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Nuclear Techniques in Food and Agriculture

Soils Newsletter

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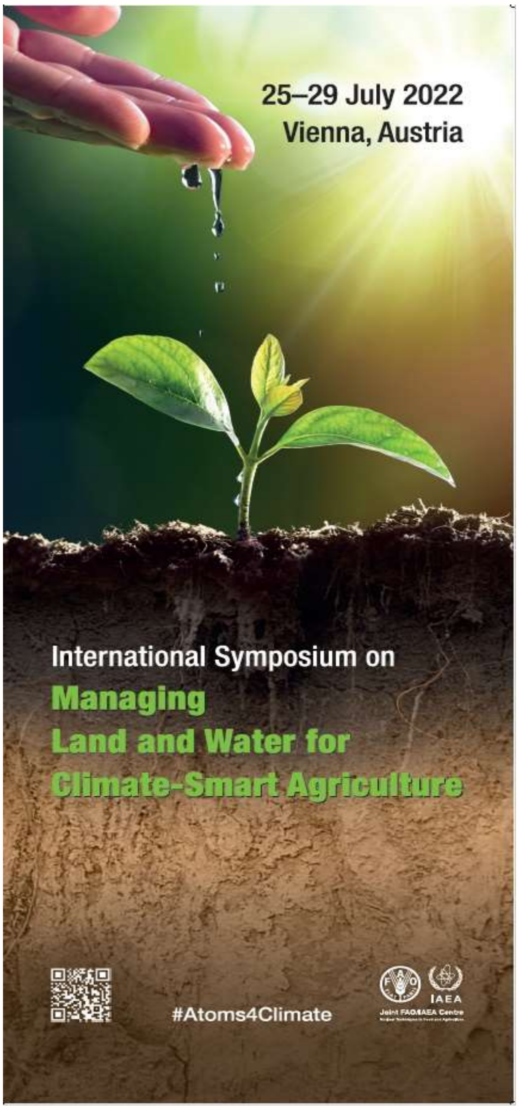
To Our Readers



The Joint FAO/IAEA Centre's Subprogramme on Soil and Water Management and Crop Nutrition (SWMCN) is in the final stage of preparing for the FAO/IAEA 'International Symposium on Managing Land and Water for Climate-Smart Agriculture' which will be held from 25-29 July 2022 in Vienna, Austria. The symposium covers a wide range of topics and aspects relating to the use of isotope and nuclear techniques for making land and water management contribute to climate resiliency. During our symposium you will learn about the various advances in nuclear-based analytical techniques as well as the latest digital technology and innovative modelling approaches.

We also use the opportunity of this symposium to highlight the challenges of agricultural pollutants, including antimicrobials and microplastics. In addition, we included two special sessions into the programme. One on the 'Global Soil Laboratory Network (GLOSOLAN)' and one on 'FAO's AquaCrop – Development and Way Forward'. The GLOSOLAN Network is part of Global Soil Partnership, an FAO initiative to support and facilitate global collective action towards sustainable soil management for food security, climate change adaptation and mitigation. The AquaCrop is internationally recognized as one of the most suitable crop models for simulating crop yield response to water, particularly under conditions in which water is a key limiting factor in crop production. The SWMCN is part of AquaCrop's core group and supporting GLOSOLAN's Mid-Infrared spectroscopy work.

The symposium will be an in-person meeting, with the possibility of remote connection. More than 350 abstracts have been received and about 110 were selected for oral presentations. The FAO/IAEA Symposium will be an exciting opportunity and platform to explore, foster and strengthen collaboration and partnerships at global level in response to the impact of climate change and a rapidly changing global environment. We hope to see you all at the symposium.

A consultancy meeting on microplastics in soils on the detection, transport and assessment of its environmental significance using isotopic techniques was held virtually in January 2022. The meeting participants discussed the formulation of a Coordinated Research Project (CRP) on the fate of microplastics in agricultural soils and to develop methodologies for detecting them, using nuclear and related techniques.

Two research coordination meetings (RCM) were also held. One was the third RCM of the CRP ‘Multiple Isotope Fingerprints to Identify Sources and Transport of Agro-Contaminants’ (D15018), which was held virtually in May 2022. A new Springer book on ‘Oxygen Isotopes of Inorganic Phosphate in Environmental Samples: Purification and Analysis’ was recently published as part of the project. The other RCM was the first meeting of the CRP on ‘Isotopic Techniques to Assess the Fate of Antimicrobials and Implications for Antimicrobial Resistance in Agricultural Systems’ (D15022), which was also held virtually in May 2022.

In July 2022, the CRP on ‘Remediation of Radioactive Contaminated Agricultural Land’ (D15019) will be due for mid-term review. Significant results have been achieved under this CRP in the past two years.. We look forward to a successful review for its continuation. You can read more about all the CRP updates in the CRP section of the newsletter.

With the end of the COVID-19 travel restrictions, several in-person Technical Cooperation (TC) project meetings have also been organised. The Subprogramme is implementing 66 TC projects in the 2022-2023 cycle.

We present two feature articles in this issue of the newsletter. The article ‘How Isotopic Techniques Can Be Used to Spot Drought Stressed Banana Crops and Help Save Them’ is part of the Belgian government funded IAEA Peaceful Uses Initiative, to develop approaches using nuclear techniques for spotting and assessing drought stress in banana plants in Arusha, Tanzania. The second article on ‘Nuclear Techniques Support Sustainability of Mountainous Agriculture in Uganda’ highlighted the serious erosion problem in Uganda.

The SWMCN Laboratory (SWMCNL) has delivered many outputs as our research and development work continued. Recently, some innovative work on soil texture mapping using proximal gamma-ray spectrometry has been initiated. Its use for soil texture mapping is based on the naturally occurring long-lived radioactive isotopes of potassium (40-K), thorium (232-Th) and uranium (238-U) which can be correlated with clay and silt content. Similarly, some preliminary work on antimicrobial resistance to study the fate of Sulfamethoxazole (SMX) as a model for antimicrobials in agricultural soils under laboratory conditions using stable isotopes was also initiated. Several incubation experiments are being conducted with ^{13}C-labeled SMX, to provide insights on SMX turnover in soils, which will help in the design of future experiments to study the fate of SMX under field conditions. This work will support the new CRP on the fate of antimicrobials (D15022) mentioned earlier.

We welcome Jason Mitchell from UK who joined the SWMCNL in April this year, as Laboratory Attendant. Jason has extensive knowledge and experience in the field and glasshouse on irrigation, machinery maintenance and operation of field equipment. We look forward to Jason’s support to the SWMCNL team. We also welcome Heleen Deroo from Belgium and Corinna Eichinger from Austria who joined the SWMCNL as interns. We wish them a good stay with us and hope their internship will provide them with practical working experience.

Finally, I would like to take this opportunity to thank all our readers for their continuous support. See you all at the Symposium!

Lee Heng
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Staff News

Jason Mitchell (UK) joined the SWMCNL in Seibersdorf in April 2022, as Laboratory Attendant. He worked for 22 years in golf course maintenance, with extensive knowledge in irrigation, construction and machine maintenance and operation. Before this, ten years working in glasshouse horticulture. He will assist in implementing greenhouse and field experiments, collecting and preparing plant and soil samples for isotope and related conventional analyses, supporting laboratory activities and maintaining field equipment.

Heleen Deroo (Belgium) joined the SWMCNL in February 2022 as an intern for six months. As part of the CRP on 'Isotopic Techniques to Assess the Fate of Antimicrobials and Implications for Antimicrobial Resistance in Agricultural Systems', she is investigating the effect of sulfamethoxazole on the activity of soil microorganisms and on soil organic matter decomposition using ^{13}C-labelled glucose. Heleen recently finished her PhD in natural resources (soil biogeochemistry) at Ghent University in Belgium.

Corinna Eichinger (Austria) joined the SWMCNLas an intern in March 2022 to assist in research activities related to the recently initiated CRP 'Isotopic Techniques to Assess the Fate of Antimicrobials and Implications for Antimicrobial Resistance in Agricultural Systems'. She is a MSc student at the University of Vienna, Austria with focus on terrestrial ecosystems and biogeochemistry. Corinna is currently finishing her MSc thesis on the impact of EDTA washing on potentially toxic metal PTM) contaminated soil using ^{13}C and ^{15}N isotopes at the Stabile Isotope Laboratory of the University of Natural Resources and Life Sciences (BOKU), Tulln an der Donau, Austria. During this internship she hopes to further deepen her knowledge on stabile isotope techniques and to learn more about antimicrobial resistance in soils.

Feature Articles

How Isotopic Techniques Can Be Used to Spot Drought Stressed Banana Crops and Help Save Them[#]

Monica Exner

Office of Public Information and Communication, International Atomic Energy Agency (IAEA), Vienna, Austria

[#]*Published as a web story https://www.iaea.org/newscenter/news/how-isotopic-techniques-can-be-used-to-spot-drought-stressed-banana-crops-and-help-save-them*

Figure 1. Scientists used nuclear techniques to assess levels of drought stress in bananas. The study was carried out in banana fields in Tanzania (Photo: M.Vantyghem/IAEA)

Whether you like your bananas slightly green or spotted, they are mostly grown in the tropics and subtropics where plants require a warm, humid climate to thrive. This is how they produce the yield that feeds the world. However, due to changing rainfall patterns and rising temperatures, bananas along with other plants suffer more and more from drought stress – a shortage of water in the root of the plant, leading to reduced harvests.

A study published this month by scientists at the IAEA and the Food and Agriculture Organization of the United Nations (FAO) as well as colleagues from Austrian and Belgian universities, highlights approaches developed using nuclear techniques for spotting and assessing drought stress in banana plants in Arusha, Tanzania. The methodologies focus on identifying the extent of the stress, which is crucial because it enables farmers to take preventive and protective action.

"The aim of this research was to shed some light onto this underexplored tropical perennial crop," said Gerd Dercon, Head of the Soil and Water Management and Crop Nutrition Laboratory at the Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture. "With perennial crops, like bananas, that grow over several years, the use of the stable isotope techniques has not been sufficiently and properly developed, making this study one of the first to provide practical tools, even for farmers, not only for scientists."

Figure 2. Scientists discussed sampling technology with local partners in Tanzania (Photo: S. Ramadhani)

The scientists explored the use of stable carbon isotopes (see the Science box) and leaf temperature as potential indicators for drought stress in banana plants. Research on other plants has shown that stable carbon isotopes and leaf temperature can be used to measure drought stress, but neither technique had been used for banana. It is an underresearched crop because of its large size, long growth period, heterogenous growth pattern (bananas grow differently even if having the same genes), and vegetative reproduction. Currently, there are no practical methods to detect drought stress in banana in the field.

However, the study found that both stable carbon isotopes and leaf temperature were highly sensitive indicators for drought stress in banana, and based on that the researchers have developed banana-tailored methods that are low-cost and therefore applicable under field conditions.

“The methods we developed can be used to test levels of drought stress and to compare different water management strategies,” said Mathilde Vantyghem, IAEA/FAO PhD researcher and lead author of the study. “With such methods, local research institutes can do quick testing and provide guidance for farmers to cope with drought stress.”

The study is part of an ongoing project funded by the Belgian government through the IAEA Peaceful Uses Initiative (PUI). In 2022 its focus will be on scaling these methods on the slopes of Mount Kilimanjaro to identify early signs of drought stress and safeguarding action.

“The way the project is developed and implemented is very interesting: it combines Belgian expertise and research through the involvement of several Belgian universities, with expertise in the field in Tanzania and other African countries,” said Caroline Mouchart, Deputy Head of Mission at the Permanent Mission of Belgium to the United Nations and International Organizations in Vienna. “Banana, in all its forms and varieties, is a very important product for a lot of countries, as a basic food and as an export product. We hope that the results of the project will benefit a lot of countries and will contribute to global efforts to promote resilient agricultural practices, better suited to climate change.”

Based on these findings, through the IAEA's training will be provided to farmers the intermediaries on using these techniques to identify early signs of drought stress and improve agronomical practices for banana cultivation.

The science

All plants absorb carbon dioxide (CO_2), and then create sugar from it with the help of water and light through photosynthesis. CO_2 consists of one carbon atom and two oxygen atoms. Most carbon atoms in the world have twelve neutrons (^{12}C), but half a percent of all the carbon has thirteen neutrons (^{13}C), which is slightly heavier. ^{13}C and ^{12}C are thus two different versions of carbon, which are called the stable isotopes of carbon.

When plants absorb CO_2 from the air, they discriminate against CO_2 with ^{13}C. Because of its heavier weight, CO_2 with ^{13}C gets absorbed more slowly by plants than CO_2 with ^{12}C. Therefore, plants favour ^{12}C.

When drought stress occurs, plants close their stomata – the little openings in the leaves through which they take in CO_2 from the atmosphere – because they do not want to lose the water that they have already accumulated. Since no more CO_2 can be absorbed through the now closed stomata, the plants will be less selective and will use any CO_2 that has already been ingested for photosynthesis, including the CO_2 with the ^{13}C atom. This means that when, later on, the amount of ^{13}C in a plant leaf is analysed, one can detect if the plant was stressed or not: If plant A has more ^{13}C in its leaves than plant B, plant A was more stressed. This is the principle of using stable carbon isotopes as an indicator of drought stress.

