Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

# Soils Newsletter

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# To Our Readers


*In IAEA's Spotlight session on 18 March 2021, Gerd Dercon and Lee Heng gave an overview of how nuclear and isotopic techniques are being used in agricultural water management through climate-smart agriculture. In the above photo, SWMCN Laboratory staff Hami Said Ahmed and Georg Weltin were busy setting up a field experiment on a cold and windy day.*

I am very happy to announce that the SWMCN Laboratory has filled the two vacant positions. Mr Oleg Menyailo from Russia joined us in July as soil chemist, and Mr Reinhard Pucher from Austria as laboratory technician. Mr Oleg Menyailo was a Professor at the Institute of Forest Siberian Branch of the Russian Academy of Sciences in Krasnoyarsk before joining the Agency. He has many years of international experience working in Germany, USA and the UK. Oleg's research has been on soil processes related to C and N turnover and greenhouse gases. He had used stable isotopes to distinguish processes of $N_2O$ production and consumption, and uncovered groups of methanotrophs responsible for oxidation of atmospheric $CH_4$ in different land use systems. Mr Reinhard Pucher is a trained chemist and has worked as a laboratory technician in Octapharma. His previous work involved the development of laboratory methods, servicing and repairing of laboratory equipment, and training of staff. We wish both Oleg and Reinhard a smooth transition into their new jobs at the SWMCN Laboratory.

The SWMCN Section managed to implement three virtual research coordination meetings (RCM) in the last six months – these were the 1st RCM of the new coordinated research project (CRP) D1.50.20 in February 2021; the 2nd RCM of CRP D1.50.18 in early March 2021; and the 2nd RCM of CRP D1.20.14 in June 2021. In the coming six months, two and possibly three RCMs will be held, i.e. the 4th (final) RCM of CRP D1.50.17 on 'Nuclear Techniques for a better understanding of the Impact of Climate Change on Soil Erosion in Upland Agro-ecosystems' in July 2021, and the 2nd RCM of CRP D1.50.19 on 'Remediation of Radioactive Contaminated Agricultural Land' in October 2021 in Japan.

Through extrabudgetary funds, a new CRP on 'Isotopic Techniques for Better Assessment of the Persistence and Transport of Antibiotics through Soils, Water and the Environment in Agricultural Catchments' will be implemented this year. A Consultants' Meeting (CM) is being organized in the coming month, and it is hoped that the 1st RCM can be implemented in 2021. The need for a CRP on this topic is pressing because it is projected that by 2050, there will be some 10 million people worldwide dying annually from resistant infections. While antimicrobial resistance (AMR) has been widely studied from the angles of human and animal health, little is known about the impacts it has on the soil, water and the environment. The FAO Director-General Mr Dongyu Qu recently called for decisive action to tackle AMR at the UN General Assembly. The CM aims to discuss novel nuclear (multielement stable isotopes fingerprinting) and related techniques that can be used to detect and trace the source and transport of AMR through soil, water and the environment. The CM and the new CRP will build on the recent publication on 'Antimicrobial movement from agricultural areas to the environment: The missing link. A role for nuclear techniques' http://www.fao.org/3/ca5386en/ca5386en.pdf.

Three interesting feature articles are presented in this issue of the newsletter – on 'Global Networking for Enhancing Climate-Smart Agriculture Benefits', '$Ag_3PO_4$ Comparison Material for Stable Oxygen Isotope Analysis' and on 'Tackling the Global Threat of Antimicrobial Resistance (AMR) – A High Priority Agenda of One Health Global Leaders Group on AMR'.

The Joint ICTP-IAEA Workshop on 'Use of Cosmic Ray Neutron Sensor for Soil Moisture Management and Validation of Remote Sensing Soil Moisture Maps' was successfully held in May 2021. A total of 54 trainees from 31 countries attended this virtual workshop.

The FAO/IAEA International Symposium on Managing Land and Water for Climate Smart Agriculture will be held in about a year's time from 25–28 July 2022 in Vienna, Austria. It is our decennial event, focusing on land and water management for climate smart agriculture. Please mark this event in your calendar.

Research and development work continued, as planned, at the Soil and Water Management and Crop Nutrition Laboratory in Seibersdorf. Only a few are mentioned here. In the area of cosmic ray neutron sensor (CRNS) technology, further progress was made to use artificial intelligence to reduce the complexity of calibrating the sensor. Similarly, new and cheaper detectors avoiding the use of Helium-3 and with lighter material for the CRNS are also being tested on the SWMCN Lab research sites. Good progress is also being made in the extrabudgetary CIALCA project on improving climate change resilience of cassava in Central Africa, especially through developing the first ever AquaCrop Cassava model using data from Africa and Latin America.

We have had a lot of staff movement in the last six months. We bid farewell to Ms Janine Halder, Ms Joanna Mleztko and Mr Tetsuya Eguchi. Janine left us in February 2021, while Joanna and Tetsuya both left us in March. We wish all of them the very best in their future undertaking. We welcome Ms Aminata Faustmann as the SWMCN Laboratory's team assistant. We also welcome our two new interns, Mr Innocent Hategekimana from Rwanda and Mr Mike Rohling from Germany. We congratulate Mr Norbert Jagoditsch who received the IAEA long service (30 years) award in April 2021. Many thanks to Norbert for his contributions to the Laboratory.

Finally, I would like to take this opportunity to once again thank all our readers for their continuous support. Continue to stay safe and healthy!

**Lee Heng**
**Head**
**Soil and Water Management and**
**Crop Nutrition Section**

# Staff

## Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture

| Name | Title | Email | Extension | Location |
|---|---|---|---|---|
| Qu LIANG | Director | Q.Liang@iaea.org | 21610 | Vienna |

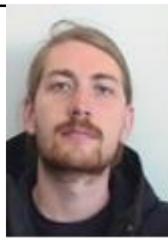
## Soil and Water Management and Crop Nutrition Subprogramme

| Name | Title | Email | Extension | Location |
|---|---|---|---|---|
| Lee Kheng HENG | Section Head | L.Heng@iaea.org | 26847 | Vienna |
| Mohammad ZAMAN | Soil Scientist | M.Zaman@iaea.org | 21645 | Vienna |
| Emil FULAJTAR | Soil Scientist | E.Fulajtar@iaea.org | 21613 | Vienna |
| Joseph ADU-GYAMFI | Soil Fertility Specialist | J.Adu-Gyamfi@iaea.org | 21693 | Vienna |
| Marlies ZACZEK | Team Assistant | M.Zaczek@iaea.org | 21647 | Vienna |
| Tamara WIMBERGER | Team Assistant | T.Wimberger@iaea.org | 21646 | Vienna |
| Gerd DERCON | Laboratory Head | G.Dercon@iaea.org | 28277 | Seibersdorf |
| Oleg MENIAILO | Soil Chemist | O.Meniailo@iaea.org | 28677 | Seibersdorf |
| Hami SAID AHMED | Soil Scientist | H.Said-Ahmed@iaea.org | 28726 | Seibersdorf |
| Maria HEILING | Senior Laboratory Technician | M.Heiling@iaea.org | 28272 | Seibersdorf |
| Christian RESCH | Senior Laboratory Technician | CH.Resch@iaea.org | 28309 | Seibersdorf |
| Georg WELTIN | Senior Laboratory Technician | G.Weltin@iaea.org | 28258 | Seibersdorf |
| Arsenio TOLOZA | Laboratory Technician | A.Toloza@iaea.org | 28203 | Seibersdorf |
| Reinhard PUCHER | Laboratory Technician | R.Pucher@iaea.org | 28258 | Seibersdorf |
| Norbert JAGODITSCH | Laboratory Attendant | N.Jagoditsch@iaea.org | 28406 | Seibersdorf |
| Aminata FAUSTMANN | Team Assistant | A.Faustmann@iaea.org | 28362 | Seibersdorf |
| Mathilde VANTYGHEM | Consultant | M.Vantyghem@iaea.org | 28576 | Seibersdorf |
| Jonas VAN LAERE | Consultant | J.Van-Laere@iaea.org | 27463 | Seibersdorf |
| Mike ROHLING | Intern | M.Rohling@iaea.org | - | Seibersdorf |
| Innocent HATEGEKIMANA | Intern | I.Hategekimana@iaea.org | - | Seibersdorf |

***Soil and Water Management and Crop Nutrition Section***
*Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture*
*Vienna International Centre, P.O. Box 100, A-1400 Vienna, Austria*
*Telephone: (+43 1) 2600+Extension; Fax (+43 1) 26007*

***Soil and Water Management and Crop Nutrition Laboratory***
*FAO/IAEA Agriculture and Biotechnology Laboratories, A-2444 Seibersdorf, Austria*
*Telephone: (+43 1) 2600+Extension; Fax (+43 1) 26007*

## Soil and Water Management and Crop Nutrition Subprogramme

| | | | |
|---|---|---|---|
|  |  |  |  |
| **L. K. Heng** | **M. Zaman** | **E. Fulajtar** | **J. Adu-Gyamfi** |
|  |  |  |  |
| **M. Zaczek** | **T. Wimberger** | **G. Dercon** | **O. Menyailo** |
|  |  |  |  |
| **H. Said Ahmed** | **M. Heiling** | **C. Resch** | **G. Weltin** |
|  |  |  |  |
| **A. Toloza** | **R. Pucher** | **N. Jagoditsch** | **A. Faustmann** |
|  |  |  |  |
| **J. Van Laere** | **M. Vanthygem** | **I. Hategekimana** | **M. Rohling** |

# Staff News

**Innocent Hategekimana** (Rwanda) joined the SWMCN Laboratory as an intern in January 2021 for 6 months. He is a MSc graduate in agro and environmental nematology from Ghent university, Belgium. During his internship, he assisted ongoing research on water use efficiency in cassava cropping systems. His work includes taking care of plants in greenhouse, physiological data collection, stable isotopes analysis and data analysis. The opportunity of working in the SWMCN Laboratory allowed him to gain practical experience about the use of stable isotopes in plant physiology and water management.

