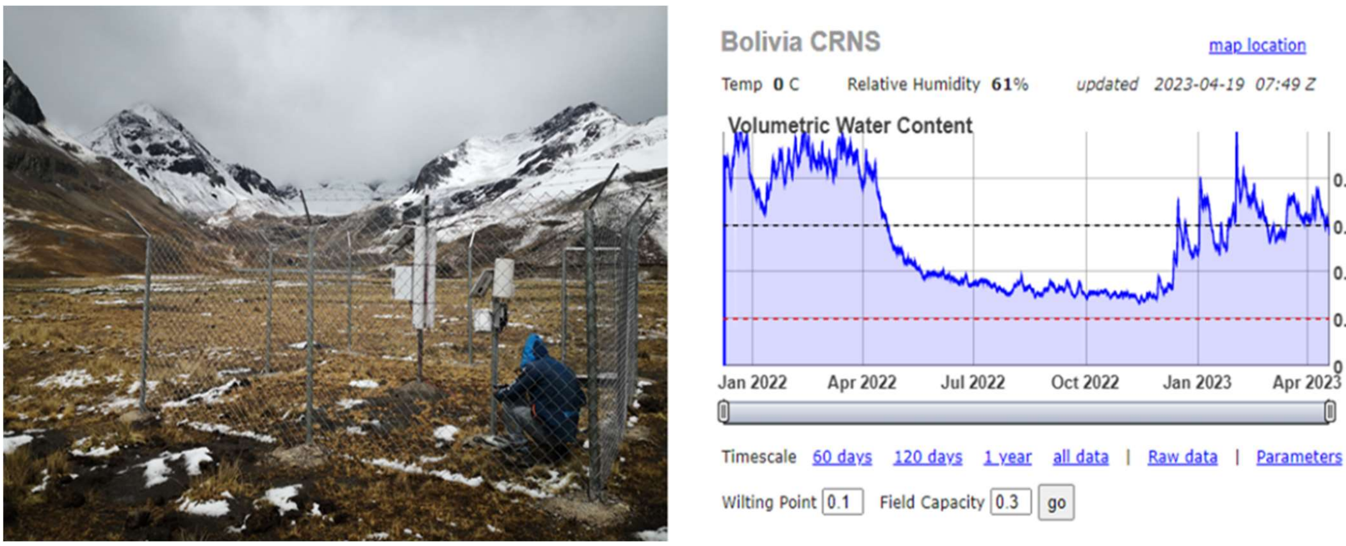

Figure 1. Cosmic Ray Neutron Sensor and low-cost weather station installed in the Huayna Potosi watershed in Bolivia (left) (photo credit: Ramírez, E., 2023), soil moisture data from CRNS (right).

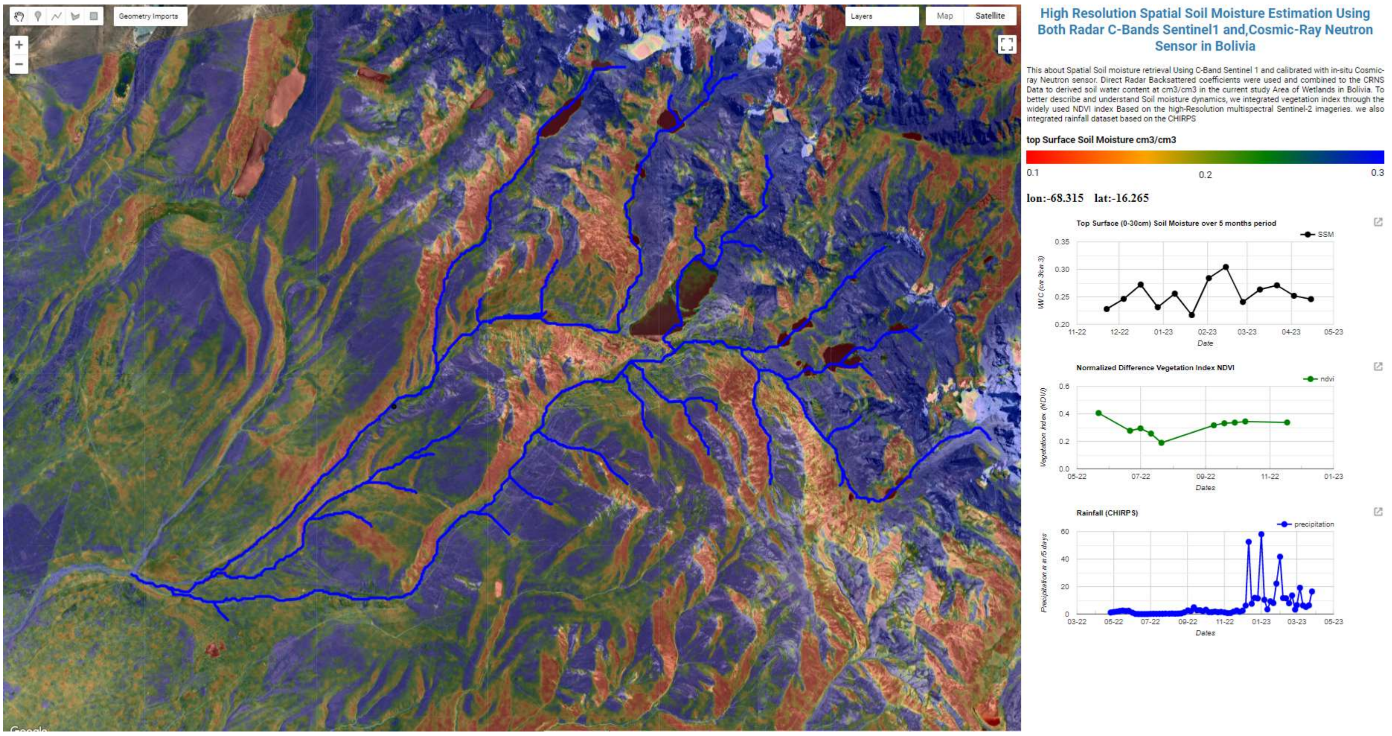

Figure 2. High-resolution soil moisture map retrieved using the sentinel-1 imagery combined with CRNS data in Huayna Potosi watershed, Bolivia.