Figure 3. Stable carbon isotope analysis was carried out on banana leaf samples (Photo: G.Dercon/IAEA)

Nuclear Techniques Support Sustainability of Mountainous Agriculture in Uganda#

Emil Fulajtar[1], Crammer Kaizzi Kayuki[2]

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#*Published as a web story* https://www.iaea.org/newscenter/news/nuclear-techniques-reveal-depth-of-soil-erosion-in-uganda

Problem to be addressed

The major threat for food security in Uganda like in most African countries is the drought and low soil fertility. Soils in tropics are strongly weathered and poor in nutrients.

Figure 1. Highly weathered tropical soil, suburbs of Kampala

Even more severe obstacle for agricultural exploitation of Africa than nutrient scarcity is the water scarcity and imbalanced seasonal distribution of rainfall. This is a serious problem also for Uganda, despite not being the driest countries of Africa.

The population density of Uganda (177 inhabitants per 1 km^2) is among highest in Africa. However, the land resources would be sufficient for food security of its population if there would be sufficient water supply. But this is not the case. Large parts of Uganda are semiarid and therefore the cultivated land occupies only 34.3% of the country which is just slightly more than pastureland (savanna) occupying 25.6% of the area.

The country comprises of three types of landscapes: 1) South-east lowland along Victoria Lake high in rainfall which is intensively agriculturally exploited (although involving abundant marches and waterlogged soils); 2) Cattle Corridor (Figure 2) occupying the great majority of central and northern part of the country, it is an undulated denudation plateau having semiarid climate and is used for pastureland (Figure 3) alternating with extensive agriculture; and 3) Highlands scattered along the eastern and western boundary of the country. These mountainous areas (Figure 4) are unlike the mountains in temperate areas very intensively inhabited and agriculturally exploited (Figure 5) because they are high in rainfall and have moderate temperatures suitable for settlement. Therefore, highlands represent productive agroecosystems very important for Uganda and 40% of the Uganda's population is concentrated in the highland regions despite only occupying 25% of the country. The population density in the highlands reaches 270 – 305 people per 1 km^2 which is much more than the average density all over the country.

Figure 2. Drylands not suitable for rainfed agriculture are occupied by savanna, Rweirabo, Southern Uganda

Figure 3. Savanna areas are used for grazing

The agricultural exploitation of the highlands is endangered by soil erosion. The cultivated land situated on steep slopes is very vulnerable to soil erosion. The land use in highlands is dominated by small family farms cultivating strip fields on very steep slopes (30-40 degrees). The traditional land structure is dominated by contour strip fields forming narrow terraces (Fifure 4). These terraces, however, are inclined. The terracing usually reduces the slope inclination from 30-40 degrees to 15-30 degrees, what is still too much for sustainable land management and thus the terracing reduces the erosion but does not prevent it. Rill erosion is abundant in some terraces (Figure 6) and gullies cutting through several terraces (Figure 7) can be found at some slopes. However, there features are distributed irregularly in space and time and are difficult to be quantified.

Figure 4. Intensive mountainous agriculture, Kigwa, Southwestern Uganda

Figure 5. Cultivated land on steep slopes

The first attempt to evaluate the erosion at national level was done by group of researchers from Uganda, Rwanda and China using the modelling approach. Their results obtained by Universal Soil Loss Equation (USLE) suggest that the mean rate of soil erosion rates in Uganda is 3.2 t/ha/y but in the highlands it ranges between 10 and 100 t/ha/y and commonly it reaches even 100 t/ha/y. Great erosion rates were calculated also for northern part of Cattle Corridor (5-50 t/ha/y).

Figure 6. Rill erosion on steep slopes

Figure 7. Gully erosion cutting across terraces

However, these numbers represent only estimates by model and lack any validation. Soil conservation strategies and policies should be based on reliable data and these can be obtained only by field measurements which can help to validate the results of models. Providing the reliable data on real erosion rates for land managers and agricultural decision makers in Uganda became the major goal of cooperation of National Agricultural Research Laboratories (NARL) in Kampala, Uganda with IAEA.

Fallout Radionuclides (FRN) Methods

The Cs-137 radionuclide is a soil erosion tracer commonly used for assessment of soil erosion rates. It is an artificial radionuclide released to atmosphere in 1950s and 1960s through the atmospheric tests of nuclear weapons. Due to air circulation it was spread to stratosphere and travelled around the globe until being deposited through wet fallout on the land surface. The next doses of Cs-137 were released by the Chernobyl and Fukushima nuclear power plants accidents but the Chernobyl Cs-137 is distributed only in Europe, and Fukushima Cs-137 only in Japan and surrounded area. The basic investigations of Cs-137 distribution and behaviour in environment were carried in

1960s and they brought background information inspiring the exploitation of this radionuclide as soil erosion tracer. The basis of Cs-137 method for erosion assessment was developed in 1970s and 1980s. Its long development was completed at the beginning of 1990 when conversion models for recalculating Cs-137 inventories to soil erosion rates were developed. A comprehensive set of models reflecting different environmental conditions and different level of available input parameters involves 4 models (from very simple to more sophisticated) for cultivated land and 2 models for undisturbed land (grasslands and forests). They made the use of Cs-137 method very convenient and since the 1990s the method spread worldwide and became routinely applied in a wide range of environmental conditions.

The principle of the method is based on the Cs-137 behaviour in soil. Since it was deposited in 1960s, the uppermost layers of soils all over the world are contaminated by very small quantities of Cs-137. This, however, is not an environmental threat for man and nature because its concentrations and radiation are much smaller that the radiation of many other natural radionuclides abundant in soil. After its deposition the Cs-137 was quickly bind to soil colloids (clays and organic matter) so it can move only together with soil particles to which it is bound. Since then it is very stable in soil and is not a subject of further translocation by leaching, physical, chemical or biological processes other than bioturbation, radioactive decay and mechanical processes moving soil particles such as soil erosion and other human activities (construction and mining). Because Cs-137 fallout stopped after the atmospheric tests of the nuclear weapons were forbidden, if the uppermost soil layer containing Cs-137 deposited from bomb tests is removed from some area, this area remains permanently depleted. If significant amount of Cs-137 is removed from some area or significant increase is noticed somewhere, it is an indicator of soil erosion and deposition or other human activities. Thus, if we know that soil in some area was not disturbed by human activities other than agriculture (such as construction or mining, etc.), the difference in Cs-137 inventories can be attributed to soil erosion and deposition.

To quantify the redistribution of Cs-137 inventories the studied area is compared to the so called 'reference area', which is known (thank to available information on land use history) to be undisturbed. The Cs-137 inventories of reference and studied site are used to calculate the redistribution rates of Cs-137 and they are recalculated to soil erosion rates by selected conversion models (usually PM, MBM1 MBM2 for cultivated land).

IAEA activities and results

The assessment of soil erosion rates in selected agroecosystems of Uganda became the objective of an IAEA Technical Cooperation (TC) Project for transferring nuclear technology to Member States. For this purpose, the Cs-137 method which is the nuclear technique commonly used for erosion assessment was used. The Cs-137 radionuclide is an erosion tracer which was successfully used for measurements of erosion rates in many TC projects and CRP in ca 70 IAEA Member States).

The main focus of this project in Uganda was on the assessment of erosion rates at terraced fields in mountainous areas (Figure 8, 9, Tables 1, 2).

Figure 8. Sampling for ^{137}Cs analyses

Transect 1	Inventory (Bq/m2)	Erosion/deposition rates (t/ha/yr) PM	MBM1	MBM2	Observation
AV SAM1	540				Deposition
AV SAM2	261	-20.5	-28.7	-21.1	Erosion
AV SAM3	527	4.9	7.0	5.0	Deposition
AV SAM4	802	31.3	44.2	31.8	Deposition
AV SAM5	428	-4.5	-5.0	-3.5	Erosion
AV SAM6	611	13.0	17.7	12.6	Deposition
AV SAM7	902	40.8	55.5	39.7	Deposition
AV SAM8	949	45.3	61.6	44.1	Deposition
AV SAM9	141	-31.9	-57.8	-44.9	Erosion
AV SAM10	355	-11.4	-13.9	-9.9	Erosion
AV SAM11	994	49.6	77.4	57.1	Deposition
AV SAM13	846	35.5	55.3	40.8	Deposition

Table 1. Soil redistribution along the slope transect

Mean Erosion (t/ha/yr)	-17.1	-26.3	-19.8
Mean Deposition (t/ha/yr)	31.5	45.5	33.0
Gross Erosion (t/ha/yr)	-6.2	-9.6	-7.2
Gross Deposition (t/ha/yr)	20.0	29.0	21.0
Net Erosion (t/ha/yr)	13.8	19.4	13.8
Sediment Delivery Ratio (%)	-222%	-203%	-191%
Eroded area (%)	36%	36%	36%
Deposited area (%)	64%	64%	64%

Table 2. Parameters summarysing soil redistributinon along thansect

At the Kyokyezo Study site in South-Western Highlands 4 slope transects (comprising of 41 soil profiles) were selected and sampled. The results of the erosion evaluation showed that a great majority of the terraces are strongly eroded. Among 41 sampled soil profiles only 4 profiles were stable (showing neither erosion, nor deposition), 6 profiles showed deposition and remaining 31 profiles were eroded. The maximum identified erosion rate was 96 t/ha/y and the average value of all eroded profiles was 30.4 t/ha/y. The mean deposition rate was much lower (16.2 t/ha/y) and because the deposition occurred only in few profiles (6 deposition profiles versus 31 erosion profiles) it is seen that most eroded soil was removed from the cultivated terraced slopes and transported to footslopes and valley or even further as suspended sediment in water courses. The mean value of soil erosion rate obtained by Cs-137 method fits very well with the estimates calculated by USLE. The model yields for study area values between 10 and 50 t/ha/year and the value of 30.4 t/ha/y calculated from ^{137}Cs redistribution fits into that range.

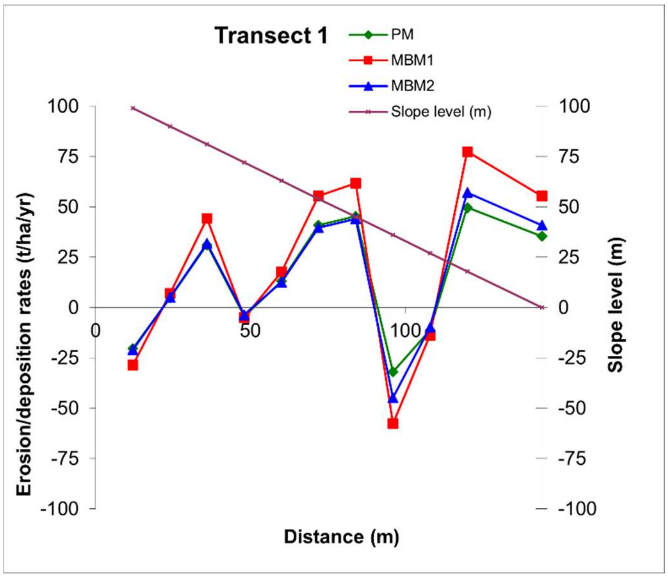


Figure 9. Graphical expression of soil redistribution

The results indicate that the soil conservation effects of terraces in the South Western Highlands of Uganda is by far insufficient. Of course, there is no doubt that the terraces significantly reduce the erosion. If there would be no terraces and the whole straight continuous slopes would be cultivated, the erosion would be tremendous. However, the measured value of 30 t/ha/y is still too high if the cultivation of this area should be sustainable. To have a better idea about the magnitude of erosion the mean value should be converted from weight units (t/ha/y) to volume units (mm/y) using an approximate estimation of mean soil bulk density (1.3 g/cm^3). This is equivalent to 2.3 mm thick layer of soil is being lost every year. As this is a mean value for a long period since the ^{137}Cs fallout deposited in soil in 1960s (with a maximum fallout in 1963), it can be calculated that since 1963 until 2018 (time of sampling) in total 12.6 cm thick layer of topsoil has been lost. Considering the depth of tillage being in this area about 20 cm (hand labour using hoe) more than 60% of cultivated topsoil layer would have been lost.

Figure 10. Abandoned terraces are used gor grazing

The results of this research confirmed the presumption that the soil conserving efficiency of traditional terraces on steep slopes of Uganda Highland are by far insufficient to preserve soil resources at long-term time scale. Additional soil conservation measures are needed urgently. Among possible measures mainly three approaches are promising: 1) no-tillage land management; 2) switch of crop rotations to crops with higher soil conserving efficiency (from maize, beans and cassava to cereals or other densely seeded crops); and 3) erosion ditches and bush strips. Even this may not be enough. Many fields already lost their production potential to such an extent that they were abandoned (Figure 10) by farmers who could not secure their livelihood other way than moving to Kampala. Some abandoned land is used as pastures but even that is not suitable and large part of the area should be reforested.

Figure 11. Steepest slopes are reforested

Fortunately, the government is already long time well aware about the land degradation problem in Uganda. Various programs of soil conservation and erosion remediations are supported mainly in the highlands.