**Aminata Faustmann** (Austria / Gambia) joined the SWMCNL team in February 2021 as a Team Assistant, replacing Joanna Mleztko. Aminata came to the IAEA in 1998, working mostly with the Department of Safeguards, and some years with the Department of Technical Cooperation (Division for Africa). During her IAEA break in service, from 2017 to 2020, she helped in Gambia in development projects to improve the living conditions of rural and urban population, with emphasis on girls' education, health system and services, sanitation and electricity provision. Aminata attended the European Secretary Academic (ESA) in Vienna. She has lived in Vienna for 29 years, and is greatly looking forward to being part of the SWMCNL team.

**Janine Halder** left the SWMCN Section in February 2021 after successfully completed her seven-year with the Agency. During the two and half years with the SWMCN Section, Janine contributed her isotope hydrology knowledge in the agricultural water pollution work, especially on tracing the nitrate sources in the Danube Watershed, which was linked to the EU Nitrates Directive. Janine also supported several CRP (D1.20.14 and D1.50.18) and TC projects (SEY5011 and SLO5004). We thank Janine for all her contribution and wish her success in her future career.

**Mike Rohling** (Germany) joined the SWMCN Laboratory as an intern in March 2021 for six months. He pursued his bachelor's degree in Agricultural Sciences (Germany), and now he is studying towards a master's degree in Environment and Bio-Resources Management (Austria). Mike's internship work at the SWMCN Laboratory focuses on the influence of N-fertilization and clay amendments on plant available radioactive caesium, which will be part of his master thesis. His research for his master's degree will help optimize remediation of radioactive contamination in agriculture. Mike will use this opportunity to get to know the basic methods of soil chemistry as well as specific methods for his particular research. After he finishes his internship and his master's program, he will have more insight into scientific work and can decide subsequently if he would like to follow a PhD program.

**Joanna Mleztko** (Poland) left the SWMCN laboratory in March 2021 on a temporary in-house reassignment to join the IAEA Department of Management, Office of Procurement Services (MTPS). Due to her many years' support in dealing with large number of laboratory procurement and shipment requests she decided to deepen her knowledge in the public procurement field. She is currently working with MTPS as a Procurement Assistant. In her new role, she is learning the Agency's procurement process from the buyer's perspective to as a requestor.

**Tetsuya Eguchi** (Japan) left the SWMCN Laboratory in March 2021 after working with us as a visiting researcher for almost two years. Tetsuya came from the National Agriculture and Food Research Organization (NARO) in Japan. His research in the SWMCN Laboratory was on evaluating zeolite amendments on radiocaesium selectivity in selected Japanese soils. The study showed the influence of K addition on solution Cs concentration differ among Japanese soils, due to the differences in clay mineralogy. This work is in support of D1.50.19 CRP on "Monitoring and predicting radionuclide uptake and dynamics for optimizing remediation of radioactive contamination in agriculture" and as part of the Practical Agreement between the Joint FAO/IAEA Centre and NARO. We thank Tetsuya for his good work and the continual support even upon his return to Japan.

**Norbert Jagoditsch** (Austria) received the IAEA long service award in April 2021, with the certificate given by Mr Qu Liang on behalf of NA DDG Ms Najat Mokhtar. Norbert worked 30 years for the SWMCN Laboratory, assisting in greenhouse and field experiments of Lab staff in various aspects of climate smart agriculture. We congratulate Norbert for receiving the award and thank him for his continuous support during the last 30 years. We wish him all the best for the future.

**Oleg Menyailo** (Russia) joined the SWMCN Laboratory as Soil Chemist in July 2021. Oleg defended his PhD from Moscow State University in 1996 and has been working at the Institute of Forest Siberian Branch of the Russian Academy of Sciences in Krasnoyarsk. Oleg obtained many competitive grants, including the Marie Curie Fellowship from the European Commission, Alexander-von-Humboldt Fellowship, Fulbright Scholarship, Russian President grant for best professors. In 2016 he was elected as a Professor of the Russian Academy of Sciences. He has many years of international experience working in Germany (4 years), USA (4 years) and the UK (2 years), and has also established a stable isotope laboratory in Krasnoyarsk, and in advising the governments on natural resources, agriculture policy and environmental issues. Oleg's research focused on soil processes, related to C and N turnover, production and consumption of greenhouse gases. He utilized nuclear techniques such as stable isotopes to distinguish processes of $N_2O$ production and consumption, uncovered groups of methanotrophs responsible for oxidation of atmospheric $CH_4$ in different land use systems.

**Reinhard Pucher** (Austria) joined the SWMCN Laboratory as Laboratory Technician in July 2021. He is a trained chemist and holds a diploma from the HTL Rosensteingasse in Austria. Before joining the IAEA, Mr Pucher worked as a laboratory technician for Octapharma company. His work involved trouble-shooting, servicing and repairing of laboratory equipment and training of staff. He also wrote SOPs and developed new laboratory methods. In SWMCN Laboratory, Mr Pucher will be working with Mr Christian Resch on the operation and analysis of stable isotope samples (N-15, C-13, O-18 and H-2) in soil, plant, water and gaseous samples for R&D as well as for CRPs.

# Feature Articles

## Global Networking for Enhancing Climate-Smart Agriculture Benefits

**_Zaman, M.[1], Luterbacher, J.[2], Jahangir, M.R.R.[3], Mulwa, R.[4], Kleineidam, K.[5], Müller, C.[5]_**

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

[2]*World Meteorological Organization, Geneva, Switzerland*

[3]*Department of Soil Science, Bangladesh Agricultural University, Mymensingh, Bangladesh*

[4]*CASELAP and School of Economics, University of Nairobi, Kenya*

[5]*Institut of Plant Ecology (IFZ), Justus Liebig University, Giessen, Germany*

### Background

Data by the International Panel on Climate Change (IPCC) clearly showed that anthropogenic emissions of the three major greenhouse gases (GHGs) carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$) have increased significantly since the industrial revolution in the mid of the 18$^{th}$ century (IPCC, 2014, Jackson *et al.*, 2020, Peters *et al.*, 2020). As a result, the earth's average surface air temperature has increased by 1.1°C (WMO, 2020b) since pre-industrial times, with much of these increases taking place since the mid-1970s (IPCC, 2014). The warming has caused several changes to our climate including extreme weather events such as frequent heat waves, droughts, floods and uneven distribution of rainfall, rising sea levels, and the melting of glaciers. Anthropogenic activities are the key contributors to the increase of the three major GHGs. Burning of fossil fuel (coal, natural gas and oil), deforestation and cultivation are the main anthropogenic sources of $CO_2$, whereas anthropogenic sources of $CH_4$ include rice paddy fields, livestock (ruminants) and landfills of wastes. The emission increase of $N_2O$ is mostly associated with land use changes, excessive use and the poor management of organic and mineral N fertilisers (119.4 million tons of N worldwide in 2019) and animal manure, high stocking rate or intensity of grazing animals, inefficient use of irrigation water and intensive cultivation.

To better understand the effect of increasing GHGs on global climate, the National Oceanic and Atmospheric Administration (NOAA) of the United States has developed an easy to understand Annual Greenhous Gas Index (AGGI) (Butler and Montzka, 2020). The AGGI is defined as the ratio of total direct radiative forcing (RF) to the RF present in 1990 being the baseline for the Kyoto protocol. Figure 1 shows a parallelism between $CO_{2\_eq}$ emissions ($CO_{2\_eq}$ = total GHG emissions, taking into account the individual climate warming potentials of the three GHGs) and the AGGI which was set to 1 in 1990 (blue line in Figure 1). Taken together, the RF of GHGs over the last 30 years has increased by 45% (Figure 1) (Butler and Montzka, 2020).