Enhancement of Fertilizer Use Efficiency in Date Palm using ^{15}N Techniques

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Date palm (Phoenix dactylifera L.) is a major crop contributing significantly to food security in the Gulf countries. Heavy and frequent irrigations used in date palm cultivation result in leaching of available nutrients from the root zone, thereby, negatively impacting productivity and product quality. Hence, under the IAEA Technical Cooperation project RAS5089 (Enhancing the Sustainability of Date Palm Production in States Parties through Climate-Smart Irrigation, Nutrient and Best Management Practices (ARASIA)), studies were conducted at the Kuwait Institute for Scientific Research (KISR) to adapt Nitrogen-15 techniques for assessing nitrogen use efficiency by date palm. In particular, the team aimed at determining the optimum N-15 enrichment of the used urea fertilizer and identifying the index plant tissue to monitor the absorption and recovery of 15N. For this purpose, eight-year-old 'Siwi' date palms growing in a sandy loam soil and irrigated with treated wastewater were given either ^{15}N enriched or normal urea (100g N/plant/year) along with basal application of fixed doses of other nutrients and micro-nutrients (Figure 1). ^{15}N enriched urea was applied through two equal splits, either in January 2021 (first split) or in April 2021 (second split). The study showed that both the lamina and complete leaflet (both lamina and midrib) from the centre of the 3rd or 4th frond (positions 1 or 2 in Figure 2) from the apex to be the most suitable index tissue for monitoring 15N absorption and recovery of applied 15N in date palms. This was based on the Ndff (Nitrogen Derived From Fertilizer, %) ratio in variously situated leaves (Figure 2). Similarly, 15N recovery (19.7 - 22.7 in lamina and 17.7 - 21.0 Ndff (%) in four samples collected at monthly intervals was higher in the 3rd and 4th fronds. The first split application given in January 2021 showed significantly higher 15N utilization (17.2 - 22.4 in lamina and 16.2 - 20.5 in lamina and midrib) than the second split application in April 2021 (6.7 - 13.3 in lamina and 6.5 - 12.5 Ndff %) thereby suggesting scope for using higher initial N dose than that in subsequent doses (say, in 60:40 or 75:25

proportions). N recovery (18.4 Ndff %) was higher in fruits from plants that were provided with 1% a.e 15N urea than those provided with 2% a.e 15N, although the level gradually declined over time (from 20.0% in June to 14.1% September). In general, 9.4-20.4% recovery of the applied 15N recorded in this study is considered very good. Significant portion of applied ^{15}N fertilizer (7.0-13.3%) found in trunk and root tissues at the termination of the study points to the establishment of a nutrient reservoir for subsequent years. The greater proportion of applied N from the first application was utilized by the plant compared to that from the second. The results also indicated good scope to relook the number of split applications for enhancing fertilizer use efficiency of N fertilizer.

Figure 1. Application of ^{15}N urea in the trench (photo credit: Thomas, B., 2021)

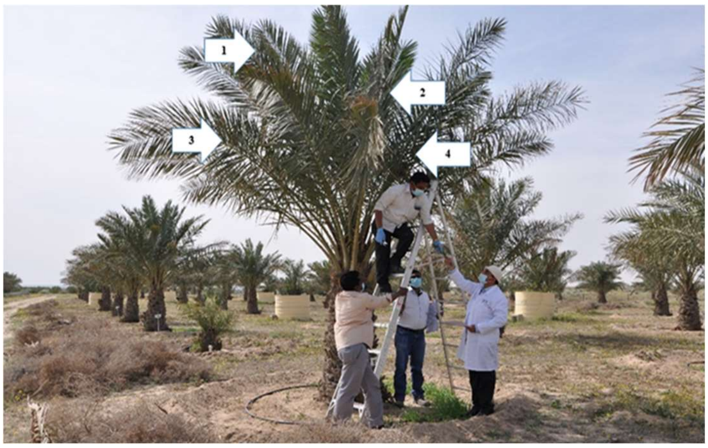

Figure 2. Scheme of sampling fronds under different split application of N (photo credit: Thomas, B., 2021)

First split application	1 (Frond 1)	Second split application	2 (Frond 2)
	3 (Frond 3)		4 (Frond 4)

Microplastics in agricultural soils: A new field for stable isotopes application

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Plastics (P) and microplastics (MP) have become major environmental pollutants in aquatic and terrestrial systems with potentially strong effect on global carbon (C) pools and fluxes [Rillig et al., 2021)]. Soils play an important role as the source and sink of these polymers. The effects of P and MP on soil microbial organisms and ecosystems are still not fully explored and analytical methods need to be developed. Stable isotopes can be used to study processes such as degradation or mineralization of MP, specially of biodegradable materials. Carbon isotopes can be used to track products of decomposition, to determine the rate of degradation under different soil conditions (temperature, moisture, fertilizer application), and to assess C turnover and the contribution to greenhouse gas emissions.

To assess the influence of the effect of nitrogen (N) and plastic particle size on the degradation of polylactic acid (PLA), a polymer which is used to produce degradable plastic products, an incubation experiment was conducted at the SWMCN Laboratory in 2022. We expected positive effect of N addition on PLA degradation rate since most C polymers and plastics are N poor and N could be a limiting factor of their degradation in soils [Guliyev et al., 2023]. The used PLA originated from sugar cane (C4 plant) with a $\delta^{13}C$ value of -10‰. We used cryo-grinding followed by sieving to 100-250 µm, 250-500 µm and 500-1000 µm to gain 3 kind of particle size fractions.

Treatments included two N levels (0 and 500 kg $N.ha^{-1}$), three PLA particle sizes and control treatments (without PLA). The soil (20g Cambisol from Grabenegg, Lower Austria, sieved to 2 mm) was incubated at constant moisture and temperature (60% water holding capacity, 22 ºC). PLA granules of 100-250µm, 250-500 µm and 500-1000 µm were added at the same carbon concentration as the soil (400mg PLA per 20g air dry soil in 100mL jars, hermetically closed). The CO_2 fluxes and isotope ratios of the emitted CO_2 was determined using a laser CRDS analyzer (Picarro 2201-i). A mixing model approach was used to estimate the amount CO_2 derived from PLA, which was used as indicator of PLA degradation.

Within 48 days of incubation, we did not observe any enrichment of respired CO_2 by ^{13}C of applied PLA, evidencing that no PLA was degraded in this period. However, the addition of N strongly affected CO_2 production rate from soil (Fig. 1) and $\delta^{13}C$-CO_2 (data not shown). The main effect of N addition was highly significant, $P<0.001$. In all the treatments, N addition reduced CO_2 accumulation rate. The main effect of plastic particle size was also significant ($P<0.001$) and interacting with the effect of N ($P<0.03$) because the effect of treatments was only observable when no N was added (Fig.1).