Reforestation of degraded areas is running already for several decades (Figure 11), and recently significant part of the area is under young eucalyptus forests.

Figure 12. Effect of terracing supported by erosion ditches

Figure 13. Effect of terracing supported by bush strips

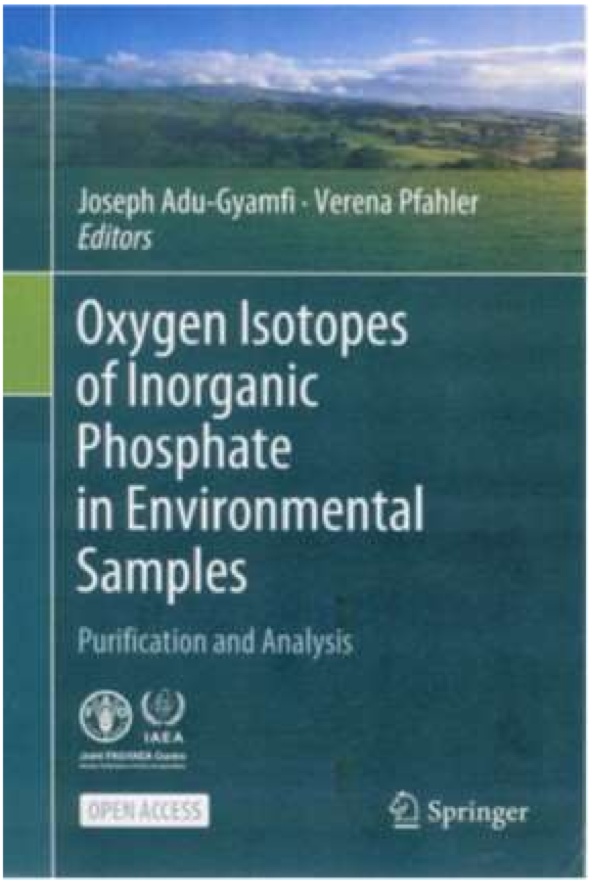
In the last years a new soil conservation programme was introduced using successfully erosion ditches (Figure 12) and row of bush grows (Figure 13) along the terrace edges. These measures are promising, and the improvement of soil conservation bring hope for maintaining food security and for better future of Uganda Highlands.

Announcements

Open Access new Springer book "Oxygen Isotopes of Inorganic Phosphate in Environmental Samples: Purification and Analysis"

Adu-Gyamfi, J.[1] and Pfahler, V. (eds), Springer, 2022

Phosphorus (P) fertilizers are known to increase crop productivity, however when applied in excess it can cause serious environment pollution. Monitoring P pollution in natural environments using stable isotopes has been difficult because P has only one stable isotope (^{31}P) making the use of P stable isotope tracing not an option. Radioactive P isotopes (^{32}P and ^{33}P) have been used but its drawbacks are the short half-life, health risks and safety procedures required to apply them in agricultural catchments. Phosphorus in organic and inorganic P forms is strongly bonded to oxygen (O), which has three stable isotopes, providing a system to track P cycling and transformations using the stable isotopes of O in phosphate ($\delta^{18}O\text{-}PO_4$). The SWMCN Subprogramme, through a Coordinated Research Project addressed the methodological problems of the $\delta^{18}Op$ protocols encountered in the field such as high loads of organic matter in the samples which makes purification challenging, and the need to improve sampling strategies in the field. This open access book distinguished itself from other publications by offering step-by-step instructions on how to extract, purify, provide modifications, and major issues to be encountered during the process. For the $\delta^{18}Op$ method to progress, further fundamental research as well as field and laboratory studies need to be conducted for a better understanding of P cycling in the environment. It is expected that the $\delta^{18}O_P$ would be extensively applied in research geared to understand phosphorus dynamics in different agro-environments.



https://link.springer.com/book/10.1007/978-3-030-97497-8

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 E. Fulajtar
Azerbaijan	AZB5004	Strengthening Best Soil, Nutrient, and Water Agricultural Practices for Cotton Production	M. Zaman
Bangladesh	BGD5033	Using Nuclear Techniques in Assessing River Bank Erosion	E. Fulajtar
Belize	BZE5012	Use of Nuclear and Isotopic Techniques for Optimizing Soil-Water-Nutrient Management in Rainfed Agriculture Systems	J. Adu-Gyamfi
Bolivia	BOL0009	Strengthening National Capacities for the Development of Nuclear Technology Applications in Bolivia	M. Zaman
Bolivia	BOL5024	Strengthened National Capacities for the Identification of the Origin and Transport of Pesticides Compounds in Agricultural Watersheds	J. Adu-Gyamfi
Botswana	BOT5024	Improving Selected Legumes and Cereals against Biotic and Abiotic Stresses for Enhanced Food Production and Security	J.Adu-Gyamfi and PBG
Bulgaria	BUL5018	Improving Crop Water Productivity and Nutritional Quality of Orchards	J. Adu-Gyamfi
Burkina Faso	BKF5024	Improving Food Crops through Mutation Breeding and Best Soil and Nutrient Management to Ensure Food Security	J. Adu-Gyamfi and PBG
Burundi	BDI5005	Enhancing Productivity of Staple Crops Using Nuclear-derived Technologies	M. Zaman and PBG
Cambodia	KAM5008	Introducing a Digital Soil Information System and Remote Sensing for Sustainable Land Use Management	L. Heng
Central African Republic	CAF5014	Strengthening Capacity for Enhancing Cassava Production and Quality through Best Soil Nutrient Management Practices	M. Zaman
Chad	CHD5009	Developing Sustainable Water Resources Management through the Use of Nuclear Isotopic Techniques in Drip Irrigation Systems	L. Heng
Colombia	COL5026	Enhancing Crop Productivity of Creole Potato Using Nuclear and Related Techniques	M. Zaman and PBG
Congo Rep. of	PRC5003	Protecting Water and Fertility in Agricultural Soils	M. Zaman
Costa Rica	COS5035	Building Capacity for the Development of Climate-Smart Agriculture in Rice Farming	M. Zaman
Costa Rica	COS7006	Strengthening National Capacities to Identify Sources of Contamination that Affect Highly Vulnerable Aquifers Using Isotopic and Conventional Techniques	J. Adu-Gyamfi and IH
Cuba	CUB5024	Strengthening National Capacities for the Adaptation or Mitigation of the Negative Impacts of Climate Change and the Sustainable Management of Land and Water, Through the Integrated Use of Nuclear Techniques	E. Fulajtar
Egypt	EGY5027	Strengthening Capacities for Combating Soil Erosion and Restoring Soil Fertility to Support Sustainable Soil and Water Management Practices and Rehabilitation of Degraded Soils for Enhanced Production and Food Security	E. Fulajtar
Gabon	GAB5004	Improving Soil Fertility Management for Enhanced Maize, Soybean and Groundnut Production	J.Adu-Gyamfi
Ghana	GHA5039	Mainstreaming Nuclear Based Climate Smart Agriculture Technologies into Sustainable Production	J. Adu-Gyamfi and PBG
Haiti	HAI5008	Strengthening National Capacities for Enhanced Agricultural Crop Productivity	J.Adu-Gyamfi

Honduras	HON5011	Implementation of Soil, Water and Nutrient Management for Sustainable Coffee Production in Honduras using Nuclear Technologies	E. Fulajtar
Indonesia	INS5044	Using Nuclear Technology to Support the National Food Security Programme	L. Heng and PBG
Interregional project	INT5156	Building Capacity and Generating Evidence for Climate Change Impacts on Soil, Sediments and Water Resources in Mountainous Regions	G. Dercon
Iran	IRA5015	Enhancing Capacity of National Producers to Achieve Higher Levels of Self-Sufficiency in Key Staple Crops	L. Heng, FEP and PBG
Iraq	IRQ5022	Developing Climate-Smart Irrigation and Nutrient Management Practices to Maximize Water Productivity and Nutrient Use Efficiency at Farm Scale Level Using Nuclear Techniques and Advanced Technology	M. Zaman
Lao PDR	LAO5006	Enhancing Crop Production with Climate Smart Agricultural Practices and Improved Crop Varieties	M. Zaman and PBG
Lesotho	LES5012	Improving Productivity of Potato and Sorghum through Mutation Breeding and Best Soil, Nutrient and Water Management Practices	M. Zaman and PBG
Madagascar	MAG5026	Enhancing Rice and Maize Productivity through the Use of Improved Lines and Agricultural Practices to Ensure Food Security and Increase Rural Livelihoods	J. Adu-Gyamfi and PBG
Malaysia	MAL5032	Strengthening National Capacity in Improving the Production of Rice and Fodder Crops and Authenticity of Local Honey Using Nuclear and Related Technologies	E. Fulajtar, PBG and APH
Mali	MLI5031	Improving Rice Productivity through Mutation Breeding and Better Soil, Nutrient and Water Management Practices	M. Zaman and PBG
Namibia	NAM5020	Enhancing Staple Crop Yields, Quality, and Drought Tolerance through Broadening Genetic Variation and Better Soil and Water Management Technologies	J. Adu-Gyamfi and PBG
Nicaragua	NIC2002	Strengthening of National Capacities in Energy Planning and Geothermal Resource Assessments through the Application of Isotopic Analytical Methods	E. Fulajtar
Pakistan	PAK5053	Strengthening and Enhancing National Capabilities for the Development of Climate Smart Crops, Improvement in Animal Productivity and Management of Soil, Water, and Nutrient Resources Using Nuclear and Related Techniques	M. Zaman with PBG and SIT
Palestine (T.T.U.T.J.)	PAL5011	Enhancing Food Security via Nuclear Based Approaches	E. Fulajtar
Panama	PAN5028	Improving the Quality of Organic Cocoa Production by Monitoring Heavy Metal Concentrations in Soils and Evaluating Crop Water Use Efficiency	J. Adu-Gyamfi
Panama	PAN5029	Strengthening National Capacities to Combat Land Degradation and Improve Soil Productivity Through the Use of Isotope Techniques	E. Fulajtar
Peru	PER5033	Application of Nuclear Techniques for Assessing Soil Erosion and Sedimentation in Mountain Agricultural Catchments	E. Fulajtar
Peru	PER5035	Improving Pasture Production Through Best Soil Nutrient Management To Promote Sustainable Livestock Production in the Highland Region	M. Zaman
Qatar	QAT5008	Developing Best Soil, Nutrient, Water and Plant Practices for Increased Production of Forages under Saline Conditions and Vegetables under Glasshouse Using Nuclear and Related Techniques	M. Zaman
Regional project Africa	RAF0056	Enhancing Nuclear Science and Technology Capacity Building through Technical Cooperation Among Developing Countries	E. Fulajtar
Regional project Africa	RAF5081	Enhancing Productivity and Climate Resilience in Cassava-Based Systems through Improved Nutrient, Water and Soil Management (AFRA)	M. Zaman and G. Dercon
Regional project Africa	RAF5086	Promoting Sustainable Agriculture under Changing Climatic Conditions Using Nuclear Technology (AFRA) 2022-2023	H. Said Ahmed and L. Heng
Regional project Africa	RAF5090	Supporting Climate Change Adaptation for Communities Through Integrated Soil–Cropping–Livestock Production Systems (AFRA)	M. Zaman and APH
Regional project Asia	RAS5089	Enhancing the Sustainability of Date Palm Production in States Parties through Climate-Smart Irrigation, Nutrient and Best Management Practices (ARASIA)	H. Said

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 Lee Heng
Regional project Asia	RAS5094	Promoting Sustainable Agricultural and Food Productivity in the Association of Southeast Asian Nations Region	M. Zaman with PBG and FEP
Regional project Asia and Pacific	RAS5099	Developing Climate Smart Crop Production including Improvement and Enhancement of Crop Productivity, Soil and Irrigation Management, and Food Safety Using Nuclear Techniques (ARASIA)	M. Zaman with PBG and FEP
Regional project Europe	RER5028	Improving Efficiency in Water and Soil Management	E. Fulajtar
Regional project Latin America	RLA5077	Enhancing Livelihood through Improving Water Use Efficiency Associated with Adaptation Strategies and Climate Change Mitigation in Agriculture (ARCAL CLVIII)	L. Heng
Regional project Latin America	RLA5084	Developing Human Resources and Building Capacity of Member States in the Application of Nuclear Technology to Agriculture	J. Adu-Gyamfi, PBG and FEP
Regional Project Latin America	RLA5089	Evaluating the Impact of Heavy Metals and Other Pollutants on Soils Contaminated by Anthropogenic Activities and Natural Origin (ARCAL CLXXVII)	J Adu-Gyamfi
Rwanda	RWA5001	Improving Cassava Resilience to Drought and Waterlogging Stress through Mutation Breeding and Nutrient, Soil and Water Management Techniques	M. Zaman and PBG
Saint Vincent & the Grenadines	SVT0001	Building National Capacity in Nuclear Technology Applications	J. Adu-Gyamfi, NAHU/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
Zimbabwe	ZIM5026	Improving Soil Quality for Optimizing Selected Cereal and Legume Productivity in Smallholder Farms	J. Adu-Gyamfi

Forthcoming Events

FAO/IAEA Events

FAO/IAEA International Symposium on Managing Land and Water for Climate Smart Agriculture, 25–29 July 2022, Vienna, Austria https://conferences.iaea.org/event/270/