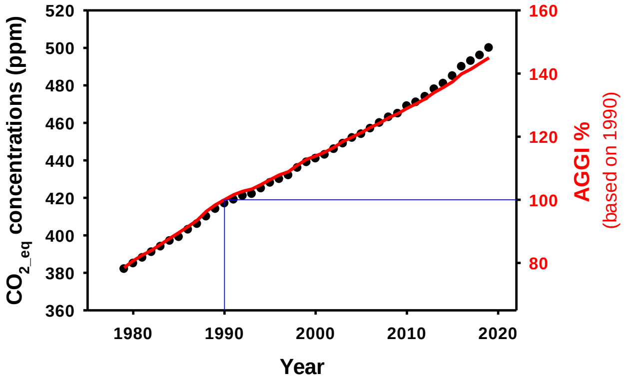



*Figure 1. $CO_{2eq}$ concentrations and the Annual Greenhous Gas Index from 1979 to 2019 (Butler and Montzka, 2020)*

Out of the three GHGs, $CO_2$ is the major contributor to the increased radiative forcing since pre-industrial time while $CH_4$ and $N_2O$ contribute to 16% and 6%, respectively (WMO, 2020a). Agriculture worldwide is responsible for approximately 75% of $N_2O$ and 42% of $CH_4$ emissions with total annual emissions amounting to more than 11 billion tonnes of $CO_{2\_eq}$ (FAO, 2020). To put this number into perspective, a typical hardwood tree (e.g. beach & oak) captures approximately 1 tonne of $CO_2$ over a lifetime of 70 years (TreePlantation, 2020). From the statistics, it is clear that agriculture is contributing appreciably to climate change (CC) through GHG emissions. In some of the developing countries, the agricultural sector can even be responsible for 90% or more to the national total $CO_{2\_eq}$ emissions (FAO, 2020). However, agriculture is, at the same time, also a victim of CC due to its negative impacts on soil quality and crop productivity. In the debate on carbon (C) sequestration, the importance of soils in capturing C has not received the same attention as the vegetation. It should, however, be appreciated that soils are a key C pool containing 1500−2400 Gt C compared to 829 Gt C in the atmosphere and 550 Gt C in vegetation (Zaman *et al.*, 2021) (Figure 2). Even small changes in the soil C content can have large effects on the atmospheric $CO_2$ concentration, which averaged in 2019 about 410.5 ppm (WMO, 2020a). Thus, it is paramount to find an integrated solution to reduce GHG emissions and at the same time making soils more resilient against CC. In a previous IAEA Coordinated

Research Project (CRP) (D1.50.16), using nuclear and related techniques, a package of technology consisting of various Climate Smart Agricultural (CSA) practices was developed such as effective use of nitrification inhibitors, biochar applications and improved cropping systems showing enhanced crop production with lower GHG emissions and increased soil C sequestration. By adopting those CSA practices, $N_2O$ emissions were reduced by approximately 50% in field trials conducted in Brazil, China, Costa Rica, Chile, Iran and Pakistan. Similarly, Germany and Ethiopia reported significant improvement in C sequestration. Ongoing research activities trying to find solutions to capture additional C in soils and thus, reducing the $CO_{2\_eq}$ emissions. A second phase CRP D1.50.20 (started in 2021) is focusing on the development and validation of additional CSA practices to increase soil C sequestration and to mitigate GHG emissions ($N_2O$, $CH_4$, $CO_2$) from agricultural ecosystems aiming to enhance agricultural productivity and sustainability.


*Figure 2. Distribution of C in the soil – plant – atmosphere continuum* (Zaman *et al.*, 2021)

**Case study: The effect of climate change on temperate grassland ecosystems**

Besides agriculture, CC affects natural environments and ecosystem services. To determine the extent of the impact on these systems, it is important to obtain data from realistic future scenarios such as the investigation of realistic future climate scenarios so that they can be used by policy makers. Therefore, the Joint FAO/IAEA Centre is working closely together with the Giessen Free Air Carbon Dioxide Enrichment study (Giessen FACE) on grassland, currently the longest running field $CO_2$ enrichment study worldwide, that has been active since 1998. Grassland ecosystems cover more than a third of the earth's terrestrial surface and are very important for capturing C. Results from the Giessen FACE clearly show that not only the quality of the biomass will decline but that the emission of GHGs, especially $N_2O$, will drastically increase under CC. Plants will take up more C and also transfer it into the soil, but this additional C does not remain there. The additional easily available C stimulates microbial activity in the rhizosphere which leads to mining of some of the more stable C compounds. The interactions between C and the N cycle result in adaptations of the microbial community entailing the aforementioned $N_2O$ stimulation, a gas that is almost 300 times more powerful for global warming than $CO_2$. This additional release of climate relevant GHG together with the absence of additional C capture transforms the grassland gradually from a typical C sink to a net C source. This highlights that we urgently need to understand the cascade of interacting CC factors on our agricultural ecosystems to derive suitable and effective mitigation options.

**Case study: Resilient rice production - Balancing climate and food security**

Cropping intensification underpins food security especially for regions that will experience large population increases in the next decades. In Asia, where 90% of rice is consumed, it is important to ensure there is enough affordable rice for everyone. Moreover, rice is an important staple food to Africa, Latin America and to some extent Europe too. Under CC and the rising world population, it is imperative to enhance rice production. But at the same time sustainable production systems need to be developed which is also demanded by national governmental policy such as the 'National Agriculture Policy 2018' of Bangladesh, one of the most densely populated countries in the world. While agricultural management emphasises increased food production, balancing agronomic production with environmental cost is a key challenge for sustainable food security and environmental safety. So far, national inventories for GHG emissions in countries such as Bangladesh are based on the IPCC default values which required regionally measured emission data. The research team at the Department of Soil Science at Bangladesh Agricultural University has been working closely with IAEA on mitigation of GHG emissions in diversified rice-based cropping systems, by using isotopic techniques to quantify nutrient pools, dynamics and GHG emissions. A focus is on increasing nutrient use efficiency through improved soil-water-fertilizer-crop management technologies including the use of composts, biochar and other organic amendments via integrated nutrient management strategies. Adoption of conservation agriculture practices for C sequestration and GHG mitigation, for instance via alternate wetting and drying practices, have already been shown to effectively mitigate $CH_4$ emissions.

### Case study: Livelihood of smallholder farmers in developing countries

Most smallholder farmers in developing countries produce mainly for subsistence, with surplus production ending in the markets. Researchers at the CASELAP and School of Economics, University of Nairobi investigate in detail the socio-economic structure of smallholder farming systems. The principle factor of production in these farming systems is labour and a combination of limited quantities of other inputs such as fertilizer and improved seeds which are, however, critical for improved production. These farming systems are therefore very fragile, and drought and famines are covariate risks that add to the farmers' woes by interrupting subsistence way of production. CC has compounded the problem by causing high rainfall variability, increased temperatures, and multiplied the frequency of extreme events. These are causing additional strain on an already delicate system by depressing agricultural production, causing increases in prices of food commodities in markets, and therefore increasing food and nutrition insecurity by limiting food availability and access. Most governments in developing countries have promoted adaptation strategies at farm level to cope with the 'new normal'. At national level, they have introduced GHGs mitigation strategies in the different economic sectors and drafted national contributions to emissions reductions as required by the Paris Agreement. A number of organizations, e.g. the CGIAR and FAO are promoting practical farm level solutions such as agroforestry, introduction of new livestock breeds and diversification of crop farming etc. All these interventions are components of sustainable agriculture which aim at taking care of the environment while increasing food production in a changing climate. A number of these practices are being tried and scaled out in different countries with the aim of increasing food for household consumption and produce excess for the market. This will ensure that the smallholder farmers are food secured and have extra income for other types of expenditure. If the organizations working on CSA practices could coalesce around a networking platform that shuns duplication, but promotes synergies of expertise and resources, the result would be an array of CC solutions for agriculture, now and in the future.

### The benefit of a concerted effort of global players to combat climate change

To combat CC and to reduce its impact on agricultural production, different organizations of the United Nations (IAEA, FAO, IPCC, WMO), various research institutes (CGIARs), universities and the private sector (e.g., fertiliser companies) are all working worldwide to develop CSA practices to reduce GHG emissions while maintaining and possibly increasing soil fertility and enhancing the soil C storage capacities. Each of the above-mentioned organisations addresses CC by using their organisation-specific approaches and employing an array of resources. What is missing, however, is an effective networking structure between the organizations to provide a platform for linking their activities. The advantage of such a platform would be to avail a full range of different resources to put effective CC mitigation options into practice for tangible results at the end users (farmers). The inclusion of UN organisations such as the IAEA in the networking structure would extend its reach to research institutes in 172 Member States. Other UN organisations (i.e., FAO, WMO, UNEP), and industry could generate synergy at the global scale. This will create an environment for academia, researchers and policy makers to work together to effectively translate ongoing work into workable solutions to CC. This kind of cross-fertilization can solve CC problems in diverse parts of the world. The results could help in building resilient systems that help smallholder producers to increase production and productivity, but also manage climate-related shocks. The measures will take into account a holistic risk management (safety and security) to enable adequate implementation.

### The Vision

By establishing an effective networking structure with other organisations (as outlined above), we anticipate taking a concerted effort into research and education on a worldwide scale. The aim is to enhance crop production with lower environmental footprints, i.e. to emit less GHGs, capturing more atmospheric $CO_2$ and sequester C to make soils more resilient to CC. An important part will be the development of innovative educational programs in the area of CC, by streamlining common efforts of Member States under the roof of an effective networking platform for information exchange and common research. This can ensure that individual efforts of academia, international organisations and research institutes are optimized by finding a coherent approach to combat CC. Suitable networking solutions bringing expertise of various partners together will lead to reduced costs to find local solutions to CC and conservation of natural resources (land and water), a clear win-win situation for all partners.

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# $Ag_3PO_4$ Comparison Material for Stable Oxygen Isotope Analysis

***Watzinger, A.[1], Schott, K.[1], Hood-Nowotny, R.[1], Tamburini, F.[2], Arppe, L.[3], Cristini, D.[4,5], Knöller, K.[4] and Skrzypek, G.[6]***

*[1] Institute of Soil Research, Department of Forest and Soil Sciences, University of Natural Resources and Life Sciences Vienna, wKonrad-Lorenz-Straße 24, 3430 Tulln, Austria*
*[2] Group of Plant Nutrition, Institute of Agricultural Sciences, ETH Zurich, Eschikon 33, 8315 Lindau, Switzerland*
*[3] Laboratory of Chronology, Finnish Museum of Natural History, University of Helsinki, Gustaf Hällströmin katu 2A, Finland*
*[4] Department of Catchment Hydrology, Helmholtz Centre for Environmental Research – UFZ, Theodor-Lieser-Strasse 4, D-06120 Halle, Germany*
*[5] Aquatic Ecology and Evolution, Limnological Institute, University of Konstanz, 78464, Konstanz, Germany*
*[6] West Australian Biogeochemistry Centre, School of Biological Sciences, The University of Western Australia, 35 Stirling Highway, Crawley WA 6009, Australia*

This article is a summary of the major findings published in *Rapid Communication in Mass Spectrometry https://doi.org/10.1002/rcm.9101* (Watzinger et al., 2021). The study was performed under the IAEA CRP D1.50.18 on *'Multiple Isotope Fingerprints to Identify Sources and Transport of Agro-Contaminants'*.