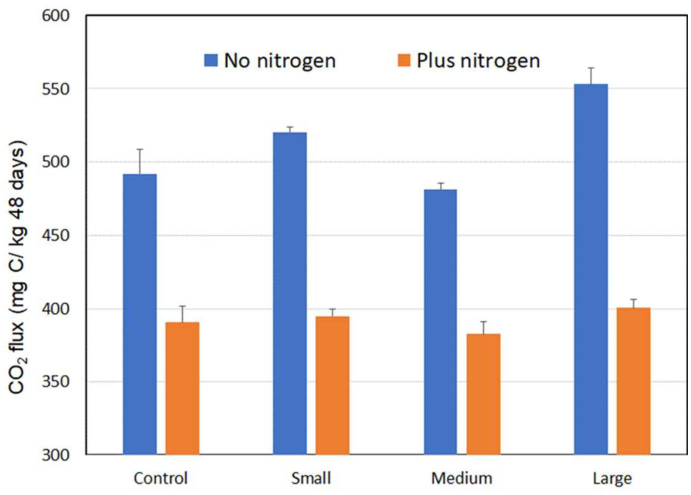

Figure 1. The effect of N addition on the amount of CO2 emitted over 48 days incubation from soil samples treated with microplastics of three different sizes and control without microplastics (Mean+SE, n=3)

Our analysis revealed significant difference in CO2 produced between control soil and soil with large size plastic addition (Fig.1) ($P<0.01$). This means that addition of large size microplastics accelerated decomposition of soil organic matter probably due to improvement of aeration. This is important result, showing that microplastic even without being decomposed can affect the fate of soil carbon by accelerating C decomposition rates. The effect of microplastic size on soil C turnover processes was largely ignored [Iqbal et al., 2020] and this is the first study where a significant effect of microplastic size is documented.

Summarizing the results, no PLA biodegradation within 48 days of soil incubation was observed. PLA is a bioplastic, produced from biomaterial, which is a degradable plastic, but this happens probably only in industrial reactors under high temperature. We showed here that PLA is not biodegradable under our investigated soil conditions.

PLA is a cheap plastic easily available on the market and has an isotopic signature of carbon around -10‰, which is well distinguishable from soil $\delta^{13}C$ values. If PLA would be biodegradable in soil, it would make PLA an ideal candidate to become a global standard for plastic decomposition studies. In further studies, we aim to use ultrasonication, to mimic the ageing of PLA plastic [von der Esch et al., 2020], and so to reduce the hydrophobicity of the PLA granule surface, trying to make PLA decomposable in soils.

References:

Rillig, M.C., Leifheit, E., Lehmann, J., 2021. Microplastic effects on carbon cycling processes in soils. PLoS Biology 19(3), e3001130. doi:10.1371/journal.pbio.3001130

Guliyev V, Tanunchai B, Udovenko M, Menyailo O, Glaser B, Purahong W, Buscot F, Blagodatskaya E. Degradation of Bio-Based and Biodegradable Plastic and Its Contribution to Soil Organic Carbon Stock. Polymers. 2023; 15(3):660. https://doi.org/10.3390/polym15030660

Iqbal, S., Xu, J., Allen, S.D., Khan, S., Nadir, S., Arif, M.S., Yasmeen, T., 2020. Unraveling consequences of soil micro- and nano-plastic pollution on soil-plant system: implications for nitrogen (N) cycling and soil microbial activity. Chemosphere 260, 127578. doi:10.1016/j.chemosphere.2020.127578

von der Esch E, Lanzinger M, Kohles AJ, Schwaferts C, Weisser J, Hofmann T, Glas K, Elsner M and Ivleva NP (2020) Simple Generation of Suspensible Secondary Microplastic Reference Particles via Ultrasound Treatment. Front. Chem. 8:169. doi: 10.3389/fchem.2020.00169

^{13}C labeling unravels carbon dynamics in banana between mother plant, sucker and corm under drought stress

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Banana plants being labeled with 13C in the growth chamber in the Seibersdorf greenhouse facilities. (photo credit: Vantyghem, M., 2021)

In 2021, an experiment on carbon allocation in banana was conducted in the greenhouse facilities of the SWMCNL in Seibersdorf (Austria), as part of the Peaceful Uses Initiative (PUI) project on "Enhancing climate change adaptation and disease resilience in banana-coffee cropping systems in East Africa" (2019). The results from this experiment have now been published in Frontiers in Plant Science, a high-impact peer-reviewed journal https://www.frontiersin.org/articles/10.3389/fpls.2023.1141682/full.

Banana (Musa sp.) is a perennial plant. As such, the yield in a certain year also depends on the plants' performance during the past years. Carbon translocation processes are what link these different generations, and understanding these processes is therefore essential for obtaining continuously high yields over time. In the experiment, it was found that drought stress affects carbon allocation in banana, whereby less energy is invested in the daughter plant i.e. the next generation when drought occurs. Moreover, the combination of drought stress and the presence of a daughter plant cause the main plant to invest less in long-term storage of carbon, making the plant less resilient. These findings were obtained through labeling with enriched stable isotope ^{13}C and innovative methodologies. By using isotopes, we were able to quantify the carbon dynamics in banana for the first time. Despite their importance, these processes remain poorly understood in perennial plants. The methods we employed can be transferred to other plants which could be a starting point for improving the resilience and sustainability of perennial farming systems.

Carbon allocation in cassava is affected by water deficit and potassium application – A ^{13}C-CO_2 pulse labelling assessment

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In January 2023, an article was published in Rapid Communications in Mass Spectrometry, in which carbon allocation of young cassava plants undergoing water stress and potassium deficiency was assessed by the use of stable carbon isotope labelling (^{13}C-CO_2). This research was conducted at the Soil and Water Management and Crop Nutrition greenhouse and laboratory with support from the Belgian government through the Consortium for Improving Agriculture-based Livelihoods in Central Africa (CIALCA, www.cialca.org). The article is open access under the following link (https://doi.org/10.1002/rcm.9426) and the abstract is given here:

Rationale: Cassava production faces challenges in a changing climate. Pulse labelling cassava with ^{13}C-CO_2 has the potential to elucidate carbon allocation mechanisms of cassava under drought stress and with potassium application. Understanding these mechanisms could guide efforts to mitigate effects of drought in cassava cropping systems.