Scientific Secretary: L. Heng

Regional Training Course on Regional Project RAS5091 'Assessing and Mitigating Agro-Contaminants to Improve Water Quality and Soil Productivity in Catchments Using Integrated Isotopic Approaches' Research design and sampling strategy 3–5 August 2022 (Virtual)

Technical Officer: J. Adu-Gyamfi

Regional training course of Regional project RER5028 on gamma spectrometry, 17–21 October, 2022, Bucharest, Romania

Technical Officer: E. Fulajtar

NON-FAO/IAEA Events

International Conference on Radiation Applications (RAP 2022), 6-10 June 2022, KEDEA Center, Thessaloniki, Greece

World Congress of Soil Science, 31 July–5 Aug 2022, Glasgow, United Kingdom https://22wcss.org/; https://soils.org.uk/wcss22/

Past Events

FAO/IAEA Events

Regional Training Course of RAF5081 on Enhancing Productivity and Climate Resilience in Cassava-Based Systems through Improved Nutrient, Water and Soil Management (AFRA), 24-28 January, 2022, Rwanda

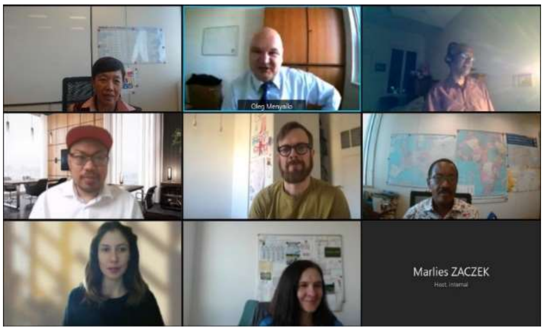
Technical Officer: Mohammad Zaman

The technical officer (TO) went to Kigali, Rwanda for five days and conducted the hands-on and lecture training. The training was opened by Mr Patrick Karangwa- the Director General of the Rwanda Agriculture and Animal Resources Development Board and Mr Nahayo Fidele- CEO of the Rwanda Atomic Energy Board. The TO explained the objectives of the training course and gave detailed presentations on the role of isotopic and nuclear techniques in developing climate smart agricultural practices for efficient use of soil, nutrient and water resources and combating climate change for the first three days along with three cost-free experts from Burundi, Germany, and Kuwait who joined virtually. The training was attended by 21 researchers (6 female, 15 male) and extension workers from Cameroon, Central African Republic, Ghana, Kenya, Nigeria, Rwanda, Uganda, and Zimbabwe. The TO along with the participants then went on a field trip to research institute of RAB, to show participants how to apply ^{15}N fertiliser, data collection and setting up demonstration trials on farmer's field. On the 5th day, the TO arranged a workshop using excel sheet to determine fertiliser applications, ^{15}N calculations to assess fertiliser use efficiency, and dilution of ^{15}N fertilisers. The TO then had one to one meeting with each participant to plan their activities for 2022, identified lab and field equipment for procurement, and field trials of cassava at farmer's field to demonstrate and disseminate the best practices. All trainees received certificates from Mr Nahayo Fidele. The participants acknowledged the IAEA, Rwanda Atomic Energy Board for hosting and organizing this training and committed to share their experience and knowledge with fellow colleagues for further capacity building.

Consultancy Meeting'Microplastics in Soils: Detection, Transport and Assessment of Environmental Significance with Isotopic Techniques', 25–27 January 2022 (virtual)

Scientific Secretaries: Oleg Meniailo and Joseph Adu-Gyamfi

This consultancy meeting (CM) was held virtually from 25 to 27 January 2022. Nine experts and consultants from seven Member States, including staff from FAO and the Austrian Environmental Agency (Umweltbundesamt), discussed the formulation of a CRP on the fate of microplastics in agricultural soils. The CRP proposal will focus on: (1) Developing cost-effective methodologies for detecting microplastics, identifying their pathways and understanding their biogeochemical significance in soils, using nuclear and related techniques; (2) Testing the developed methodologies under laboratory and field conditions; (3) Providing guidance on the application of the methodologies to help countries develop strategies to mitigate the spread of microplastics and their decomposition products in the environment; and (4) Establishing a network of laboratories for improving data interpretation in relation to the presence and degradation of microplastics in soils.



Participants of the consultancy meeting: 'Microplastics in Soils: Detection, Transport and Assessment of Environmental Significance with Isotopic Techniques'

First Coordination Meeting of Regional TCP on "Improving Efficiency in Water and Soil Management" (RER5028), 14-18 March 2022 (virtual)

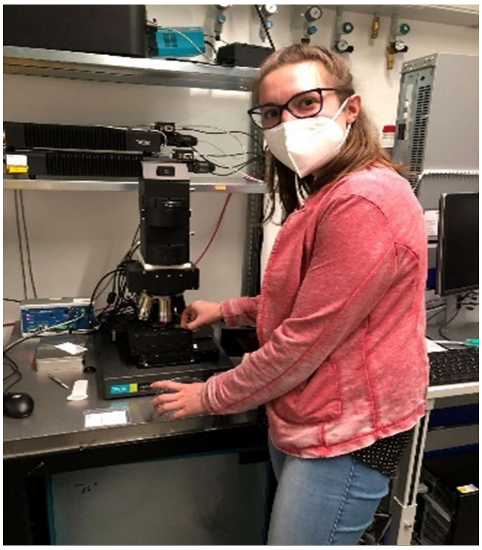
Technical Officer: Fulajtar, E.

The major objective of this new regional Technical Cooperation project is to exploit nuclear techniques for measuring soil moisture and contribute to improving soil water management. Two nuclear techniques will be used: gamma ray spectrometer (GRS) and cosmic ray neutron sensor (CRNS) and these novel technologies will be transferred to 18 European countries. The first coordination meeting assessed the state of the art of soil water research in project partner countries and the availability of the soil related nuclear techniques. Based on that the work plan was revised and the needs of procurement and training activities were assessed. It was concluded that the regional training course on gamma spectroscopy will be organized in autumn 2022.

Scientific visit for discussing collaboration on the use of stable isotopes for tracing the fate of antimicrobials and microplastics in soil, 15–18 May 2022, Halle and Munich, Germany

Technical Officers: J. Adu-Gyamfi, J., and O. Meniailo.

Mr Joseph Adu-Gyamfi and Mr Oleg Meniailo travelled to Germany to discuss (1) the new proposed CRP on microplastics at the Helmholtz Centre for Environmental Research (UFZ) in Halle, and (2) methodologies for the synthesis and stable isotope analysis of labelled antibiotics at the Technical University of Munich related to the CRP on antimicrobial resistance (AMR).



PhD student Ms Kara Müller demonstrating the use of Raman Micro spectroscopy at the Technical University of Munich, Germany

The conclusions from the missions are: (1) The UFZ could be a potential collaborator on the proposed new CRP on plastics (P) and microplastics (MP), focusing on the microbial decomposition of both conventional and bio-degradable plastics and microplastics using stable isotope techniques, (2) TUM and IAEA agreed to work together (with inputs from FAO) to prepare a state-of-the-art technical paper on "Plastics and microplastics on soil ecosystem and environment: A role of nuclear and related techniques", (3) For the CRP on AMR, working groups were proposed to develop protocols for sampling and analysis of labelled antibiotics sulfamethoxazole and AMR genes. The visit will help further strengthen the collaboration between the SWMCNL and TUM/UFZ.

Professor Martin Elsner of the Technical University of Munich showing an LC-IRMS

First Coordination Meeting of Regional Technical Cooperation Project RAF5086 'Promoting Sustainable Agriculture under Changing Climatic Conditions Using Nuclear Technology (AFRA)', 9–13 May 2022, Vienna

Technical officer: H. Said

Seventeen countries participated in the first coordination meeting of the new regional project on 'Promoting Sustainable Agriculture under Changing Climatic Conditions Using Nuclear Technology (AFRA)'. This regional project aims to address the challenges posed by climate change to food security by using advanced nuclear technology, such as cosmic ray neutron sensing (CRNS) for landscape water management, gamma ray spectrometry for monitoring soil properties and digital technology such as remote sensing to improve agricultural practices and to enhance water and nutrient use efficiencies. The objective of this meeting was to develop the country work plan. The Programme Management Officer together with the Technical Officer coordinated the discussion on planning the work and procurement requests. The meeting also involved a visit to the SWMCNLin Seibersdorf.

Group photo at RAF5086 coordination meeting in Vienna

Interregional Training Course on Climate Change Adaptation Strategies for Soil and Water Management in High Mountainous Regions, 12–17 June 2022, Bolzano, Italy.

Technical Officer: G. Dercon

In view of the important role mountains play in providing freshwater for growing food, regulating and supporting elements such as the climate, water flow and water quality, and with their ecosystems being among the most sensitive to rapid global warming, the interregional IAEA Technical Cooperation project INT/5/156 on "Building Capacity and Generating Evidence for Climate Change Impacts on Soil, Sediments and Water Resources in Mountainous Regions" was approved in November 2019. Building on the 5-year TC project INT/5/153 which ended in 2019, the new project's overall goal is to contribute to the conservation of ecosystem services, as well as to the resilience of local mountain communities in the Andes and the Himalayas, with the purpose of improving their ability to adapt to climatic changes and better manage land and water resources at high altitudes.

This training course (7–17 June 2022) aimed to equip INT5/156 participating countries and experts with the tools to develop effective climate change adaptation strategies or action plans grounded in the evidence generated by nuclear science and technology within the scope of the project case studies. This course targeted at bridging the gap between science and policy to ensure that nuclear science and technology for climate have impact and lead to relevant adaptation actions in mountainous regions.

In total, 16 participants from 8 Member States in the Andes and the Himalayas attended the training course. This course was held at the Global Mountain Safeguard Research Programme (GLOMOS). GLOMOS is a collaborative programme and scientific alliance between the United Nations University Institute for Environment and Human Security (UNU-EHS) and Eurac Research based in Bolzano, Italy. GLOMOS represents an interface between the international mountain research community and the UN system. Conducting applied and transdisciplinary research to support livelihoods and sustainable mountain development GLOMOS also facilitates a greater recognition of mountain-related topics within international frameworks and the 2030 Agenda for Sustainable Development.

Coordinated Research Projects

Project Number	Ongoing CRPs	Project Officer
D12014	Enhancing Agricultural Resilience and Water Security Using Cosmic-Ray Neutron Technology	E. Fulajtar and H. Said Ahmed
D15018	Multiple Isotope Fingerprints to Identify Sources and Transport of Agro-Contaminants	J. Adu-Gyamfi and L. Heng
D15019	Remediation of Radioactive Contaminated Agricultural Land	G. Dercon and L. Heng
D15020	Developing Climate-Smart Agricultural Practices for Mitigation of Greenhouse Gases	M. Zaman and L. Heng
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) aimed at testing the potential of using a cosmic ray neutron sensor (CRNS) and gamma ray sensor (GRS) for agricultural water management, 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: 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. It was lucky that the project started about half year before the problems with traveling restriction 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 could be collected.

In winter 2019 and spring 2020 the first results of the CRP were published in international scientific journals and presented at EGU General Assembly (4-8 May 2020, virtual) and at IEEE International Workshop: Metrology for Agriculture and Forestry (3-5 November, 2021, virtual). These publications presented interpretations of soil water content datasets collected by the SWMCNL team at Petzenkirchen, Austria monitoring station.

Soil moisture monitoring was interrupted at some sites in spring and summer 2020 due to the travel restrictions, lockdowns and home office. Installation of CRNS and GRS at some sites were also delayed. Nevertheless, in late summer and autumn the measurements and installations of new sites continued and the major activities were successfully implemented and already in its first year the CRP brought significant scientific achievements:

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

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

The Second Research Coordination Meeting was held virtually on 7 - 11 June 2021. Its main achievement was the initiation of the methodological guidelines, which will be the major output of the project. The time during the lockdowns and home office periods were exploited very efficiency for writing of publications and the inputs for this guidelines and the manuscript for publication.

The most important methodological achievements presented in this guidelines are: neutron signal noise filtering, CRSPy tool (neutrone counts processing using Python language), agriculture soil moisture products (root zone depth estimation and precipitation estimation) and approach using CRNS for remote sensing soil moisture products (SENTINEL, ASCAT) validation. The mid-term evaluation is planned in autumn 2022.

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

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

This 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 stable isotope tools, and create guidelines to adapt the new toolkit to a variety of agricultural management situations. Nuclear techniques are used to achieve the objectives including a combined stable isotope ($\delta^{18}O$' $\delta^{2}H$, $\delta^{13}C$, $\delta^{15}N$,' $\delta^{13}C$-DIC, $\delta^{15}N$-NO_3 $\delta^{18}O$-NO_3 $\delta^{18}Op$, $\delta^{34}S$) techniques and compound specific stable isotope (CSSI)-based monitoring approach for evaluating pesticide in-situ degradation, transport and transformation.