## Background

Phosphorus (P) is one of the common elements in the Earth's crust and crucial for all life forms due to its abundance in several important biomolecules (DNA, RNA, biomembranes, ATP). Phosphorus has only one stable isotope $^{31}P$ and several radioactive isotopes. In nature, phosphorus is usually present as phosphate ($PO_4^{-3}$) and almost exclusively as the $^{31}P$ isotope. Recently the stable isotopic composition of oxygen in phosphate has been increasingly used in environmental studies to identify sources of phosphate pollution and to understand biological processes in aquatic and terrestrial ecosystems[1,2]. Accurate measurement of the stable oxygen isotope ratio requires certified calibration standards similar to the sample matrix. The suitability of a $Ag_3PO_4$ reference standard for the determination of the oxygen isotope composition has long been recognized and various $Ag_3PO_4$ in-house laboratory standards have been in use[3].

## Rationale

A silver phosphate reference material ($Ag_3PO_4$) for the measurement of the stable oxygen isotope compositions is much needed; however, it is not available from the authorities distributing reference materials. This study aimed to calibrate a new $Ag_3PO_4$ comparison material produced by the University of Natural Resources and Life Sciences (BOKU) and test the consistency between laboratories using exactly the same normalization method and standards in each laboratory.

## Methodology

The University of Natural Resources and Life Science (BOKU) prepared silver phosphate comparison material (named BOKU $Ag_3PO_4$) for measurement of the stable oxygen isotope composition from a commercially available $Ag_3PO_4$ and distributed it to other stable isotope laboratories. The contributing laboratories were the University of Natural Resources and Life Science (BOKU), The University of Western Australia (UWA), the University of Helsinki (UH), and the Helmholtz Centre for Environmental Research (UFZ). The instruments used to perform the measurements were high-temperature conversion elemental analysers coupled with continuous flow isotope ratio mass spectrometers.

The working gas $\delta^{18}O$ value was set to 0 ‰ and the normalization was done by a three-point linear regression using the reference materials IAEA-601, IAEA-602 and NBS 127. Each laboratory analysed the comparison material in a minimum of two independent measuring rounds (on different days) with a minimum of 10 individual measurements.

### Results

The arithmetic mean ($\bar{x}$) and standard deviation (1σ) of the $\delta^{18}O$ value of the new BOKU $Ag_3PO_4$ comparison material from the single measurements was 13.74 ± 0.33 ‰ on the VSMOW-SLAP scale (n=100), while the mean ($\bar{x}$) and standard deviation (1σ) of the laboratories was 13.71 ± 0.19 ‰ (n=4) (Figure 1). Three major uncertainty sources were considered and combined into the uncertainty budget: (i) the uncertainty of the reference materials used for the normalization to the VSMOW-SLAP scale and their propagation during the normalisation procedure; (ii) the uncertainty associated with the homogeneity of the BOKU comparison material and analytical reproducibility and (iii) the uncertainty associated with the analytical scatter between participating laboratories. Using this approach, the uncertainty was estimated to be 0.34 ‰.

### Conclusions

To conclude, the mean $\delta^{18}O$ value and combined uncertainty of the new BOKU $Ag_3PO_4$ comparison material were determined as 13.71 ± 0.34 ‰ on the VSMOW-SLAP scale. The new material is available for stable isotope research laboratories to facilitate the calibration of their laboratory comparison material and requests can be sent to Andrea Watzinger (andrea.watzinger@boku.ac.at). The differences between uncertainties calculated using various methods should be taken into account when comparing analytical uncertainties from different laboratories and publications.

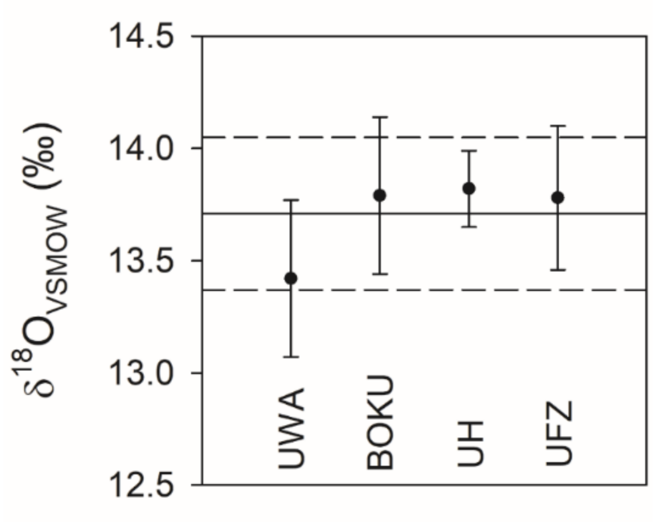


*Figure 1. The arithmetic means and standard deviations (1σ) of the single labs normalized using IAEA-601, IAEA-602 and NBS127. The arithmetic mean of all laboratories' results is given as solid line with combined uncertainty (k = 1) as dotted line.*

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## Tackling the Global Threat of Antimicrobial Resistance (AMR) - A High Priority Agenda of One Health Global Leaders Group on AMR


***Adu-Gyamfi, J.[1]***

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


Realizing the global threat of antimicrobial resistance (AMR), the President of the United Nations General Assembly, Volkan Bozkır, convened a High-Level Interactive Dialogue on AMR involving government representatives, leaders from pharmaceutical and agricultural companies, representatives from United Nations institutions, international organizations, civil society groups as well as members of the general public, and members of the One Health Global Leaders Group on AMR, to discuss and recommit to actions aim at addressing AMR in a virtual meeting on 29 April 2021. In his open address, the Director-General of FAO, Dr Qu Dongyu, remarked that due to AMR, drug-resistant infections are placing an ever-increasing burden on human, animal, and environment, and that AMR is becoming more and more visible complex threats to global health, food safety and food security, potentially also leading to substantial socio-economic damage. He concluded that 'we could turn this around– if we act coherently, swiftly, and decisively'.

Antimicrobial resistance occurs when bacteria, viruses, fungi and parasites change over time and no longer respond to medicines making infections harder to treat and increasing the risk of disease spread, severe illness and death. AMR poses threats to human wellbeing, animal health and welfare, food safety and the environment and is a major obstacle for countries to achieve the Sustainable Development Goals.

For some time now, AMR has been approached mainly from the human and animal health angles, however little is known about the impacts that AMR in the environment (Figure 1). The Joint FAO/IAEA Centre on Nuclear Techniques in Food and Agriculture, in collaboration with the Technical University of Munich (TUM) focuses on the methodologies that can be used to detect and trace the source and transport of antibiotics through the soil and water, and more importantly, the nuclear techniques (multi-element stable isotope fingerprinting) in an FAO publication "*Antimicrobial movement from agricultural areas to the Environment: The missing link. A role for Nuclear Techniques*" http://www.fao.org/3/ca5386en/ca5386en.pdf.

Looking into the future, the Joint FAO/IAEA Centre, in collaboration with TUM has prepared a Guiding Document and a Proposal on "Isotopic Techniques for Assessing the Persistence of Antibiotics through the Environment in Agricultural Catchments". The proposal aims to reduce antibiotic resistant-related death through the development of a cost-effective methodology for the detection of antibiotics from the source to the environment in agricultural areas and to provide government agencies (policymakers, regulators – EPAs) and resources managers with the information needed to advise veterinaries and farmers for a sustainable management of AMR source (i.e., manure management) in agriculture, and to establish a network of nuclear techniques and data interpretation in relation to the detection of antibiotics in the environment.