Methods: Forty-eight cassava plants received a nutrient solution high or low in potassium. Water deficit was imposed on half of the plants at bulk root initiation stage, after which they were labelled for 8 h with ^{13}C-CO_2 in a 15 m3 growth chamber. Plants were harvested 8 h, 9 days and 24 days after labelling, and separated into leaves, stems and roots. The $\delta^{13}C$ values of the different parts were measured using an isotope ratio mass spectrometer, from which ^{13}C excess was calculated.

Results: Water deficit decreased transpiration ($P< 0.001$) and increased carbon respiration ($P< 0.05$). Potassium application increased assimilate distribution to the roots ($P< 0.05$) at 9 days after labelling, more strongly for plants under water deficit. The opposite was found at 24 days ($P< 0.05$) with the legacy of water deficit additionally increasing assimilate distribution to roots ($P< 0.05$). Youngest, fully expanded leaves contained up to 47% of initial ^{13}C excess at 24 days after labelling.

Conclusions: Pulse labelling proved to be successful in shedding light on carbon allocation in relation to water and potassium availability. This technique, once adapted to field conditions, could further be used to improve fertilizer recommendations or change agronomic practices to cope with plant stress.

Cassava plants growing in the field in the East of the Democratic Republic of Congo, a target area for the CIALCA project. (photo credit: Van Laere, J., 2022)

Cassava plants were labelled with ^{13}C-CO_2 in a walk-in growth chamber in the SWMCN greenhouse in Seibersdorf. (photo credit: Van Laere, J., 2021)

Impact of urease inhibitor and biofertilizer application on nitrous oxide emissions

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Nitrous oxide (N_2O) is a powerful greenhouse gas and has a severe effect in depleting stratospheric ozone. Sufficient nitrogen (N) fertilizer should be used to meet the global food demand but field application of synthetic N fertilizers is the most important source of anthropogenic emission of N_2O. Therefore, new innovative management strategies are needed to reduce N_2O emissions while increasing crop production.

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 in the east of Vienna, to determine the effect of urease inhibitor and biofertilizer on N_2O emissions (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: T1 (control treatment - without N fertilizer), T2 (Urea only), T3 (Urea+Urease Inhibitor (UI)), T4 (Urea+Biofertilizer), T5 (Urea+UI+Biofertilizer). All treatments received 50 kg N ha^{-1} at tillering stage (GS 31), except T1. In this study N-(n-butyl) thiophosphoric triamide (nBTPT) or “Agrotain” was used as UI and Azotobacter chroococcum or “AZOTOHELP” was used as biofertilizer.

Soil N_2O gas fluxes were measured using the static chamber method, eight times between 3 to 84 days after fertilizer application. Gas sampling was performed at the same time each day of measurement, between 8:00 and 10:00 h, to minimize diurnal variation and better represent the mean daily fluxes. A PVC chamber (24 cm height and 24 cm diameter) was inserted into the soil 5 cm deep. The chamber was composed of two separate parts joined together with an airtight rubber band. Gas samples were taken at 0 and 30 minutes after closing the chambers using a 500 mL syringe. The gas sample was then immediately transferred from the syringe to a pre-evacuated 1L gas sampling bag with multi-layer foil. Nitrous oxide in the gas samples was analysed using off-axis integrated cavity output spectroscopy (ICOS, Los Gatos).

The statistical analysis showed that UI had a significant effect ($p < 0.05$) on N_2O emissions. However, this effect was only observed during the first week after the N fertilizer application (Figure 2). Further, the results showed that the highest N_2O emission, within this week after adding urea fertilizer, was under the U+UI treatment (T3), which was significantly higher by about 139, 91, 79% compared to the Urea+Biofertilizer (T4), Urea (T2), Urea+UI+Biofertilizer (T5) treatments, respectively. No significant difference was observed between these last three treatments, i.e. T2, T4 and T5, in this period. Due to the ability of UI to reduce ammonia volatilization, we assume that pollution swapping from ammonia volatilization to nitrous oxide emission occurred, explaining the stimulus of UI on nitrous oxide emission. The lower N_2O emission in the treatments receiving biofertilizer, compared to the one with no biofertilizer, may be caused by the ability of Azotobacter to reduce N_2O emission by N2O-fixation, N2 fixation and reduction of N_2O to N2.

Figure 1. Nitrous oxide chambers in the field. (photo credit: Mirkhani, R., 2022)

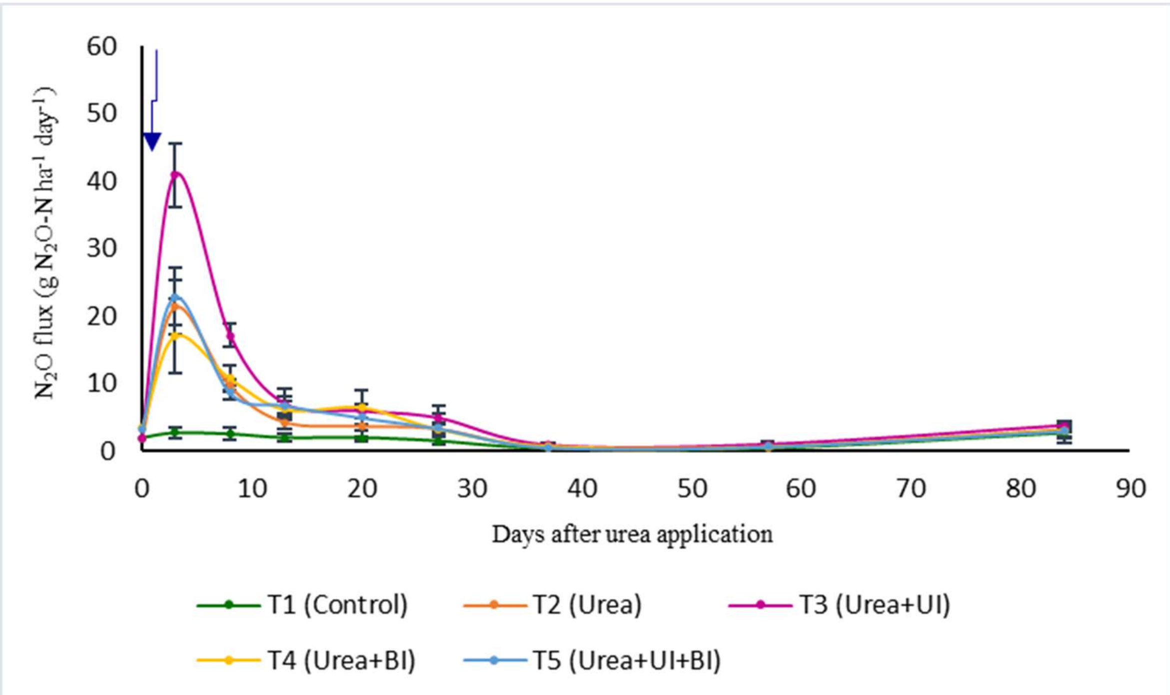

Figure 2. The effect of different fertilization treatments (T1: control treatment; T2: Urea; T3: Urea+UI; T4: Urea+Biofertilizer; T5: Urea+UI+Biofertilizer) on N2O emissions. Each value represents a mean of four replicates with standard deviation shown by vertical bars. The solid arrow indicates the time of N fertilization.