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 to enable the participants to complete the work on their respective research projects. The CRP has achieved two of the three specific objectives namely to (1) develop, evaluate and standardize an integrative isotope approach for identifying and apportioning sources of contaminants in agro-ecosystems, (2) apply the combined approach to different agro-ecosystems to control contaminants. During last two years, the CRP proposes to focus on the third specific objective “to provide guidelines and decision trees for adapting and applying the toolbox” and furthermore to develop appropriate remediation strategies to reduce the environmental risk.

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

(1) A collaboration with the Mekong River Commission (MRC) on monitoring the source and transport of agro-contaminants along the Mekong river that flows through China, Myanmar, Thailand, Laos, Cambodia and Viet Nam. A similar collaboration between IAEA and the Joint Danube Survey in Europe to apply stable isotopes to monitor nitrate from tributaries to the mainstem of the transboundary Danube River was successfully achieved and published (https://www.nature.com/articles/s41598-022-06224-5.pdf).

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

The Final RCM is planned for October 2023 (venue to be decided). The preliminary CRP achievements include:

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

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

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

(4) $\delta^{34}S(SO_4)$ and $\delta^{18}O(SO_4)$ for partitioning different sources of pollutants from household waste and from mining areas in the catchment tested [Nambeelup Brook, W. Australia].

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

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

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 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 under[1]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 has designed the roadmap to develop new isotope techniques to better understand the dynamics of radiocaesium and radiostrontium in the soil. The first steps have now been made for stable isotope techniques that allow stable caesium and stable strontium to mimic the behaviour of their radioisotope equivalents. Significant 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. Further, decision-support tools are being developed to improve strategies for remediation of radioactive contamination in agriculture. It has been planned to present the first CRP results at the FAO/IAEA International Symposium on Managing Land and Water for Climate-Smart Agriculture to be held in July 2022.

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 (CO_2), methane (CH_4), and nitrous oxide (N_2O) have increased significantly since the industrial revolution and as a result, the Earth's average surface air temperature has increased about 1.2°C. This warming of the Earth has led to extreme weather events such as frequent heat waves, droughts, floods, and uneven distribution of rainfall, rising sea levels and melting of glaciers. The GHGs with the largest global warming potential are N_2O and CH_4, which predominantly originate from agriculture. Based on the outputs of the previous CRP (D15016), climate-smart agricultural practices are a promising tool to enhance crop production with lower environmental footprints. However, more quantitative data on the effect of soil processes (e.g. carbon- and nitrogen-dynamics) on emissions of GHGs in relation to land-use changes are urgently needed. Therefore this new CRP as phase-2 was started with the objective to develop and validate climate-smart agricultural practices, based on isotopic and related techniques, to increase soil carbon (C) sequestration, mitigate GHG emissions (N_2O, CH_4, CO_2) and limit gaseous losses of ammonia (NH_3) and dinitrogen (N_2) from agricultural ecosystems, with the aim to enhance agricultural productivity and sustainability. The 1st RCM took place virtually on 8–12 February 2021. After the 1st RCM, all CRP participants have started establishing field trials to develop and validate climate-smart agricultural practices, to increase soil C sequestration, mitigate emissions of GHG and NH_3 from agricultural ecosystems, with the aim to enhance agricultural productivity and sustainability. Measurements of gaseous emissions of GHGs and collection of soil and plant samples for chemical analyses are currently underway.

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

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

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. The second RCM is proposed to be held either in Viet Nam or China on 8-12 August 2023.

Developments at the Soil and Water Management and Crop Nutrition Laboratory

Topsoil texture mapping using proximal gamma-ray spectrometry

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Soil texture is an important property controlling many ecosystem services provided by soil resources. Therefore, soil texture mapping is an important tool for establishing sustainable resource management in agriculture. However, traditional soil texture mapping is labor-intensive and expensive (soil sampling and laboratory analyses). Having a proximal sensing technique to accurately map soil texture would be a big step forward, in particular at a sufficiently detailed spatial scale for soil management purposes.

At the SWMCNL, a wide range of studies have started in 2022, to assess the use of nuclear technology, such as Gamma-ray spectrometry (GRS) (figure 1), for supporting soil texture mapping. The GRS recently became a relevant method for area-wide soil moisture monitoring (footprint of 0.2 ha) and has become a robust and validated alternative to conventional devices, which measure soil moisture at point level.

The use of GRS for soil texture mapping is based on the fact that the naturally occurring long-lived radioactive isotopes of potassium (40-K), thorium (232-Th) and uranium (238-U) can be correlated with clay and silt.

The SWMCNL will work with the Hydrological Open Air Laboratory (HOAL) in Petzenkirchen (Lower Austria) to evaluate the ability of the GRS to determine the topsoil texture. The first results of this exploratory research are expected at the end of 2022.

Figure 1. Gamma-ray sensor model MS 350 in Petzenkirchen, Austria.

Use of stable carbon isotopes for characterizing water use efficiency of cassava (*Manihot esculenta*) under field conditions: a case study in Colombia

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In the Caribbean region of Colombia, a gradual increase in average air temperature between 4°C and 6°C and a reduction in precipitation of up to 30% are predicted for the years 2070 - 2100 (Pabón Caicedo, 2012). Therefore, adapting agricultural systems is imperative to mitigate the negative effects of climate change on crop growth.

Temperature variations and long periods of drought will be a limiting factor for cassava production. As part of the

CIALCA project (www.cialca.org) and in close collaboration with The Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT), a field experiment was conducted in 2021 to test and upscale the use of stable carbon isotope (^{13}C) techniques for assessing intrinsic water use efficiency (WUE_i) of cassava under field conditions. In total 14 varieties were tested in two locations in the Caribbean Region of Colombia (Momil and Repelón), and two replicates per location were evaluated (Figure 1).

The selected varieties are classified by the CIAT cassava program as drought tolerant (4 varieties) or drought susceptible (3 varieties) based on CIAT's expert knowledge in terms of yield and physiological response. In addition, seven commercialized cassava varieties adapted to the local Caribbean conditions in Colombia were tested (further indicated as regional).

At four months after planting (MAP), a wide set of morphological and physiological parameters were measured on three leaf categories of the cassava plant: (i) Youngest Fully Expanded Leaf (YFEL), (ii) Middle leaves and (iii) Lower leaves. All varieties were harvested in both locations at nine MAP. Carbon isotopic signature was obtained for bulk leaves material for each of the three categories, and this for each studied variety. For better comprehension, only results from YFEL are presented here. Through linear mixed modelling, it was shown that there are significant differences in carbon isotope signature between varieties ($p < 0.01$) but also between both locations ($p < 0.05$) for the Youngest Fully Expanded Leaf (Figure 2). A Tukey statistical test was performed to observe which varieties differed from each other. Three main groups could be identified when data from both locations are merged. Two out of four varieties (COL1734 and COL1468), classified by the CIAT team as drought-tolerant, presented, as expected, higher values for the carbon isotopic signature, suggesting a higher WUE_i. However, the variety COL1734, with a high WUEi, was characterized by a significant lower root yield (Figure 3) as compared to COL1468, although it does not differ significantly from it. The two other varieties of this drought tolerant group are part of the larger middle group.

COL2215 regional variety showed the most negative value in the YFEL, although only significantly different from both above mentioned varieties, yet with moderate yields. The opposite happened with BRA846 (Susceptible).

Although these data are currently exploratory, it is observed that $\delta^{13}C$ may be considered an indicator of WUE_i for cassava varieties. However, other physiological indicators should be used to explain WUE and its relationship with yield, as this could be a fundamental basis for the selection of drought-tolerant varieties.

On the other hand, with the data analyzed jointly from the two locations, it is shown that there is a significant difference between the three categories of plant leaves (p>0.001). Leaves located higher, had a lower $\delta^{13}C$ than leaves located lower in the canopy. The stomatal opening and closing of plants are regulated by both exogenous and endogenous factors. Therefore, these differences will allow us to evaluate which leaf category can best explain WUE_i in this trial.

Figure 1. Cassava fields from Colombian Caribbean region and selection of leaves for the different leaf categories

Isotopic composition of extracted sugars and cellulose is currently being analyzed at the SWMCNL. These results can give us information on different periods during plant development. The obtained data will then be compared to values from previous experiments in the CIALCA project (Van Laere, J. 2022).

This research makes it possible to understand how the plant behaves under drought in the field in early bulking stage. Finally, the goal is to include this indicator and other indicators as fundamental parameters for crop improvement of cassava with regards to their drought tolerance.

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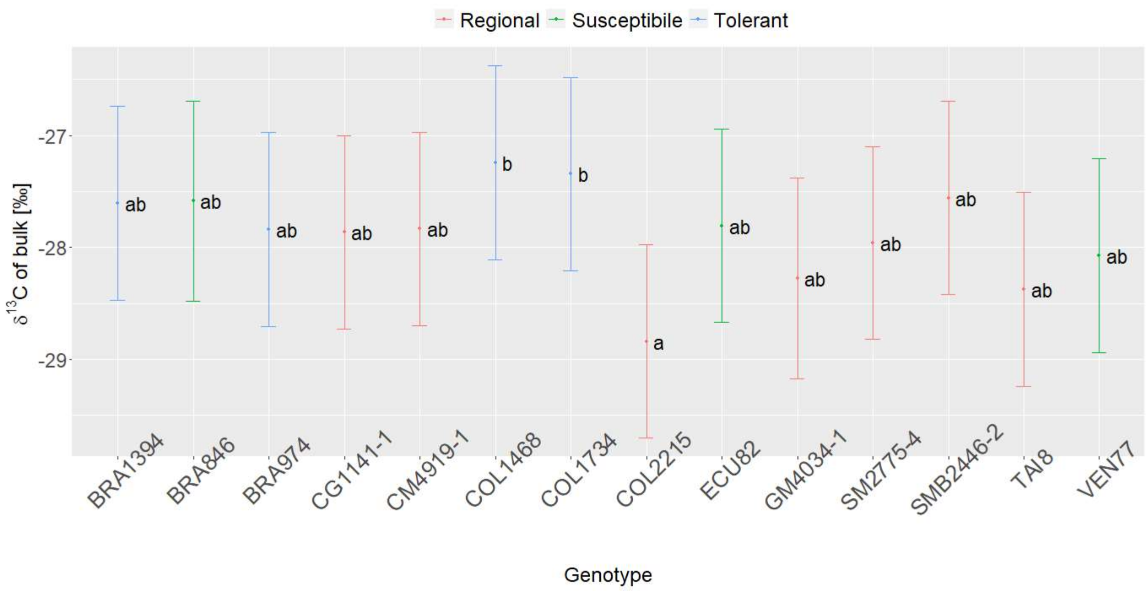

Figure 2. Comparison of the means of the δ13C value for each of the varieties at the two locations. This graph shows only the values obtained in YFEL for each variety (4 observations per variety). Varieties with different letters indicate a significant difference in δ13C (p<0.05)

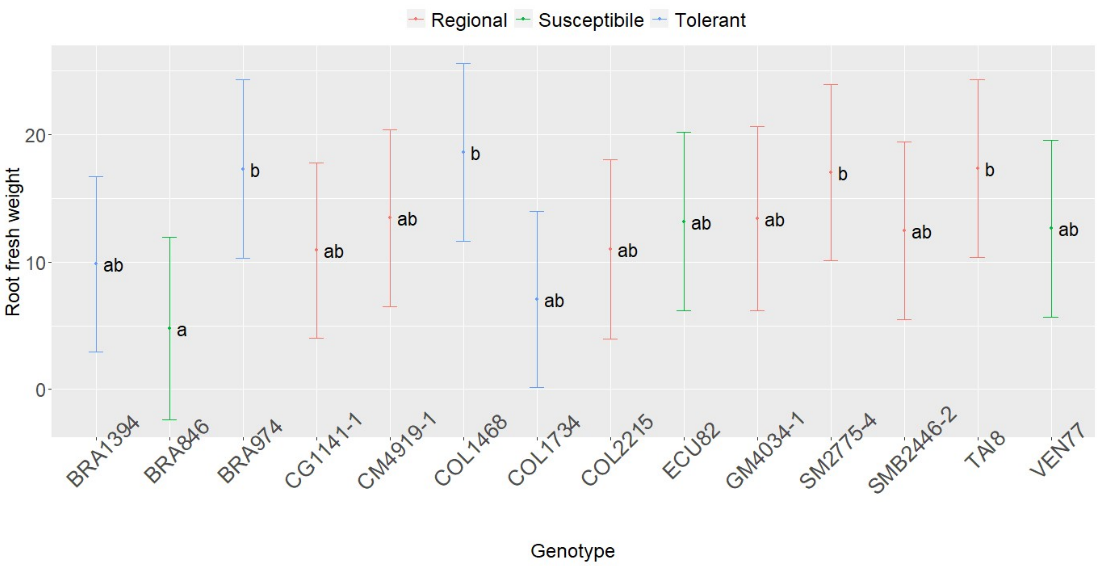

Figure 3 Description of the performance of 14 varieties averaged over the two locations (4 observations per variety). Varieties with different letters indicate a significant difference in yield (p<0.05), root fresh weight is in kg for four monitored plants, after nine months after panting.