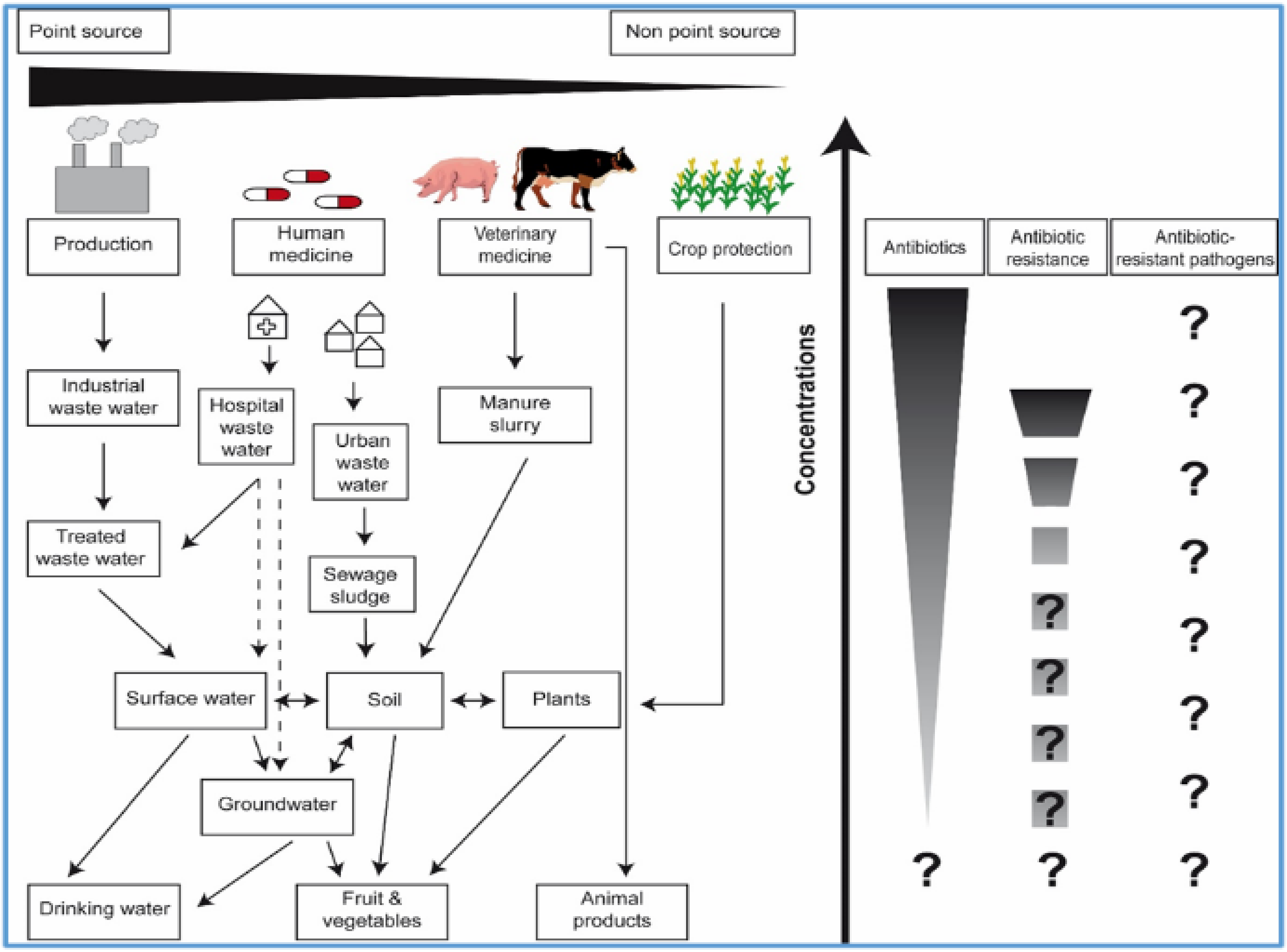


*Figure 1. Input pathways for antibiotics, antibiotic resistance and antibiotic-resistant pathogens into the environment and the food chain (left) and current knowledge gaps about their concentration behaviour throughout the process (right)*

# 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 | E. Fulajtar |
| Bangladesh | BGD5033 | Using Nuclear Techniques in Assessing River Bank Erosion | E. Fulajtar |
| Central African Republic | CAF5011 | Building National Capacities for Improving the Efficiency of Biological Nitrogen Fixation for Food Security, Fertility Restoration and Rehabilitation of Degraded Soils | M. Zaman |
| Central African Republic | CAF5012 | Building Capacities in Developing Best Agricultural Practices for Enhanced Production of Maize and Its Quality – Phase I | M. Zaman |
| Cambodia | KAM5005 | Enhancing Soil, Water and Nutrient Management for Sustainable Rice Production and Optimized Yield | J. Adu-Gyamfi |
| 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 |
| Costa Rica | COS5035 | Building Capacity for the Development of Climate-Smart Agriculture in Rice Farming | M. Zaman |
| Cuba | CUB5023 | Strengthening National Capacities for the Development of New Varieties of Crops through Induced Mutation to Improve Food Security While Minimizing the Environmental Footprint | E. Fulajtar |
| Gabon | GAB5003 | Building National Capacities for Monitoring Sedimentation of Dams and Harbors and the Management of Remediation Operations | E. Fulajtar |
| Gabon | GAB5004 | Improving Soil Fertility Management for Enhanced Maize, Soybean and Groundnut Production | J.Adu-Gyamfi |
| Haiti | HAI5008 | Strengthening National Capacities for Enhanced Agricultural Crop Productivity | J.Adu-Gyamfi |
| Indonesia | INS5044 | Using Nuclear Technology to Support the National Food Security Programme | L. Heng and PBG |
| Interregional project | INT0093 | Applying Nuclear Science and Technology in Small Island Developing States in Support of the Sustainable Development Goals and the SAMOA Pathway | J. Adu-Gyamfi |
| 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 | Lee 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 |
| Laos | LAO5004 | Enhancing National Capability for Crop Production and Controlling Trans-Boundary Animal Diseases | M. Zaman and APH |

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|---|---|---|---|
| Lesotho | LES5009 | Determining Soil Nutrient and Water Use Efficiency Using Isotope Techniques | J. Adu-Gyamfi |
| 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 |
| Malawi | MLW5003 | Developing Drought Tolerant, High Yielding and Nutritious Crops to Combat the Adverse Effects of Climate Change | E. Fulajtar 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 | MLI5030 | Developing and Strengthening Climate Smart Agricultural Practices for Enhanced Rice Production — Phase I | M. Zaman |
| Myanmar | MYA5027 | Monitoring and Assessing Watershed Management Practices on Water Quality and Sedimentation Rates of the Inle Lake - Phase II | L. Heng |
| Namibia | NAM5017 | Improving Crops for Drought Resilience and Nutritional Quality | J. Adu-Gyamfi and PBG |
| Pakistan | PAK5051 | Developing Isotope-Aided Techniques in Agriculture for Resource Conservation and Climate Change Adaptation and Mitigation | M. Zaman |
| 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 |
| Peru | PER5033 | Application of Nuclear Techniques for Assessing Soil Erosion and Sedimentation in Mountain Agricultural Catchments | E. Fulajtar |
| 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 | RAF5079 | Enhancing Crop Nutrition and Soil and Water Management and Technology Transfer in Irrigated Systems for increased Food Production and Income Generation (AFRA) | L. Heng |
| Regional project Africa | RAF5081 | Enhancing Productivity and Climate Resilience in Cassava-Based Systems through Improved Nutrient, Water and Soil Management (AFRA) | M. Zaman and G. Dercon |
| Regional project Asia | RAS5080 | Developing Sustainable Agricultural Production and Upscaling of Salt-Degraded Lands through Integrated Soil, Water and Crop Management Approaches - Phase III | M. Zaman |
| Regional project Asia | RAS5083 | Reducing greenhouse gas emissions from agriculture and land use changes through climate smart agricultural practices | M. Zaman |
| Regional project Asia | RAS5084 | Assessing and improving soil and water quality to minimize land degradation and enhance crop productivity using nuclear techniques | J. Adu-Gyamfi |
| 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 Latin America | RLA5076 | Strengthening Surveillance Systems and Monitoring Programmes of Hydraulic Facilities Using Nuclear Techniques to Assess Sedimentation Impacts as Environmental and Social Risks (ARCAL CLV) | 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 |

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|---|---|---|---|
| Regional project Latin America | RLA5078 | Improving Fertilization Practices in Crops through the Use of Efficient Genotypes in the Use of Macronutrients and Plant Growth Promoting Bacteria (ARCAL CLVII) | J. Adu-Gyamfi |
| 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 |
| Rwanda | RWA5001 | Improving Cassava Resilience to Drought and Waterlogging Stress through Mutation Breeding and Nutrient, Soil and Water Management Techniques | M. Zaman and PBG |
| Senegal | SEN5041 | Strengthening Climate Smart Agricultural Practices Using Nuclear and Isotopic Techniques on Salt Affected Soils | M. Zaman |
| Seychelles | SEY5011 | Supporting Better Sustainable Soil Management as Climate Change Adaptation Measures to Enhance National Food and Nutrition Security | L. Heng |
| Sierra Leone | SIL5021 | Improving Productivity of Rice and Cassava to Contribute to Food Security | M. Zaman and PBG |
| Sudan | SUD5037 | Application of nuclear and related biotechnology techniques to improve of crop productivity and lively hood of small scale farmers drought prone areas of Sudan | J. Adu-Gyamfi and PBG |
| Saint Vincent & the Grenadines | SVT0001 | Building National Capacity in Nuclear Technology Applications | J. Adu-Gyamfi, NAHU and NAPC |
| Togo | TOG5002 | Improving Crop Productivity and Agricultural Practices Through Radiation Induced Mutation Techniques | E. Fulajtar and PBG |
| Zambia | ZAM5031 | Improving the Yield of Selected Crops to Combat Climate Change | L. Heng and PBG |

# Forthcoming Events

## FAO/IAEA Events

**Final Research Coordination Meeting of CRP D1.50.17. 'Nuclear Techniques for a Better Understanding of the Impact of Climate Change on Soil Erosion in Upland Agro-Ecosystems'**, 5-9 July 2021, Vienna, Austria.

*Technical Officers: L. Heng and E. Fulajtar*

**Workshop on Regional Project RAS5084 'Assessing and Improving Soil and Water Quality to Minimize Land Degradation and Enhance Crop Productivity Using Nuclear Techniques' (RCA), 'Developing Database on Soil Erosion, Soil and Water Quality'**, 17-18 July 2021, (virtual)

*Technical Officer: J. Adu-Gyamfi*

**Final Coordination Meeting of Regional Project RLA5076 'Strengthening Surveillance Systems and Monitoring Programmes of Hydraulic Facilities Using Nuclear Techniques to Assess Sedimentation Impacts as Environmental and Social Risks',** 23-26 August 2021, (virtual)

*Technical Officer: J. Adu-Gyamfi*

**Second Research Coordination Meeting of CRP D1.50.19. 'Monitoring and Predicting Radionuclide Uptake and Dynamics for Optimizing Remediation of Radioactive Contaminated Agricultural Land'**, 4 – 8 October 2021, Japan

*Technical Officers: G. Dercon and L. Heng*

**Final Coordination Meeting of Regional Project RAS5084 'Assessing and Improving Soil and Water Quality to Minimize Land Degradation and Enhance Crop Productivity Using Nuclear Techniques' (RCA),** 15-19 November 2021, Christchurch, New Zealand.