*UI: Urease Inhibitor

*BI: Biofertilizer

Predicting cesium dynamics and uptake using Mid-Infrared Spectroscopy (MIRS)

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The release of radiocaesium radionuclides (RCs) has affected food safety after the accidents at the Fukushima Daiichi nuclear power plants. ^{137}Cs is of major concern in terms of agriculture due to its relatively long half-life, and easy absorption by plants. Countermeasures include using potassium fertilizer to reduce radiocaesium contamination in agricultural products. However, the relation between the transfer from soil to crop and exchangeable potassium (Kex) differs depending on the soil, meaning that several parameters influence caesium (Cs) uptake by plants. The reason remains unclear, but previous studies suggested that exchangeable ^{137}Cs (^{137}Cs ex) could be a crucial factor in explaining the variation (Suzuki et al.,2022). Also, the solid/liquid distribution coefficient (Kd) of Cs has been used to explain the Cs dynamics in soil (Absalom t al.,1995). Thus, these parameters could be involved in the determination of the risk of ^{137}Cs uptake by plants, whereas the methods to obtain this soil information are often impractical because they are expensive to analyze and time-consuming. Mid-Infrared Spectroscopy (MIRS) can predict soil parameters faster and more cost-effectively. However, the prediction of Cs-related parameters except for Kex using MIRS has yet to be assessed (Soriano-Disla et al., 2014; Knox et al., 2015; Nguyen et al. 1991; Albinet et al. 2022). This study aimed to assess whether MIRS can predict Cs-related parameters in soil like Kd, ^{137}Csex/^{137}Cstotal, Kex, and soil organic carbon, and this for volcanic soils (Andosols), taking into account the limited number of samples.

In total, about 1685 soil samples were collected from agriculture fields in the Fukushima Prefecture in Japan from 2013 to 2019. So far, 575 out of 1685 soil samples were analysed. For the spectra data, the soil samples were further prepared by grinding in air-dry stage through mills (MORTAR GRINDER RM 200 and MM200, Retsch, Germany). The MIRS data were obtained using a Thermo Scientific Nicolet iS20 Spectrometer at the SWMCNL in Seibersdorf (Austria). Four replicates of the spectra data were obtained for each soil sample, and the average of the four replicates was used for the modelling.

The mathematical approach for developing the soil property prediction models was based on Partial Least Squares Regression (PLSR). The wet chemistry data were log10 transformed and before the modelling, the CO_2 spectral region was removed, and the noise of the spectra was removed using a Savizky-Golay transformation (Savitzky et al., 1964). Furthermore, the spectral data were systematically centered and normalized by standard normal variate transform, and then the outliers were detected by calculating Mahalanobis distance and removed. The whole dataset was separated into training (75%) and test (25%) using Kennard- Stone or 20 times random splitting. In this report, we present only the results from the 20 times random splitting approach. In the training dataset, a 10-fold cross-validation was applied to calculate RMSEP (root mean square error of the prediction) and to choose the optimal number of components for the PLSR modeling. A number of components up to 10 were selected to avoid overfitting. Then, a pairwise comparison of predicted versus measured values was performed in each dataset. Pre-processing of spectra and model calibrations for PLSR were implemented within the free R Programming Language using the 'soilspec' package (Wadoux, A.M.J.C et al., 2021).

The PLSR methods provided a relatively high accuracy score for the prediction of soil organic carbon, where the R^2 (coefficient of determination) of the test dataset was 0.82 ± 0.04. This was as expected; however, this confirmation was essential as it allowed to trust the spectral data. However, due to the limitation of the available dataset of Kd, the validation scores of Kd of ^{133}Cs was below 0.2. One of the reasons for the low accuracy is the small number of samples with a narrow range. The other reason can be considered as the low concentration of the original data, which was close to the detection limit. On the other hand, the results of ^{137}Csex / ^{137}Cstotal prediction showed relatively higher values. Although the R^2 value was 0.36 ± 0.07, we could see an increase in accuracy, with an increase in samples, which is promising, when more soil samples will be analyzed. To identify the spectral features which are interpreted as important for the prediction, the variable importance on projection was calculated. As for the estimation of ^{137}Csex / ^{137}Cstotal, the region that can be related to clay mineralogy, quartz, and organic matter was considered influential. Indeed, the dynamics of Cs is highly related to clay mineralogy especially to the 2:1 type clay minerals. Also, a previous study indicated that organic matter affects the Cs mobility in the soil (Fan et al., 2014). On the other hand, the modeling of Kex showed that less than 600 samples produced only a low-accurate estimation. A previous study by Albinet et al. (2022) also showed that the accuracy was not high when the sample size was small but increased quickly with increasing number of samples. An additional reason for the low accuracy of the prediction can be explained by the narrow range of the dataset. Furthermore, the soil samples were obtained in Fukushima and the most important soil type was Andosol. This soil type fixes not only Cs but also potassium in the soil mineral. Therefore, the dynamics of exchangeable potassium is complicated and that is way it might have been hard to predict in this case.

In conclusion, the prediction of one of Cs- related parameters, ^{137}Csex / ^{137}Cstotal in soil, using MIRS was properly performed although it still requires further investigation, i.e., an increase in MIRS data. Estimation of Kd provided low accuracy scores due to a dataset with a limited number of samples, but also due to lower Kd values. Increasing the range of Kd data may be promising. The accuracy of the estimation of Kex was not high, probably because of the narrow range of the dataset and the complicated dynamics of potassium in Andosol. The remaining samples will be analyzed and added to the dataset, which is expected to improve the accuracy of the modeling.