Preliminary results from a ^{13}C labeling experiment in banana – evidence of continued carbon supply from mother to daughter plant

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In the previous newsletter from January 2022, we introduced a labeling experiment with banana which was performed in the SWCNL greenhouse. In the scope of the PUI (Peaceful Uses Initiative) project on *Enhancing climate change adaptation and disease resilience in banana-coffee cropping systems in East Africa*, funded by Belgium, we attempted to quantify and understand carbon fluxes in banana plants. Banana reproduces vegetatively, by forming suckers. These daughter plants remain connected to the mother plant, but it is unclear whether a dependency remains in place once the suckers become photosynthetically active themselves. In this experiment we exposed mother plants to labeled $^{13}CO_2$, so that we could determine what happened with the CO_2 built in by the mother plant and eventually, determine how much of this photosynthate would end up in the daughter plant.

We found that a carbon flux between mother and daughter plants does indeed exist (Figure 1). From 4 hours after labeling, we see an increase in the ^{13}C concentration in the phloem sap of the suckers' leaves. The phloem system is responsible for the transport of photosynthates from source to sink organs in plants. retrieving the ^{13}C label in the phloem sap of the sucker indicates that the sucker is receiving photosynthates from the mother plant and thus acts as a sink. The phloem sap ^{13}C concentration reaches a maximum after 24 hours. From 48 hours onwards, the flux seems to stabilize and persist.

Evidence for this persisting flux can also be seen in the ^{13}C concentrations in the leaves of the sucker (Figure 2). These start to increase from 48 hours onwards, as the ^{13}C accumulates. The largest excess amount of ^{13}C was found in the young and new leaves, which is according to expectations. These leaves are not or not fully developed yet and act as carbon sinks.

Important to note is that this constant flux of ^{13}C to the sucker persists, despite a strong decrease in ^{13}C concentration in the mother plant (result not shown). This highlights the important role of the corm. All carbohydrate transport passes through the corm. These results indicate that transport is not immediate, but carbohydrates are stored temporarily in the corm and are then transported to the sink tissues (in this case: the sucker) at a steady rate. The corm clearly plays an important role in regulating source-sink transport in banana plants.

Further analysis of the results will focus on the effect of drought on this transport. It is expected that the corm might play a role as a mitigating structure there as well. The knowledge that mother plants maintain a carbon flux to daughter plants, and that this is regulated by the corm, can help us formulate better recommendations for the management of banana plants, both under optimal and water limited conditions.

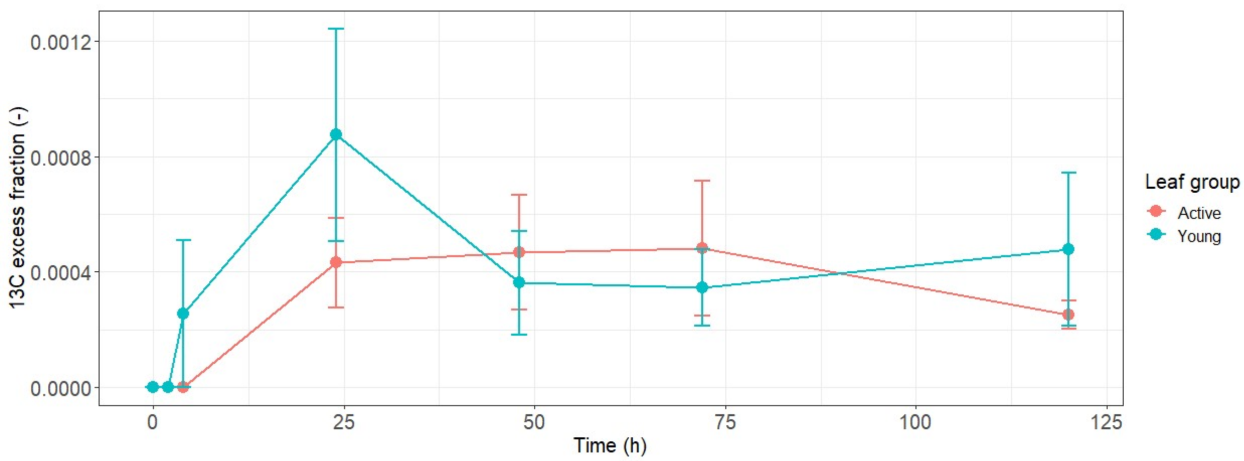

Figure 1. Evolution in time of the ^{13}C concentration in the phloem sap of the sucker plants' leaves, expressed as ^{13}C excess fraction (fraction of the total ^{13}C amount taken up by the plant). Values are given for two different groups of leaves, whereby "Active" consists of the fully developed photosynthetically active leaves and "Young" of the partially developed youngest leaves. Time is

expressed as hours after labeling.

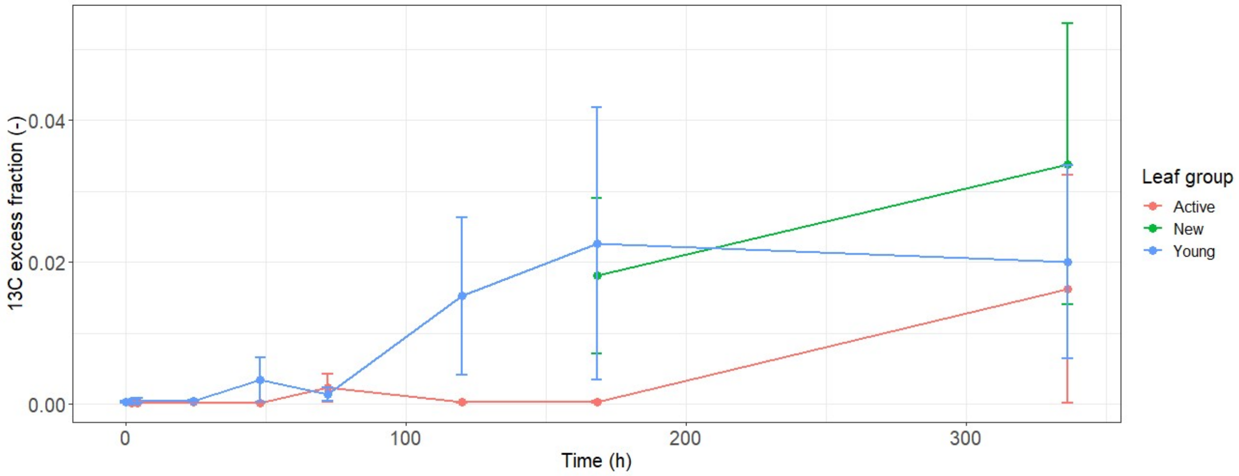

Figure 2. Evolution in time of the bulk leaf ^{13}C concentration in the sucker, expressed as ^{13}C excess fraction (fraction of the total ^{13}C amount taken up by the plant). Values are given for three different groups of leaves, whereby "Active" consists of the fully developed photosynthetically active leaves, "Young" of the partially developed youngest leaves and "New" to leaves that developed after the labeling took place. Time is expressed as hours after labeling

Advances on Antimicrobial Resistance (AMR): uncovering the fate of Sulfamethoxazole in agricultural soils with stable isotopes

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Antimicrobial resistance (AMR) is defined as the ability of microorganisms (bacterial, fungus, viruses and parasites) to withstand the effects of antimicrobials. Antimicrobials (AM) are used to treat bacterial and other microbial infections in both humans and animals and are also used as a growth promoter in animals. The preventative and therapeutic use of antibiotics (AB) in animal farming has been shown to contribute to an increase in AMR, and antimicrobials, antimicrobial resistance genes and/or bacteria can eventually end up in agricultural fields through the use of manure solids (Binh et al., *2008)* or wastewater (Negreanu et al., *2012)* and sludge as soil fertilizer (Krzemiński et al., *2020)*. Livestock farming is thus a source for AMR (FAO and IAEA, *2019)*, which is currently one of the most serious global health problems with about seven hundred thousand fatalities per year. While a lot of previous research on sulfamethoxazole (SMX) degradation was carried out in water tanks, less knowledge is available on SMX mineralization in soils (Ouyang et al., *2019)*. The recently initiated FAO/IAEA Coordinated Research Project (CRP) on *'Isotopic Techniques to Assess the Fate of Antimicrobials and Implications for Antimicrobial Resistance in Agricultural Systems'* targets the antibiotic sulfamethoxazole (SMX) as a model AM and will determine its fate in agricultural systems under laboratory and field conditions.

The FAO/IAEA Soil and Water Management & Crop Nutrition (SWMCN) Laboratory will support the ongoing CRP by conducting several incubation experiments with ^{13}C-labeled SMX. This would provide us with some insights on SMX turnover in soils, which might help design a strategy for studying the fate of SMX under field conditions. Several pieces of equipment were purchased and are now being installed at the SWMCNL. This includes (a) a Gas Chromatography-Isotope Ratio Mass Spectrometry (GC-IRMS) for compound-specific multi-element stable isotope fingerprinting, (b) a Cavity Ring-Down Spectroscopy (CRDS) analyzer (Picarro 2201-i), which precisely and continuously measures $\delta^{13}C$ in carbon dioxide (CO_2) and in methane (CH_4), (c) a Peltier-technology incubator Memmert for the incubation of soil samples amended with antibiotics at different temperature regimes. We intend to assemble an automated incubation system, where soil microcosms will be incubated for days or weeks, unattained by an operator, with constant monitoring of the CO_2 and CH_4 fluxes and their C-isotopic composition through discrete sampling of the closed chamber headspace. This approach could then be compared with the alternative, more established setup of a closed flux chamber with closed-loop recirculation of the headspace, which however requires the physical presence of an operator. With the new automated system, we target several research questions during the CRP. For instance, we aim to obtain new data on temperature and moisture sensitivity of SMX decomposition. In a later phase, we would also study the temperature and soil moisture sensitivity of SMX mineralization in soils under the influence of N and P fertilizers. Indeed, by applying ^{13}C-

labeled SMX to soil and subsequently tracking ^{13}C incorporation into CO_2 and CH_4, we should be able to distinguish the relative contribution of soil organic matter and SMX to the fluxes of both greenhouse gases. By means of GC-IRMS, we then want to determine ^{13}C incorporation into phospholipid-derived fatty acids (PLFAs) to estimate the proportion of SMX-C assimilated by different microbial groups.

Also, there is a gap in knowledge how SMX affects the soil microbial community and activity, and how this reflects in the decomposition rates of soil organic C and freshly added organic substances. To fill this gap, we set up an experiment in which ^{13}C-labeled glucose was applied together with unlabeled SMX (Fig. 1). Preliminary findings show inhibitory effects on overall decomposition rates at higher concentrations of newly applied SMX (starting from 10 mg SMX kg^{-1} soil). This shows that contamination with antibiotics in the environment could have implications on soil C stocks and turnover. Yet, it is unknown whether this effect could be counteracted by AMR that may arise in soil microorganisms (leading to less inhibition by SMX) on the long term.

Figure 1. Measurements of soil CO_2 and CH_4 fluxes and their C-isotopic signatures using the newly acquired Picarro 2201-i analyzer.

Altogether, the research experiments on isotopically labeled SMX will provide important insights on SMX mineralization in agricultural soils and on the environmental consequences of SMX contamination for soil microbial life and soil C dynamics.

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Determining the contribution of nitrogen fertilizer and mineralization to volatilized ammonia using nitrogen-15 technique

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Ammonia volatilization (AV) is one of the main pathways of nitrogen fertilizer loss, resulting in reduction of crop yields and a negative impact on the environment. The global demand for food is growing rapidly as the world's population grows and reducing AV through proper fertilizer management is essential to increase fertilizer use efficiency and consequently crop yield.

In 2022, the SWMCNL assessed the contribution of nitrogen derived from urea fertilizer to ammonia volatilization. Further, it used the same assessment to find out how the soil itself contributes to this process, and how fertilizer application may influence it. To answer these research questions, the SWMCNLteam used samples and datasets from a previous field experiment carried out in 2020.

In this previous field experiment, the main aim was to better understand the role of urease and nitrification inhibitors on ammonia emission in maize cropping systems. The main results were discussed in previous Newsletters (IAEA, 2021; IAEA, 2022). In this set-up ^{15}N labelled fertilizer was also used to assess nitrogen use efficiency.

In 2022, the samples taken in 2020 to calculate ammonia emissions for the treatments with and without urea, were further analysed in the laboratory; this time to know, as explained above, where the nitrogen in the ammonia emission is coming from. The use of ^{15}N labelled fertilizer has the unique advantage over other methods to precisely identify the nitrogen pathway.