*Technical Officer: J. Adu-Gyamfi*

**Final Coordination Meeting of Regional Project RLA5078 'Improving Fertilization Practices in Crops through the Use of Efficient Genotypes, Macronutrients and Plant Growth Promoting Bacteria (ARCAL CLVII),** 6-10 December 2021, Panama City, Panama.

*Technical Officer: J. Adu-Gyamfi*

**The FAO/IAEA International Symposium on Managing Land and Water for Climate Smart Agriculture**, 25-28 July 2022, Vienna, Austria.

*Scientific Secretary: L. Heng*

## Non-FAO/IAEA Events

**26th UN Climate Change Conference (COP26),** 1-12 November 2021, Glasgow, UK. https://www.ukcop26.org/

# Past Events

## FAO/IAEA Events

**Strengthening Climate Smart Agricultural Practices for Salt affected soil SEN5041,** Senegal 15– 17 December 2020, (virtual)

*Technical Officer: Mohammad Zaman*

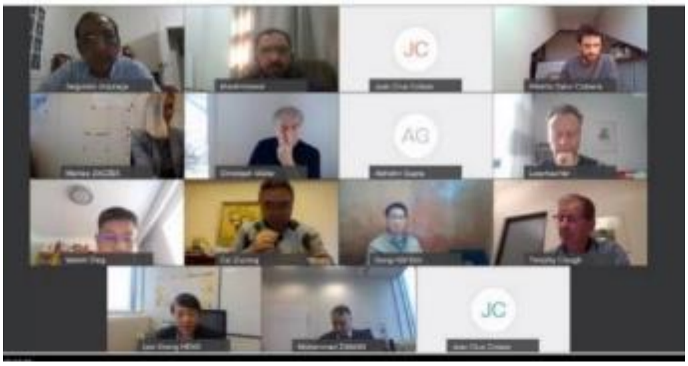
Twenty researchers, extension workers and academic persons participated in this virtual training on improved soil, nutrients and water management practices to mitigate salinity, reduce greenhouse gases and enhance rice production using nuclear and related techniques. The experts also provided basic training on performing $^{15}N$ tracing experiments, the interpretation of $^{15}N$ data, and an easy-to-use spreadsheet for nitrogen use efficiency (NUE) calculations.

*Participants of the SEN5041 training*

**First Research Coordination Meeting of CRP 'Developing Climate Smart Agricultural practices for carbon sequestration and mitigation of greenhouse gases' (D1.50.20)**, 8-12 February 2021, (virtual)

*Project Officers: Mohammad Zaman and Lee Heng*

The 1st RCM took place virtually on 8-12 February 2021, initiated from Vienna, Austria to review individual experimental plans of the research contractors with regard to the objectives of the CRP, and to provide the research contract holders with suggestions for the next 18 months. To equip CRP participants with advanced knowledge and skills of isotopic techniques, three training sessions on $^{15}N$ tracing technique to precisely measure $N_2O$ and $N_2$ emissions, ammonia volatilisation and assessing C budget were also provided. Twelve countries participate in this CRP: nine research contract holders, one each from Argentina, Bangladesh, Brazil, China, Costa Rica, Ethiopia, India, Pakistan and Viet Nam, two agreement holders from China and New Zealand, and two technical contractors from Germany and Spain.

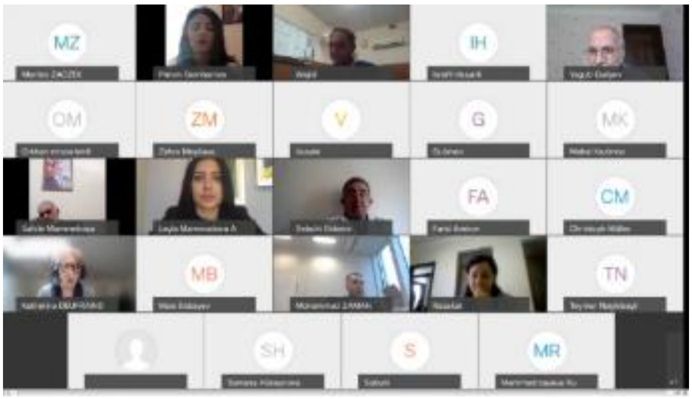


*Participants of the 1st Research Coordination Meeting of the CRP D1.50.20*

**Climate Smart Agricultural Practices for Cotton Production and the Role of $^{15}N$ Technique,** 22-23 February 2021, (virtual)

*Technical Officer: Mohammad Zaman*

On the special request of Azerbaijan government, a virtual training was organized to equip the participants with the advanced knowledge and understanding of developing improved soil, nutrient and water management practices of enhancing nutrients and water use efficiencies, building soil fertility and increasing cotton production with lower environmental foot prints using isotopic and related techniques.



*Participants of the training on climate smart agricultural practices for cotton production*

The training course covered a range of topics including: (1) major issues and challenges of low nutrient and water use efficiencies on farm for cotton production, (2) strategic application of essential plant nutrients of nitrogen, phosphorus and potassium for cotton, (3) the challenge of addressing low nutrient and water use efficiencies of and the role of isotopic techniques, (4) conservation agricultural practices to improve soil quality and health for sustainable cotton production, and (5) $^{15}N$ fertilizer application for studying fertilizer use efficiency. The participants acknowledged IAEA for organizing this virtual training and committed to share their experience and knowledge with fellow colleagues for further capacity building.

**Second Research Coordination Meeting of CRP D1.50.18. 'Multiple Isotope Fingerprints to Identify Sources and Transport of Agro-Contaminants'** 1– 4 March 2021, (virtual)

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

The research coordination meeting (RCM) was held virtually from 1–4 March 2021. The purpose of the meeting was to review the progress made since the first RCM, develop a workplan and activities to realize the project outputs, and formulate recommendations for future work. Fifteen member states including eight research contract holders from China, Ghana, India, Morocco, Romania, Sri Lanka, Slovenia and Viet Nam, six agreement holders from Austria, France, Germany, Ireland, Switzerland and United Kingdom, and one technical contract holder from Australia participated. Ten observers from Romania, India, Morocco, Costa Rica, France, and FAO (Italy) participated.

*Participants of the second research coordination meeting of the CRP D1.50.18*

The meeting started with an introduction of participants and a welcome address by Ms Lee Heng (Head-SWMCN). A presentation of the RCM objectives and expected outputs was delivered by the Project Officer of the CRP, Mr Joseph Adu-Gyamfi. The summary of the presentations and discussion sessions covered 4 main themes: (1) Develop/validate and modify guidelines for the use of stable isotopic multi-tracer to track phosphorus, pesticides, and sulphur pollutants from agricultural catchments, (2) Case studies of combined stable isotopes of phosphate, carbon, nitrogen, and sulphur by participants countries, (3) Inter-laboratory comparison studies on a silver phosphate reference material for quality control in the use oxygen isotopes in phosphate, (4) Develop individual workplans to realize the objectives of the CRP results of the successful case studies in field applications of protocols of combined stable isotopes of phosphate, carbon, nitrogen, and sulphur were reported by participants countries. The major conclusion of the meeting was that the stable isotope results should always be interpreted with respect to the hydrochemistry.

**IAEA Spotlight Session: Too Much Water, Too Little Water — how the IAEA Helps Farmers Adapt to Climate Change.** 18 March 2021, (virtual)

*Technical Officer: Gerd Dercon and Lee Heng*

Gerd Dercon and Lee Heng gave an overview of how nuclear and isotopic techniques are being used to address various issues in agricultural water management through climate-smart agriculture at the IAEA's Spotlight session, as part of the World Water Day celebration. The Spotlight session covered the following topics:

- the challenges agricultural water management are facing due to climate change
- the potential of nuclear and isotopic techniques to address those challenges
- the future prospects of water management, particularly, in agriculture

https://iaeacloud.sharepoint.com/sites/intranet/newsandevents/newsstories/Lists/Posts/Post.aspx?ID=575

**Climate Smart Agricultural practices for Cassava Production and the Role of $^{15}N$ Technique, RAF 5081,** 13– 16 April 2021, (virtual)

*Technical Officer: Mohammad Zaman*

Cassava, a starchy root vegetable for more than 700 million people, is the third largest source of carbohydrates worldwide, after rice and maize, and a major cash crop for many farmers in Africa. The continent produces around 55% of the world's output. However, in many parts of Africa, poor farming practices, declining soil fertility, low fertilizer application and climate change are contributing to low average yield of cassava production compared to other parts of the world. A virtual training was arranged under the regional TCP (RAF5081) from 13– 16 April 2021 to equip the participants with the advanced knowledge and understanding of the improved soil, nutrient and water management practices to increase cassava production and the role of stable isotopic technique of $^{15}N$ to assess fertiliser use efficiency and mitigating greenhouse gases. The training was attended by 18 researchers, two each from Burkina Faso, Burundi, Central African Republic, Congo, Democratic Republic of the Congo, Ghana, Nigeria, Rwanda, and Uganda. Mr. Abdulrazak Shaukat, Director TC Africa welcomed the training participants and presented a brief overview of the role of TC Africa in addressing the challenges of food security in Africa. The technical officer and the expert, Christoph Müller provided the virtual training covering a range of topics including: $^{15}N$ technique to measure fertilizer use efficiency and N losses, climate smart agricultural practices to enhance cassava production, improve soil fertility and conserve nutrients and water under changing climate, case studies of increased cassava production from Burundi and Central Africa Republic, experimental design for cassava demonstration trials. The participants acknowledged IAEA for organizing this virtual training and committed to share their experience and knowledge with fellow colleagues for further capacity building.