			Metrics					
Soil properties	N	unit	RMSE			R^2		
Organic carbon	567	%	0.54	±	0.03	0.82	±	0.04
Kd	162	L/kg	31.6	±	12.2	0.13	±	0.09
$^{137}Cs_{ex}$ / $^{137}Cs_{total}$	554	-	0.04	±	0.003	0.36	±	0.07
K_{ex}	573	mg/100gDW	19.7	±	2.30	0.16	±	0.08

Table 1. PLSR model performance in predicting soil properties. Figures reported are averages and standard deviations of metrics calculated on test datasets split 20 times randomly. N is the number of soil samples in the whole dataset. Note that the unit and the RMSE are reported as the information of original (untransformed) data, while R2 score is reported as the information of the transformed data

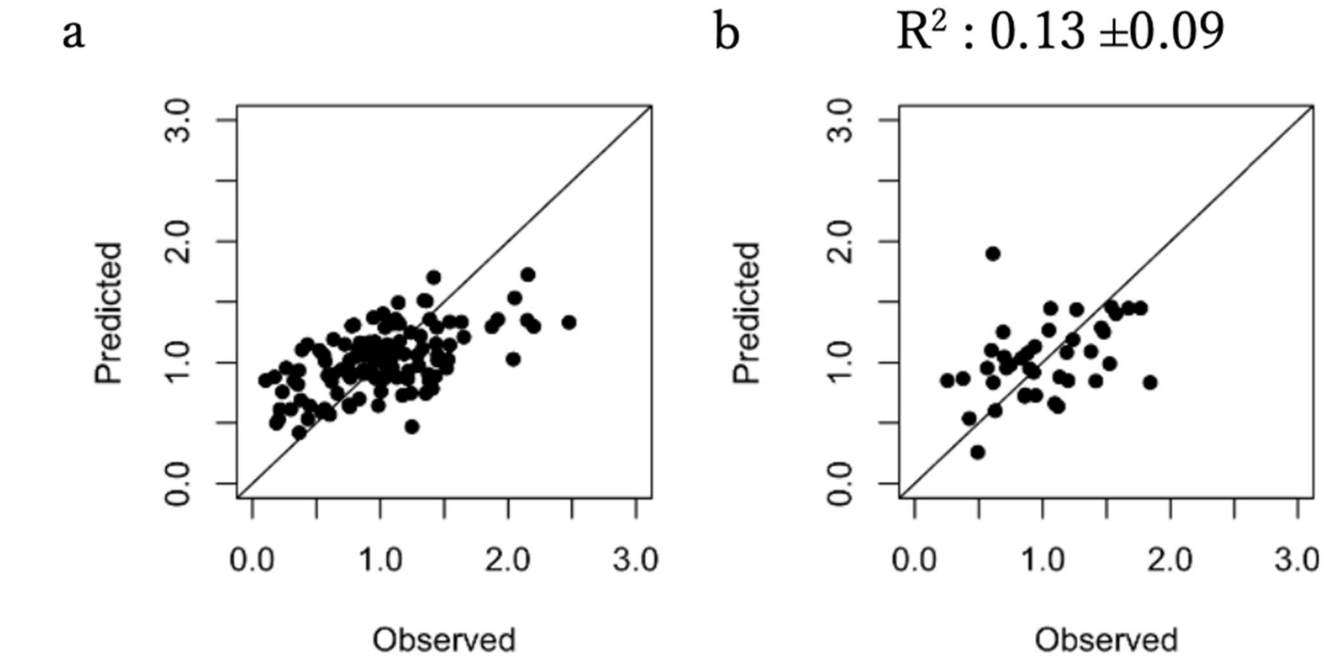

Figure 1. Scatterplot of observed versus predicted value of log 10 (Kd). The left-hand side plot (a) shows the observed against predicted values for the training dataset, while the right-hand side plot (b) shows the observations against predictions for the test dataset. The dataset was split by randomly and one of them are shown.

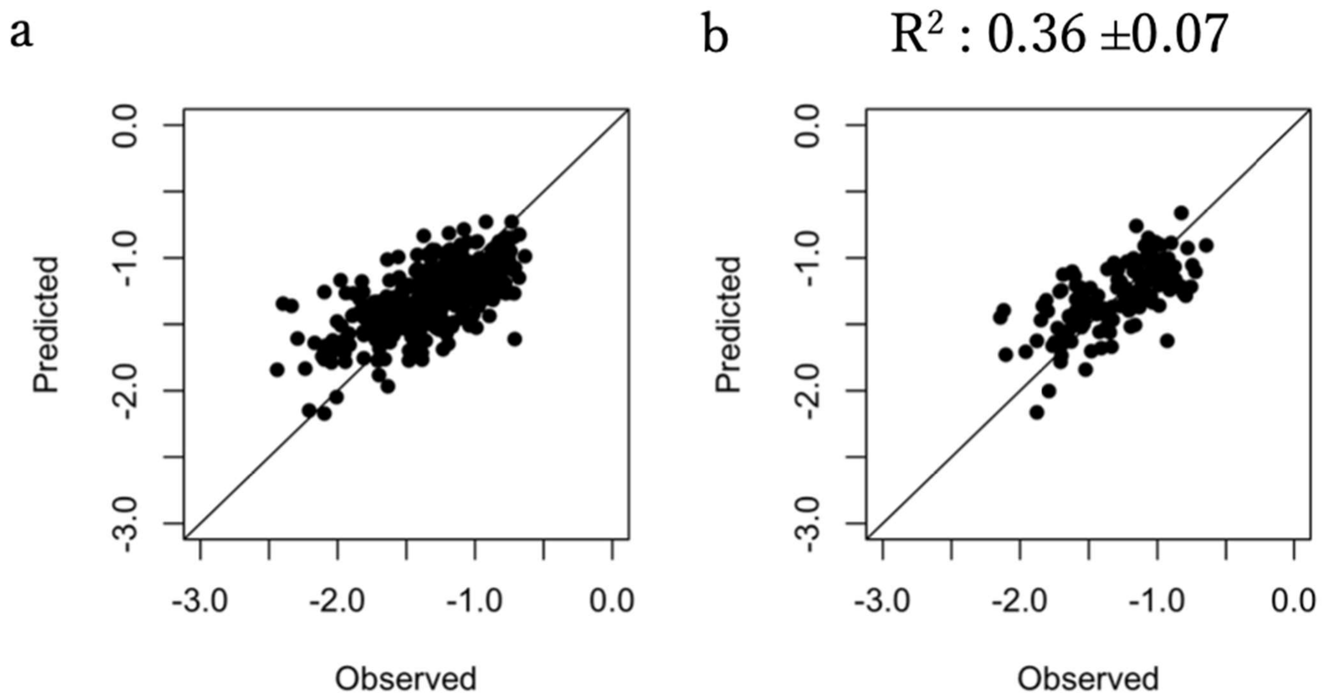

Figure 2. Scatterplot of observed versus predicted value of log 10 (137Cs ex / 137Cs total). The left-hand side plot (a) shows the observed against predicted values for the training dataset, while the right-hand side plot (b) shows the observations against predictions for the test dataset. The dataset was split by randomly and one of them are shown.