Labelled urea was used and two ^{15}N microplots inside each main plot (8 m × 8 m) were installed. In these microplots, ^{15}N-labeled urea replaced the unlabeled urea according to the time of fertilizer application. Each microplot for ^{15}N-labelled urea was 2.5 m by 2.5 m, and the buffer zone between microplots was 1 m to minimize ^{15}N contamination from adjacent microplot (Figure 1). For these microplots, ^{15}N-labeled urea was used with an enrichment of 5.23 atom% ^{15}N excess. The first microplot received ^{15}N-urea at 20 Days After Planting (DAP) and unlabeled urea at 34 DAP, the second microplot received ^{15}N-urea at 34 DAP and unlabeled urea at 20 DAP. Ammonia volatilization was measured with semi-static chambers for all treatments. NH_3 chambers were installed inside the ^{15}N microplots. Figure 1 shows the position of the ammonia chambers inside each ^{15}N microplot.
The total cumulative NH_3 emissions from urea alone after the first and second split applications were 13.9 kg N ha^{-1} and 18.0 kg N ha^{-1}, respectively. The cumulative NH_3 emissions from control treatment (T_1) at the same time were 2.7 kg N ha^{-1} and 3.6 kg N ha^{-1}, respectively. This method is based on the difference in AV between experimental treatments and control treatment (non-fertilized plots). This assumes that AV in control plots indicates the amount of AV from the soil source, whereas AV of the fertilized treatments presents AV from soil and fertilizer sources. It also assumes that all nitrogen transformations, i.e., mineralization, immobilization, and other process in the case of nitrogen, are the same for control and experimental plots. Therefore, the amount of AV in urea treatment was subtracted from the amount of AV in control treatment. Accordingly, about 20% of the ammonia volatilized from the soil source and the rest is attributed to the added urea fertilizer.

However, through the use of the ^{15}N labelled fertilizer, it was found that the fraction of nitrogen in the ammonia samples derived from the soil is not constant but changes significantly due to nitrogen fertilizer application. The results show that the nitrogen in the ammonia derived from the fertilizer (Ndff $_{\text{ammonia-gas}}$) was 65% and 53% after the first and second split applications, respectively. Therefore, the fraction of nitrogen in the ammonia samples derived from the soil source (Ndfs $_{\text{ammonia-gas}}$) was 35% and 47% after the first and second split applications. So, the use of the ^{15}N technique shows that adding nitrogen fertilizer likely increased the rate of mineralization by changing the ratio of carbon to nitrogen. Figure 2 shows the fraction of nitrogen in the samples derived from the ^{15}N-labeled fertilizer and soil.

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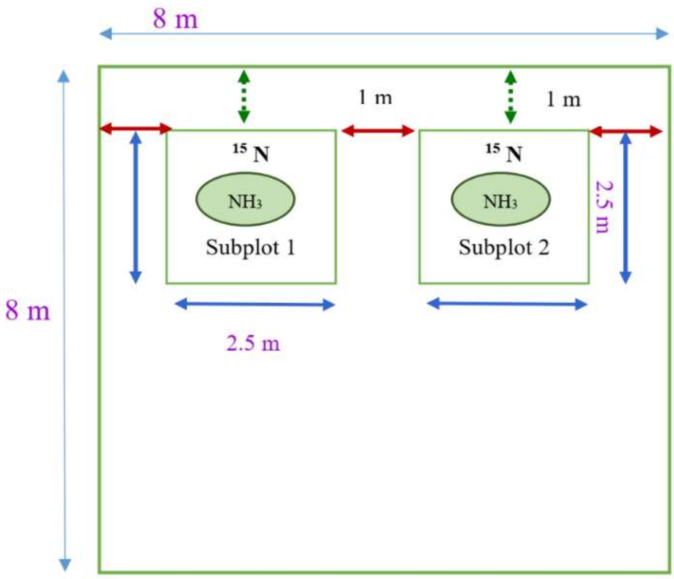

Figure 1. A schematic diagram of ^{15}N microplots inside each main plot.

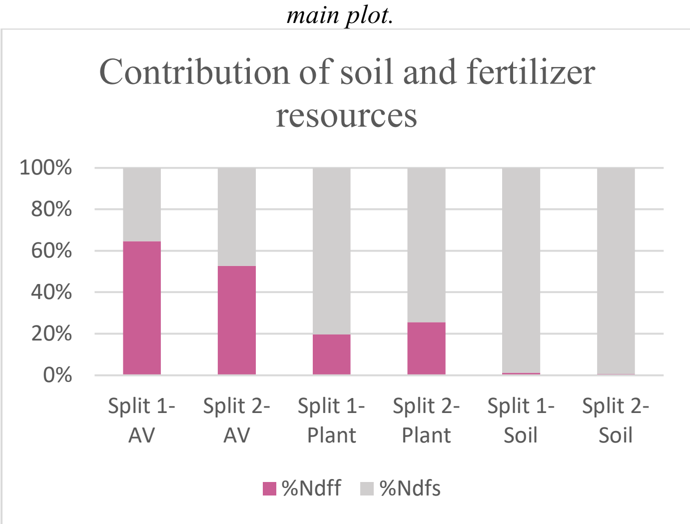

Figure 2. Contribution of soil and fertilizer resources in ammonia gas, plant and soil samples using ^{15}N technique.

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: an update on the nitrogen uptake analysis

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Sustainable agricultural development requires that we place a high degree of importance on nutrient and water management. Continued research contributes to a more efficient use of scarce resources and helps reduce costs and negative environmental impacts.

To optimize water and nitrogen (N) use efficiency of maize cropping systems in Southeast Africa, a set of field experiments is being conducted in Chilanga, Zambia. A first experiment was implemented in 2021. The aim was to obtain the optimal level of water and N to achieve the highest yield with minimal adverse effect to the environment while adapting to climate change. A simplified sampling method to determine ^{15}N signatures in plant samples for estimating nitrogen fertilizer use efficiency through the ^{15}N isotope dilution method was tested. This sampling method is based on punching leaves instead of using the more labor-intensive bulk sampling.

Maize was planted at three N and three irrigation levels (see for a more detailed description in the Soils Newsletter Vol. 44 No. 2 Jan 2022). Punched samples (Fig. 1) from five leaves (at different vegetation stages) of four maize plants per microplot applied with ^{15}N enriched fertilizer were collected as well as whole plants (bulk samples) for ^{15}N analysis. The percent of nitrogen derived from fertiliser (%Ndff) was then compared with the bulk sample.

Figure 2. Collecting punched leaf samples from a young leaf

Preliminary analysis shows that in this case young leaves would give a better representation of the bulk sampling. Figure 2 illustrates this, showing leaf number 2 (1 being the youngest and 5 the oldest) with the narrowest correlation with bulk data. More refining of the results (Fig. 3) showed that punched leaf samples near the stem are a more desirable position compared to the top and middle of the leaf. Further research is needed to confirm these findings, because it may be possible that the number of leaves with the best correlation is not stable and may depend on fertilizer application and sampling timing.

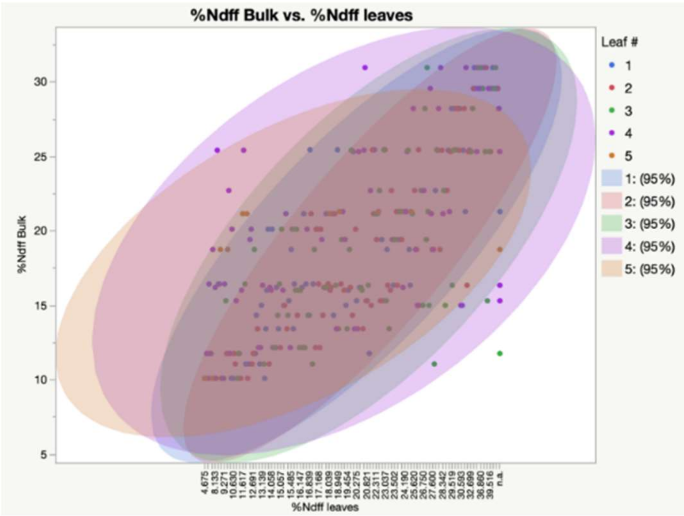

Figure 3. Relating %Ndff of bulk plant and %Ndff of leaves of said plant (1 being the youngest and 5 the oldest)

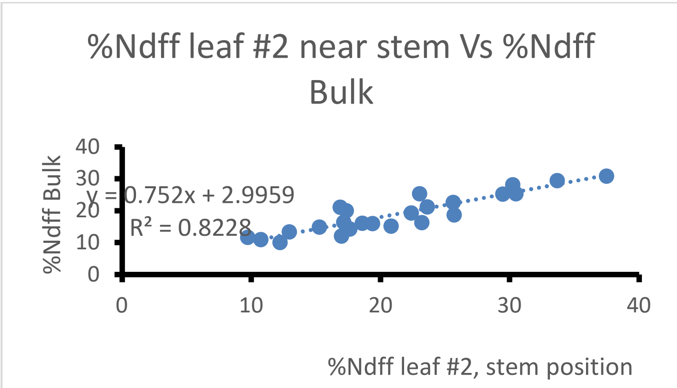

Figure 3. Relationship between %Ndff of leaf #2 and %Ndff of bulk samples

This project has been supported through the ICTP/IAEA Sandwich Training Educational Programme (STEP). Through this fellowship, the fellow Mumba Mwape can join the SWMCNL team three times over a three-year period. You can find more information about ICTP/IAEA STEP opportunities on the following website: ICTP - ICTP/IAEA Sandwich Training Educational Programme.

Tree specii and stand density: the effects on soil organic matter contents, decomposability and susceptibility to microbial priming

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Forest stand density has been shown to have different, albeit small, effects on soil carbon. We hypothesized that the absence of a density effect on soil carbon (C) storage could be explained by a loss of old soil C. This replacement of old by fresh C could result in zero net C sequestration by soils but could also alter the quality of the soil organic matter. We used one afforestation experiment in Siberia, in which three tree species (spruce, larch and Scots pine) have been grown for the last 30 years at 18 levels of stand density, ranging originally from 500 to 125,000 stems per ha. We selected five density levels and studied the C and nitrogen (N) contents in mineral soils at 0–5 cm depth. The age of the soil C was measured under larch and spruce for three levels of density by radiocarbon (14C) dating. In all soil samples, we determined the stability of the soil organic matter (SOM) by assessing two indices: C decomposability (mineralization of C per unit of soil C) and primability (susceptibility of the SOM to microbial priming). The stand density affected the soil C and N contents differently depending on the tree species. Only under spruce did both the C and N contents increase with density; under larch and pine, the covariation was insignificant and N even tended to decline with a density increase. With the ^{14}C data, we were able to show the strong dilution of old SOM by fresh C derived from the trees; the effect was stronger with a higher density (Fig. 1). This provides the first evidence that a density increase increases the fractions of new C versus old C and this can happen without altering the total C contents such as under larch. Although the stand density altered the soil C and N contents only under spruce, it altered C decomposability under all tree species; with a density increase, the C decomposability declined under spruce but increased under larch and pine. This is relevant to predicting C losses from forest soils with different tree species and densities. Higher C losses would occur under larch and pine with higher densities but under spruce, a density increase would reduce the losses of C from the soil. Furthermore, although no significant covariation of stand density with C primability was detected, we first observed strong tree species effects on C primability. Twice as much C was lost from the soil under larch than under spruce or pine by an equal addition of C-glucose. This indicated that elevated C deposition from roots and exudates to the soil as predicted due to an elevated CO2 concentration would most strongly accelerate the soil C turnover and C losses under larch than under spruce and Scots pine. Overall, the tree species altered the susceptibility of the soil C to an elevated C input and the stand density had a strong effect on the decomposability of the SOM, which is an important parameter of C stability. The effect of stand density is, therefore, important to consider even if the stand density does not affect the total soil C.

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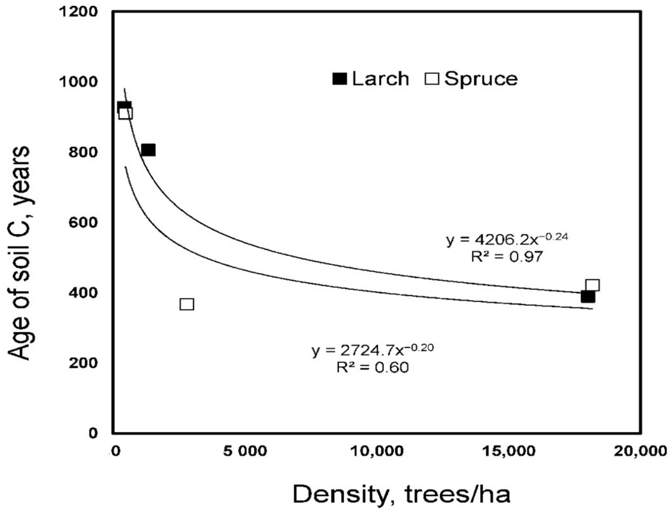

Figure 1. Dependency of age of soil carbon on stand density for spruce and larch.

Unprecedented role of soil weathering stage on radiocaesium revealed

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PhD R&D highlights the importance of studies to improve baseline information and decision-making for optimizing remediation of radioactive contamination of agricultural land

Under the CRP D15019 on "Remediation of Radioactive Contaminated Agricultural Land", two PhD studies are being carried out through two research agreement holders, i.e. Belgian Nuclear Research Centre and University of Leuven, in close collaboration with the SWMCNL. They are important pillars for the R&D activities to better understand the dynamics of radiocaesium in under-explored agro-ecosystems and to optimize remediation by improved decision-making tools.