*Participants of the RAF5081 training*

**Soil, Water and Nutrient Management Practices for enhanced cassava and rice production in Sierra Leon and the role of nuclear techniques** SIL5021, 21–22 April 2021, (virtual)

*Technical Officer: Mohammad Zaman*

The purpose of this virtual training to improve cassava as well as rice production using climate smart agricultural practices in Sierra Leon. Additionally, training also focussed on the role of stable isotopic technique ($^{15}N$) to measure fertiliser use efficiency under rice and cassava production system. The training was attended by 8 researchers.

*Participants of the SIL5021 training*

The training event was opened by PMO, who highlighted the issue of food security, subsistence farming and lack to technical resources in Sierra Leon. The technical officer described the objectives of the virtual training, and the role of isotopic and related techniques to develop climate smart agricultural practices for cassava and rice production. The technical officer along with another expert, Mr Christoph Muller, then provided training covering a range of topics including improving soil fertility, nutrients and water use efficiencies, best soil, nutrients and water management practices for cassava and rice production, and the role of $^{15}N$ technique in measuring fertiliser use efficiency to minimise N fertiliser losses to the atmosphere and water bodies.

**Joint ICTP-IAEA Workshop on the Use of Cosmic Ray Neutron Sensor for Soil Moisture Management and Validation of Remote Sensing Soil Moisture Maps,** 10, 12, 14, 17 and 19 May 2021, (virtual)

*Organizers: E. Fulajtar, P. Cremelini*

The workshop was organized by the International Centre for Theoretical Physics (ICTP), Trieste, Italy in cooperation with Joint FAO/IAEA Centre. The purpose was to provide training on the use of Cosmic Ray Neutron Sensor (CRNS) for agricultural water management and for the validation of remote sensing soil moisture products. Four lecturers from Austria, Italy, UK and USA provided 15 lectures in six major thematic areas: Basic principles and operation of CRNS; CRNS data processing; CRNS soil moisture products; Use of CRNS data for validation of remote sensing soil moisture products; Use of CRNS data for hydrological modelling; Use of CRNS data for agricultural applications. The event had very good response worldwide. Participants were selected among 86 applicants. In total 54 trainees 31 countries attended this workshop.


*Participants of the Joint ICTP-IAEA Workshop*

**Second Research Coordination Meeting of CRP D1.20.14. 'Enhancing agricultural resilience and water security using Cosmic-Ray Neutron Sensor',** 7 - 11 June 2021, (virtual)

*Technical Officers: E. Fulajtar and H. Said Ahmed*

The objective of the 2nd RCM was to update the results of CRP, discuss the publishing activities and initiate the preparation of CRP outputs and prepare the group for mid-term review. The meeting showed that the CRP has already in its 2nd year very good results despite some delays in field works on CRNS monitoring sites caused by travel restrictions due to covid-19. Several achievements including method development, developed soil moisture products, and the work on final publications has begun.

The meeting was attended by 4 research contract holders from China (2 institutions), Brazil (2 institutions) and Mexico, four technical contract holders from Italy, Netherlands, Spain and USA and two research agreement holders from Denmark and UK.

# Coordinated Research Projects

| Project Number | Ongoing CRPs | Project Officer |
|---|---|---|
| D1.20.14 | Enhancing Agricultural Resilience and Water Security Using Cosmic-Ray Neutron Technology | E. Fulajtar and H. Said Ahmed |
| D1.50.17 | Nuclear Techniques for a better understanding of the Impact of Climate Change on Soil Erosion in Upland Agro-ecosystems | L. Heng and E. Fulajtar |
| D1.50.18 | Multiple Isotope Fingerprints to Identify Sources and Transport of Agro-Contaminants | J. Adu-Gyamfi and L. Heng |
| D1.50.19 | Remediation of Radioactive Contaminated Agricultural Land | G. Dercon and L. Heng |
| D1.50.20 | Developing Climate Smart Agricultural Practices for Mitigation of Greenhouse Gases | M. Zaman and L. Heng |

**Enhancing Agricultural Resilience and Water Security using Cosmic-Ray Neutron Sensor (D1.20.14)**

*Project Officers: E. Fulajtar and H. Said Ahmed*

This CRP which started in 2019 to 2024, aimed to test the potential of a cosmic ray neutron sensor (CRNS) for its applications in agriculture and environment protection, especially on irrigation scheduling and management of extreme weather events. Understanding soil water dynamics is of paramount importance for soil water and irrigation management, water conservation, improvement of soil fertility and the development of crop management strategies. CRNS provides soil moisture data on a large scale and in real time, which has a great value for land and water management. In addition to CRNS, the Gamma Ray Spectrometer (GRS) will be used in soil moisture assessment. The GRS has a much smaller footprint than CRNS and thus it is especially useful in heterogeneous areas with small fields and greater soil and relief variability.

The objectives of the CRP are to: (1) advance the capabilities of CRNS for Best Management Practices (BMP) in irrigated and rainfed agricultural production systems; (2) integrate CRNS, GRS, remote sensing and hydrological modelling for improving agricultural water management and its resilience at regional scales; and (3) develop approaches using CRNS and GRS for long-term soil moisture monitoring in agricultural systems and early warning systems for flood and drought management. The final output of the CRP will be a set of methods, tools applicable in irrigation scheduling, flood prediction and drought management.

This CRP was approved in March 2019. It involves ten partners: four research contract holders (two partners from Brazil, two partners from China and Mexico), three research agreement holders (Denmark, Netherlands and United Kingdom) and three technical contract holders (Italy, 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 technical contract holders and research agreement holders to support research contract holders through the provision of methodological guidance, help with data processing and using the collected data form soil moisture dynamics modelling and remote sensing validation.

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

2020 the progress reports summarizing the results of the 1st project year were submitted, evaluated and all contracts were renewed. Due to travel restrictions related to Covid-19 some activities, mainly the installation of cosmic ray neutron sensors and gamma ray sensors at some sites were delayed. Nevertheless, despite of these travel restrictions the major activities were successfully implemented and already in its first year the CRP brought significant scientific achievements:

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

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

The Second Research Coordination Meeting was held virtually from 7 - 11 June 2021. The objective was to update the findings and results of the CRP, especially the case studies of project partners, discussing the publishing of the CRP outputs and initiate the preparation of the group for mid-term review.

**Nuclear Techniques for a Better Understanding of the Impact of Climate Change on Soil Erosion in Upland Agro-ecosystems (D1.50.17)**

*Project Officers: L. Heng and E. Fulajtar*

This five-year CRP (2016-2021) aimed to develop nuclear techniques to assess the impacts of changes in soil erosion occurring in upland agro-ecosystems and to distinguish and apportion the impact of climate variability and agricultural management on soil resources in upland agro-ecosystems.

Nuclear techniques have been used to achieve these two research objectives, including fallout radionuclides (FRN) such as $^{137}Cs$, $^{210}Pb$, $^{7}Be$ and $^{239+240}Pu$, Compound-Specific Stable Isotope (CSSI) techniques as well as the Cosmic Ray Neutron Sensor (CRNS).

The first Research Coordination Meeting (RCM) was held in Vienna, Austria from 25 to 29 July 2016, the second RCM took place at the Centre National de l'Energie, des Sciences et des Techniques Nucléaires (CNESTEN) in Rabat, Morocco from 16 to 20 April 2018 and the third RCM was held in Vienna, Austria from 14 to 17 October 2019.

As reported in our previous soil newsletters, since the start of the project in April 2016, substantial achievement has been made in developing and refining FRN and CSSI techniques to deepen our understanding of erosion processes impacting upland agro-ecosystems. On 13 March 2019, the IAEA mid-term review of the CRP praised the output obtained.

So far, the CRP team has published more than 20 peer-reviewed publications acknowledging explicitly the CRP and produced 4 manuals/guidelines. Indeed, key activities carried out within this CRP have led to the publication of an IAEA TECDOC, on how to effectively use the CSSI technique based on $\delta^{13}C$ signatures of fatty acids to determine the origin of sediment (IAEA-TECDOC-1881 published in September 2019; https://www.iaea.org/publications/13564/guidelines-for-sediment-tracing-using-the-compound-specific-carbon-stable-isotope-technique).

Two books were also published, in 2017 and 2019, i.e. an FAO handbook on the use of $^{137}Cs$ for soil erosion assessment (http://www.fao.org/3/a-i8211e.pdf) and a Springer open-access handbook on the assessment of recent soil erosion rates using $^{7}Be$ (https://www.springer.com/gp/book/9783030109813).

Currently, an additional IAEA publication - which will be ready by the end of the CRP - is being prepared on the $^{137}Cs$ resampling method which appears to be the most suitable approach to fulfil the second challenging objective of the CRP. Moreover, as reported by some CRP contractors (e.g. MOR), this isotopic-based approach also allowed them to evaluate the effectiveness of soil conservation measures.

The final RCM of the CRP will take place in Vienna, Austria, in a hybrid format (virtual and in-person), from 5 to 9 July 2021.