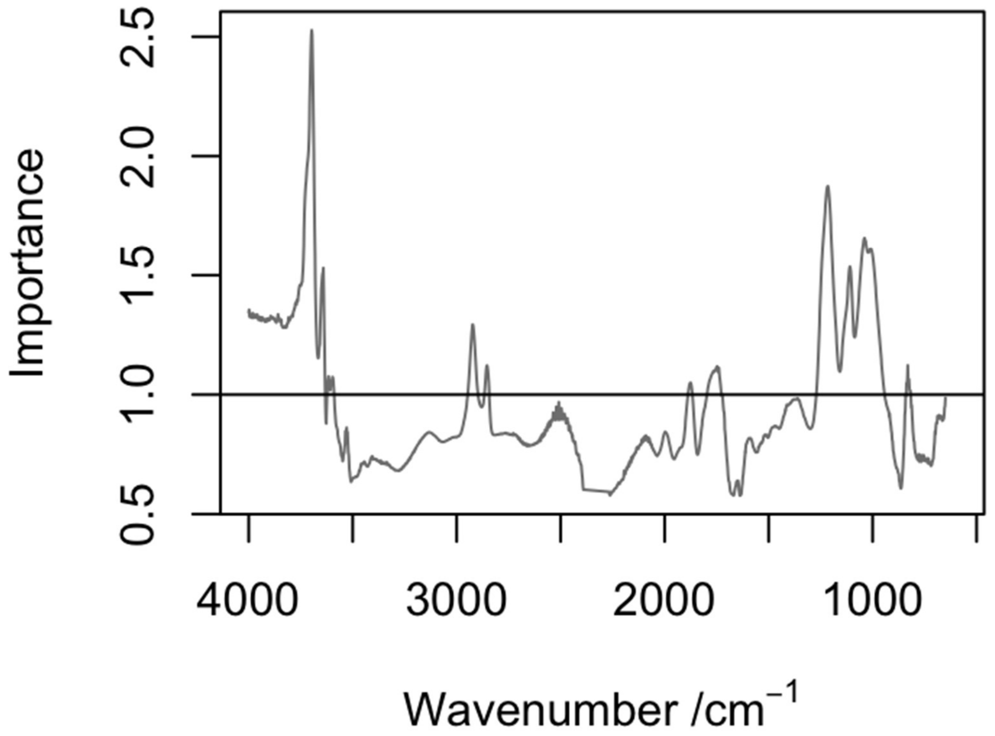

Figure 3. Importance of each wavenumber on projection of the principal components on the estimation for log 10 ($^{137}Cs_{ex}$ / $^{137}Cs_{total}$).

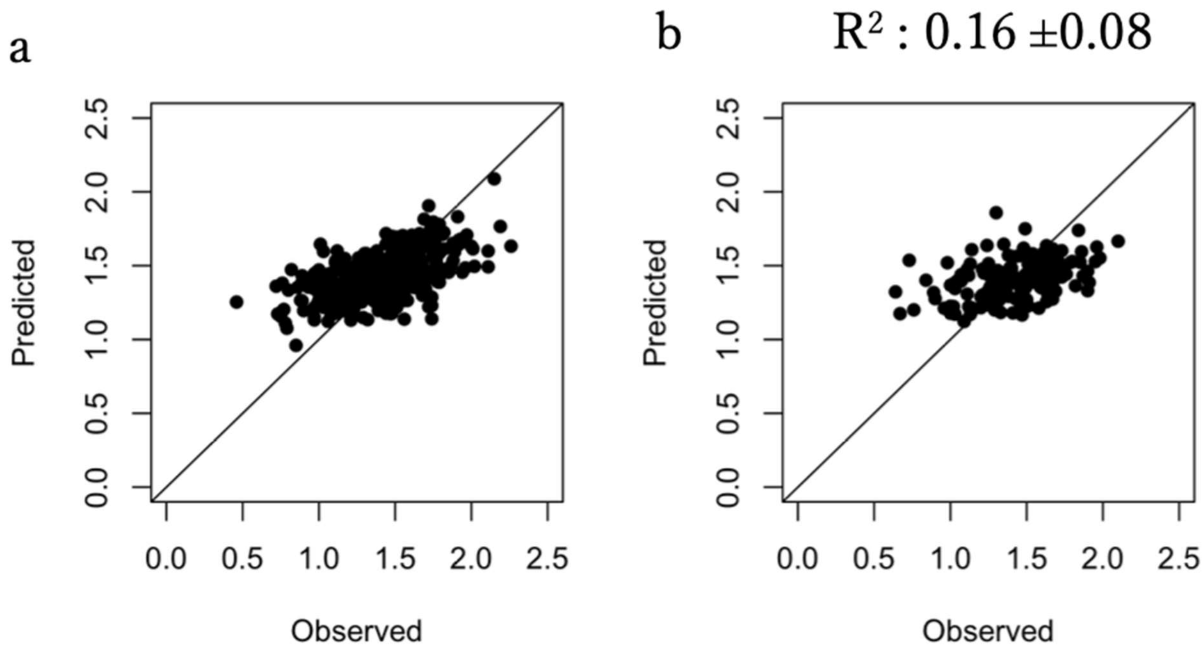

Figure 4. Scatterplot of observed versus predicted value of log 10 (K ex). The predictions are made by a PLSR model. The left-hand side plot (a) shows the observed against predicted values for the training dataset, while the right-hand side plot (b) shows the observations against predictions for the test dataset. The dataset was split by randomly and one of them are shown.

Publications

BIRINDWA, R.D., VAN LAERE, J., MUNYAHALI, W., DE BAUW, P., DERCON, G., KINTCHE, K., MERCKX, R. (2023). Early planting of cassava enhanced the response of improved cultivars to potassium fertilization in South Kivu, Democratic Republic of Congo. Field Crops Research 296, 108903.