Pot experiments assessing ^{137}Cs transfer factor

Radiocaesium (^{137}Cs) is of concern when released into the environment after a nuclear accident because ^{137}Cs has a half-life of 30 years, it is mobile in water and biochemically similar to nutrients such as potassium (K). The bioavailability of ^{137}Cs is quantified by a transfer factor (TF) which is the ratio of the ^{137}Cs in the plant material and ^{137}Cs in the soil. Current models predict the TF based on soil and plant properties. However, these models perform poorly for soil and climate conditions that contrast sharply with those with which the model was originally calibrated, such as young, volcanic soils and highly weathered, tropical soils. That is the logical result of the fact that most data come from the accident in Chernobyl and Fukushima. It is very likely that current data do not sufficiently cover the contrasting global soil mineralogies that, in turn, affect ^{137}Cs fixation and K buffering capacity.

A laboratory pot experiment was set up with soils from more contrasting locations than ever done (cf. IAEA, 2010), including soils from Kenya, Tanzania, Madagascar, China, and the Philippines (Figure 1). Soils were spiked with ^{137}Cs on which ryegrass was grown. Soils originated from a variety of parent rocks in contrasting weathering stages, so the mineralogical compositions differ markedly.

The TF varied by 4 orders of magnitude, illustrating a huge effect of soil on ^{137}Cs bioavailability (Figure 2). This wide range of TF values can neither be explained by soil plant properties such as the clay content, nor the organic matter. The TF can be partly explained by the negative relation with the cation exchange capacity, or better by the exchangeable K soil content. However, TF predictions can probably be improved by including soil mineralogy. The data from soil mineralogy will reveal this in the near future. The aim of this research is to improve the ^{137}Cs soil-plant transfer predictions used for emergency preparedness and the recovery phase in case of nuclear power plant accidents.

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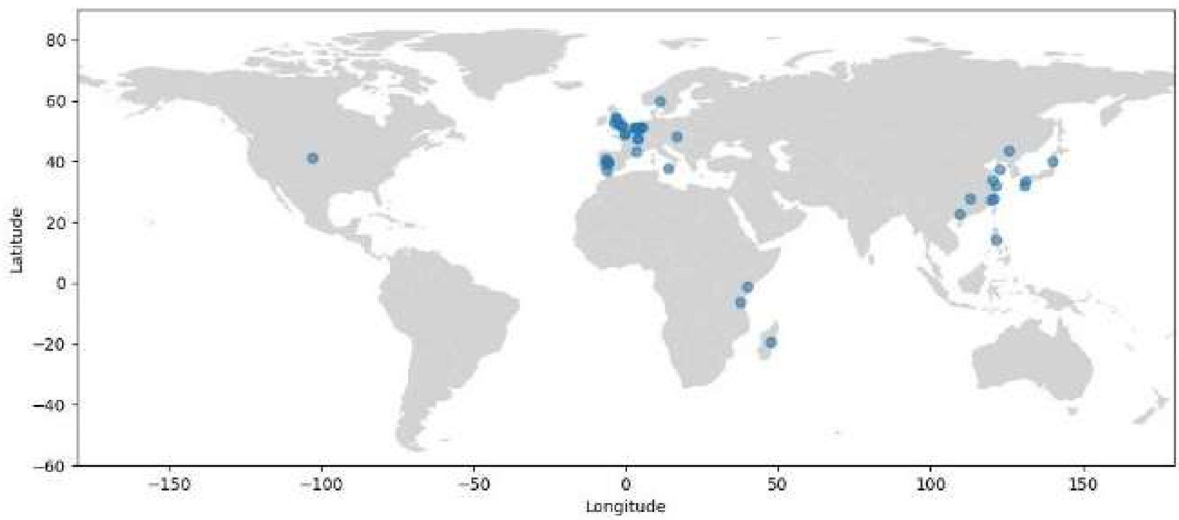

Figure 1. Origin of soil samples used in the pot experiment.

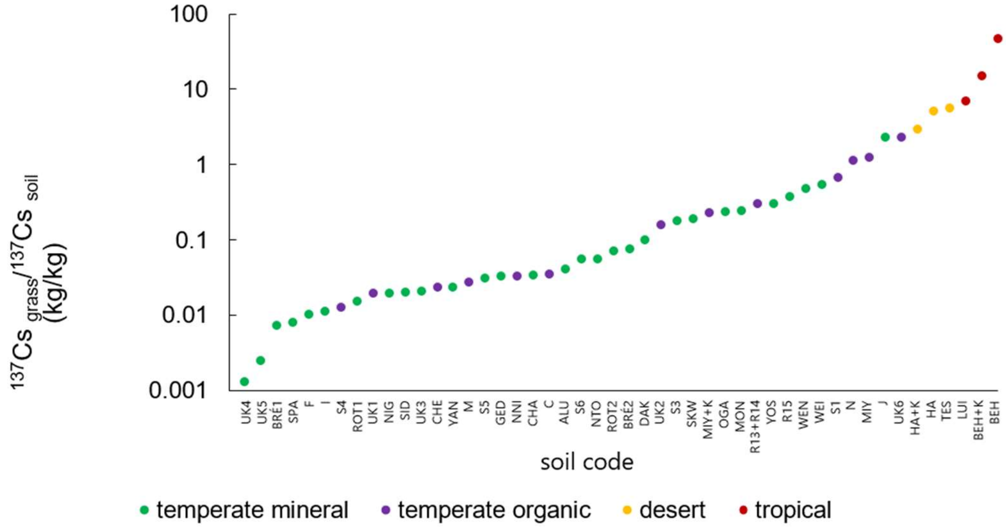

Figure 2. The ^{137}Cs transfer factors in ascending order and categorised by general soil origin. Soil codes are listed on the x-axis with code+K for K-fertilised soils

Optimizing remediation decisions in response to off-site effects found in large-scale nuclear emergencies affecting food and agriculture

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After a large-scale nuclear emergency a large proportion of the surrounding area will become contaminated with radioactive substances, especially with radiocaesium (Morino et al., 2011). A major part of the radiocaesium deposited on the ground will become fixed tightly to the soil particles as seen in Fukushima (Qin et al., 2012). Subsequent migration of the deposited radiocaesium to the river system can occur through the physical movement of soil particles (Yoshimura et al., 2015). Many studies have reported radiocaesium wash-off resulting from soil erosion in Fukushima (Evrard et al., 2015; Onda et al., 2020) and Chernobyl (Konoplev et al., 2021). Radiocaesium wash-off originating from soil erosion of contaminated upslope sites can affect the concentration of radiocaesium in river water over long periods (Matsunaga et al., 1998). Therefore, the potential downstream effects of radiocaesium wash-off needs to be taken into account when optimizing the remedial efforts for the whole watershed. If contaminated water from the downstream river system will be used for irrigation of agricultural crops, caution is needed to prevent recontamination. Even more, when the erosion of upslope agricultural parcels or forest areas can directly cause an influx of contaminated soil particles to the downslope fields.

The priority of remediation should be given to fields which will have a significant contribution of radiocaesium to the river outlets and/or other agricultural parcels. Radiocaesium wash-off depends on the amount of eroded soil and the radiocaesium concentration in the soil. Both these factors are strongly impacted by many of the traditional remedial actions used for decontaminating agricultural areas. Therefore, minimizing the flow of radiocaesium wash-off from soil erosion to sensitive receptors, such as the river systems is of vital importance. A Cellular Automata Based Heuristic Solution Method for Minimizing Flow (CAMF) is being adapted to take into account the movement of contaminated sediments in the landscape. Using an iterative workflow the model will identify the areas with the highest contribution of radiocaesium wash-off to the outlet, therefore these areas need to be prioritized for remediation (Figure 1). This model will be further integrated in the on-site decision support system (OREFA) developed by Belgium counterpart under CRP D15019, where it can help improve with the efficient allocation of resources for remediation of agricultural regions.

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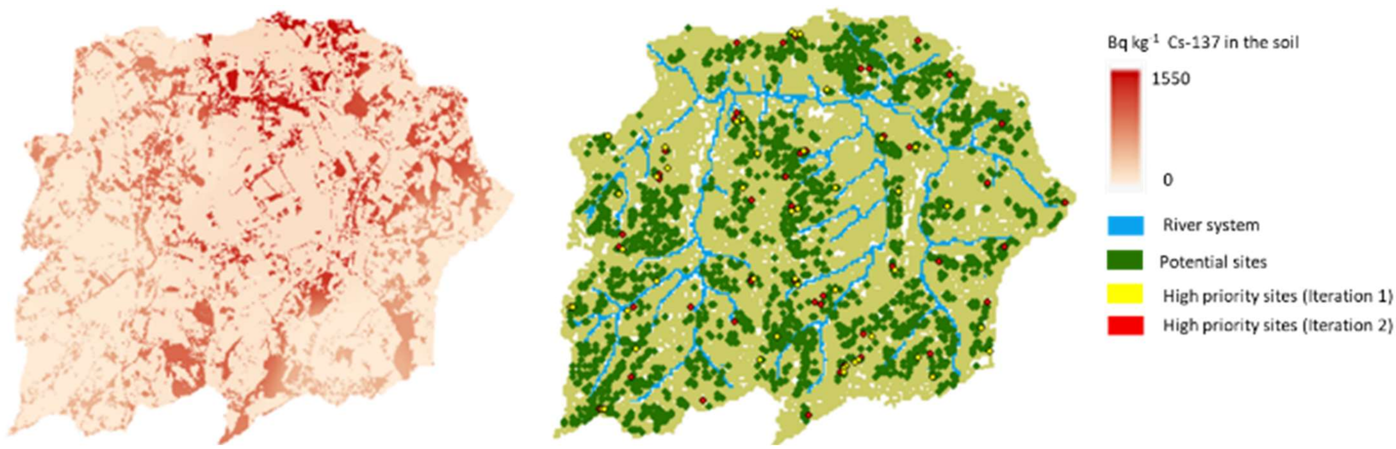

Figure 1. Identification of priority areas for remediation decisions based on the movement of contaminated sediments in the Maarkebeek catchment, using Cellular Automata Based Heuristic Solution Method for Minimizing Flow (CAMF). The modelled contamination levels found in the soil sediments (Left) and identification of high priority areas from the CAMF model (Right).

SWMCNL participates in the international ring trial for supporting calibration transfer of infrared soil spectroscopy instrumentation

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Infrared soil spectroscopy is a non-destructive and cost-effective method used for rapid soil property prediction, which does not require any hazardous chemicals. Every single soil spectrum contains information of numerous soil parameters. Thus, it has a high potential in facilitating soil property monitoring and preparing regional and worldwide soil data bases. However, the prediction of soil properties through spectroscopy depends on the quality and availability of spectral libraries and reference measurements through wet chemistry analysis. The variability of the spectral response across different instruments and the lack of standards limits the comparability, but also the direct and worldwide use of these libraries.

Figure 1. MIR spectroscopy measurement of soil samples

To assess this lab-to-lab variability of spectra and to support the development of calibration transfer models, the Woodwell Climate Research Center initiated in 2022 a soil spectroscopy ring trial, through the Soil Spectroscopy for Global Good initiative.

The SWMCNL is one of the 19 groups across 15 nations participating in that comparison. Every laboratory received 60 reference samples at large range in soil properties and spectral response, including wet chemistry analysis data from the USDA NRCS National Soil Survey Center – Kellogg Soil Survey Laboratory (NSSC-KSSL) and ten samples without any background information from the North American Proficiency Testing (NAPT) program.

The NSSC-KSSL samples will be used to develop calibration transfer models, the NAPT samples will be used as an independent test set.

Enhancing capacity of national producers to achieve higher levels of self-sufficiency in key staple crops (TC-IRA5015)

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Nitrification and urease inhibitors (NI and UI) have been proposed as means to increase nitrogen use efficiency (NUE) and crop yield. However, a positive response to the use of inhibitors depends on environmental factors. The effectiveness of using inhibitors (2-NPT: N-(2-nitrophenyl) phosphoric acid triamide as UI, and MPA: N-[3(5)-methyl-1H-pyrazol-1-yl) methyl] acetamide as NI) on winter wheat yield and NUE was investigated under the national TC project IRA5015 in the semi-arid region of Iran (Figure 1). Grain yield in urea + UI (4.3 t ha^{-1}) and urea + UI + NI (4.5 t ha^{-1}) increased by about 5% and 10%, respectively, compared to the farmer practice (4.1 t ha^{-1}). Our results showed that NUE in urea+UI (33%) and urea+UI+NI (35%) increased by about 10% and 17%, respectively, compared to the farmer practice (30%). Given that the use of inhibitors incurs additional costs for farmers, it is paramount to compare their effectiveness with other methods that increase productivity and NUE. In the second year of the TC project, an evaluation of the effect of biofertilizers (plant growth promoting rhizobacteria) and nitrification-urease inhibitors on NUE and crop yield will be carried out.

Figure 1. Field experiment in Karaj (Iran)

Rayehe Mirkhani is currently a fellow at the SWMCNL funded by the IAEA Technical Cooperation Programme for six months, where she is being trained in the use of stable isotope techniques to trace nitrogen losses through ammonia volatilization.

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Websites and Links

- Soil and Water Management and Crop Nutrition Section: https://www.iaea.org/topics/land-and-water-management
- Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture: https://www.iaea.org/topics/food-and-agriculture
- Food and Agriculture Organization of the United Nations (FAO): http://www.fao.org/home/en
- New communication materials outlining successes in the area of nuclear techniques in food and agriculture: https://www.iaea.org/sites/default/files/cb5847en.pdf

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