DE JONGE, C., GUO, J., HALLBERG, P., GRIEPENTROG, M., SMITTENBERG, R., PETERSE, F., BOECKX, P., AND DERCON, G. (2023). Using biomarker lipids to reconstruct soil fertility through time, EGU General Assembly 2023, Vienna, Austria, 24–28 April 2023, egu23-16684, https://doi.org/10.5194/egusphere-egu23-16684

EICHINGER, C., MIRKHANI, R., KHENG HENG, L., MITCHELL, J., HOOD-NOWOTNY, R. C., AND DERCON, G. (2023). Effect of urease inhibitor and biofertilizer on wheat yield and related crop parameters, EGU General Assembly 2023, Vienna, Austria, 24–28 April 2023, EGU23-12259, https://doi.org/10.5194/egusphere-egu23-12259

GIANESSI, S., POLO, M., STEVANATO, L., LUNARDON, M., FRANCKE, T., OSWALD, S., AHMED, H., TOLOSA, A., WELTIN, G., DERCON, G., FULAJTAR, E., HENG, L., AND BARONI, G. (2023) Testing a novel sensor design to jointly measure cosmic-ray neutrons, muons and gamma rays for non-invasive soil moisture estimation, Geosci. Instrum. Method. Data Syst. Discuss. [PREPRINT], HTTPS://DOI.ORG/10.5194/GI-2022-20, IN REVIEW, 2022.

GULIYEV, V., TANUNCHAI, B., UDOVENKO, M., MENYAILO, O., GLASER, B., PURAHONG, W., BUSCOT, F., BLAGODATSKAYA, E. (2023). Degradation of Bio-Based and Biodegradable Plastic and Its Contribution to Soil Organic Carbon Stock. Polymers, 15(3): 660. https://doi.org/10.3390/polym15030660

HEILING, M., MIRKHANI, R., RESCH, C., PUCHER, R., TOLOZA, A., AND DERCON, G. (2023). Determining the contribution of nitrogen fertilizer and mineralization to volatilized ammonia through the use of nitrogen-15, EGU General Assembly 2023, Vienna, Austria, 24–28 April 2023, EGU23-12071, https://doi.org/10.5194/egusphere-egu23-12071

HOOD-NOWOTNY, R., FERNÁNDEZ-BALADO, C., SCHOTT, K., WAWRA, A., KONZETT, M., HEILING, M., AND DERCON, G. (2023). Cover crop C inputs; Multiple aerial and isotope insights from a long-term field trial., EGU General Assembly 2023, Vienna, Austria, 24–28 April 2023, EGU23-11961, https://doi.org/10.5194/egusphere-egu23-11961

KAN, A., HEILING, M., TOLOZA, A., ALBINET, F., SHINANO, T., AND DERCON, G. (2023). Prediction of caesium dynamics in soil using Mid-Infrared Spectroscopy (MIRS), EGU General Assembly 2023, Vienna, Austria, 24–28 April 2023, EGU23-5501, https://doi.org/10.5194/egusphere-egu23-5501

MENYAILO, O., DEROO, H., EICHINGER, C., DERCON, G. (2023). Biogeochemical consequences of agricultural soil contamination with Sulfamethoxazole (SMX). EGU General Assembly 2023, Vienna, Austria, 24–28 April 2023, EGU23-4926. https://doi.org/10.5194/egusphere-egu23-4926

MIRKHANI, R., RESCH, C., WELTIN, G., HENG, L. K., MITCHELL, J., CLARE HOOD-NOWOTNY, R., DERCON, G. (2023). Effect of urease inhibitor and biofertilizer on nitrous oxide emission, EGU General Assembly 2023, Vienna, Austria, 24–28 April 2023, EGU23-11242, https://doi.org/10.5194/egusphere-egu23-11242

MWAPE, M., SAID AHMED, H., PHIRI, E., HEILING, M., DERCON, G., RESCH, C. (2023). 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, EGU General Assembly 2023, Vienna, Austria, 24–28 April 2023, EGU23-6729, https://doi.org/10.5194/egusphere-egu23-6729, 2023

SAID AHMED, H., TOLOZA, A., RAB, G., BRUNNER, T., HENG, L. K., STRAUSS, P., MBAYE, M., DERCON, G. (2023). Mobile Gamma-ray spectrometry for soil texture mapping, EGU General Assembly 2023, Vienna, Austria, 24–28 April 2023, EGU23-6905, https://doi.org/10.5194/egusphere-egu23-6905, 2023.

TAYLOR, A., KALNINS, A., KOOT, M., JACKSON, R., TOLOZA, A., SAID AHMED, H., GODDARD, R., BLAKE, W. (2023). Portable gamma spectrometry for rapid assessment of soil texture, organic carbon and total nitrogen in agricultural soils. J Soils Sediments. https://doi.org/10.1007/s11368-023-03488-w

VANTYGHEM, M., BEELEN, E., HOOD-NOWOTNY, R., MERCKX, R., DERCON, G. (2023). Carbon allocation in banana plants – the effect of drought stress and suckers. EGU General Assembly 2023, Vienna, 24-28 April, 2023. https://doi.org/10.5194/egusphere-egu23-13571

VANTYGHEM, M., BEELEN, E., HOOD-NOWOTNY, R., MERCKX, R., DERCON, G. (2023). 13C labeling unravels carbon dynamics in banana between mother plant, sucker and corm under drought stress. Frontiers in Plant Science. 14: 1141682. 10.3389/fpls.2023.1141682

VAN LAERE, J., WILLEMEN, A., DE BAUW, P., HOOD-NOWOTNY, R., MERCKX, R., DERCON, G. (2023). Carbon allocation in cassava is affected by water deficit and potassium application – A 13C-CO2 pulse labelling assessment. Rapid Communications in Mass Spectrometry 37(2), e9426.

WATZINGER, A., PROMMER, J., SPIRIDON, A., KISIELINSKA, W., HOOD-NOWOTNY, R., LEITNER, S., WANEK, W., RESCH, C., HEILING, M., MURER, E., FORMAYER, H., WAWRA, A., MILOCZKI, J. (2023). Functional redundant soil fauna and microbial groups and processes were fairly resistant to drought in an agroecosystem. Biology and Fertility of Soils. https://doi.org/10.1007/s00374-023-01728-2

Websites and Links

- Soil and Water Management and Crop Nutrition Section: https://www.iaea.org/topics/land-and-water-management
- Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture: https://www.iaea.org/topics/food-and-agriculture
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