**Multiple Isotope Fingerprints to Identify Sources and Transport of Agro-Contaminants (D1.50.18)**

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

This five-year CRP (2018-2023) aims to develop protocols and methodologies for using multiple stable isotope tracers to monitor soil, water and nutrient pollutants from agriculture, establish proof-of-concept for an integrated suite of analytical stable isotope tools, and create guidelines to adapt the new toolkit to a variety of agricultural management situations. Nuclear techniques are used to achieve the objectives including a combined stable isotope ($\delta^{18}O$' $\delta^{2}H$, $\delta^{13}C$, $\delta^{15}N$,' $\delta^{13}C$-DIC, $\delta^{15}N$-$NO_3$ $\delta^{18}O$-$NO_3$ $\delta^{18}Op$, $\delta^{34}S$) techniques and compound specific isotope (CSSI)-based monitoring approach for evaluating in-situ degradation, transport, transformation and fate of pesticides.

The second research coordination meeting (RCM) was held virtually from 1–4 March 2021. The purpose of the meeting was to review the progress made since the first RCM, develop a workplan and activities to realize the project outputs, and formulate recommendations for future work. Fifteen member states including eight research contract holders from China, Ghana, India, Morocco, Romania, Sri Lanka, Slovenia and Viet Nam, six agreement holders from Austria, France, Germany, Ireland, Switzerland and United Kingdom, and one technical contract holder from Australia participated. Ten observers from Romania, India, Morocco, Costa Rica, France, and FAO HQ in Rome, Italy participated.

The achievements from the CRP to-date include:

(1) A new passive sampler to facilitate stable isotope analysis of pesticides in fresh water developed and validated.

(2) A database of stable isotope values ($\delta^{13}C$ ‰) of 120 commercial formulation of pesticides from 17 manufactures developed.

(3) A new field validated protocol on the use of ($\delta^{18}Op$) as forensics in water quality investigations to distinguish between fertilizer phosphorus from agriculture and sewerage disposal validated.

(4) A new silver phosphate ($Ag_3PO_4$) reference material for the measurement of the stable oxygen isotope composition developed for inter laboratory quality assurance comparison of analysis.

(5) Results of the successful case studies in field applications of protocols of combined stable isotopes of phosphate, carbon, nitrogen, and sulphur were reported by participants countries.

*Commercial pesticide formulations and (Photo Credit: G. Imfeld, France)*

The stable isotope results should always be interpreted referring to the hydrochemistry of major ions, major ion ratios, and nutrient concentrations, e.g. Na/Cl or $SO_4$/Cl or $\delta^{15}N(NO_3)$ vs $1/NO_3$ or $\delta^{15}N(NO_3)$ vs $\ln NO_3$. Furthermore, a proper sampling design, including spatial and temporal resolution that is appropriate to the land management and hydrological context, is essential for conducting successful catchment-scale studies. The Third RCM is planned to be held on 25-28 July 2022 in Vienna, Austria.

*Passive samplers for evaluating pesticide isotope signatures (Photo Credit: G. Imfeld, France)*

**Remediation of Radioactive Contaminated Agricultural Land (D1.50.19)**

*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-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 D1.50.19 was developed as a follow up to CRP D1.50.15. 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 Research Coordination Meeting (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.

Since the beginning of 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 in the soil. Significant progress has 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.

The second RCM of this CRP is planned to be held in October 2021 in Japan. The RCM will be combined with a one-day symposium organized by the National Agriculture and Food Organization of Japan and the Joint FAO/IAEA Centre, looking at the way forward with regard to remediation of radioactive contamination in agriculture.

**Developing Climate Smart Agricultural practices for carbon sequestration and mitigation of greenhouse gases (D1.50.20)**

*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 (D1.50.16), 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 1$^{st}$ Research Coordination Meeting (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.

# Developments at the Soil and Water Management and Crop Nutrition Laboratory

## Virtual calibration of Cosmic-Ray Neutron Sensors (CRNS) using artificial intelligence

***Said Ahmed, H.[1], Mbaye, M.[2], Franz T.[3], Weltin, G.[1], Dercon, G.[1], Heng, L.[4], Fulajtar, E.[4], Strauss, P.[5], Rab, G.[5], Rosolem, R.[6,7], Power, D.[6]***

[1]*Soil and Water Management & Crop Nutrition Laboratory, Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture, Department of Nuclear Sciences and Applications, International Atomic Energy Agency, Vienna, Austria*
[2]*Centre d'Etude Régional pour l'Amélioration de l'Adaptation à la Sécheresse (CERAAS), Institut Sénégalais de Recherche Agricole (ISRA), Thies, Senegal*
[3] *School of Natural Resources, University of Nebraska Lincoln, Nebraska, USA*
[4]*Soil and Water Management & Crop Nutrition Section, Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture, Department of Nuclear Sciences and Applications, International Atomic Energy Agency, Vienna, Austria*
[5]*Institute for Land and Water Management Research, Federal Agency for Water Management Austria, Petzenkirchen, Austria*
[6]*Faculty of Engineering, University of Bristol, Bristol, UK*
[7]*Cabot Institute for the Environment, University of Bristol, Bristol, UK*

Cosmic Ray Neutron Sensors (CRNS) is a nuclear technology developed to estimate soil moisture (SM) content in large areas of up to 20 to 30 ha. The technology has demonstrated its ability to support agricultural water management, hydrology studies and land surface modelling (Figure 1).

*Figure 1. Cosmic Ray Neutron Sensors (CRNS) in Petzenkirchen, Austria*

The current approach of calibrating the CRNS is based on labor-intensive sample collection (Figure 2). Depending on the land use, plant sampling may also be required for calibration, for example due to significant crop biomass water interference. Finally, the current calibration method includes corrections considering several parameters influencing neutron counts, the proxy for soil moisture, such as soil lattice water and organic carbon content.

The focus of this study was to investigate and develop an alternative calibration method to the currently available field calibration method. To this end, artificial intelligence came in. A Deep Neural Network (DNN) model architecture under the TensorFlow machine learning framework was tested to calibrate the CRNS.

A first trial of using Deep Learning was based on more than 8 years of CRNS data from Petzenkirchen (Austria). This dataset consists of four hidden layers with activation function and a succession of batch normalization.

Prior to build the Deep Learning model, data analysis consisting of pertinent variables selection was performed with multivariate statistical analysis of correlation. Among nine features, five were effectively pertinent and included in the machine learning artificial neural network architecture. The five input variables were the raw neutrons counts (N1 and N2), air humidity (H), air pressure (P4) and temperature (T7). To train the DNN model, 80% of the data from CRNS between 2017-2020 were used and 20% for validation.

The DNN model was characterized by a coefficient of determination of 0.94 and the model predicted the soil moisture with less than 1% error (MAE=0.08) (Figure 3).

These preliminary results are encouraging and proved that an artificial intelligence-based method could be an effective alternative for CRNS for the current field calibration method.

The next step is to test this calibration model with CRNS datasets obtained under different agro-ecological conditions.


*Figure 2. Soil sampling for Cosmic Ray Neutron Sensors (CRNS) calibration in Rutzendorf, Austria.*

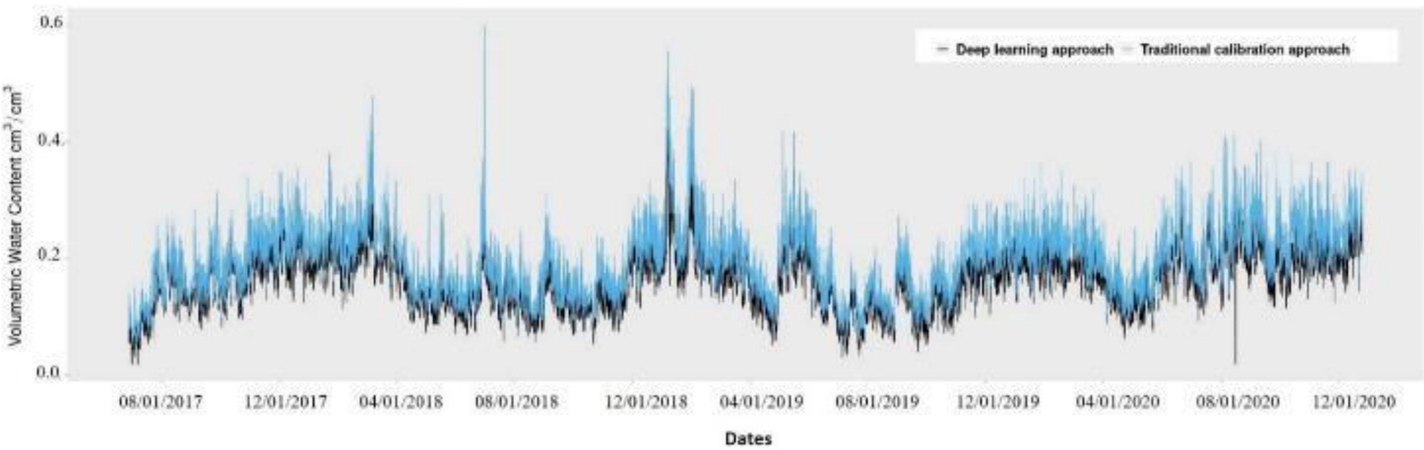



*Figure 3. Comparison of CRNS soil moisture content data obtained with traditional versus Deep Learning (DNN) calibration.*

# Assessment of a novel Cosmic Ray Neutron Sensor for area-wide soil moisture monitoring

***Said Ahmed H.[1], Weltin, G.[1], Toloza, A.[1], Baroni, G.[2], Gianessi, S.[2], Dercon, G.[1], Heng, L.[3], Fulajtar, E.[3], Franz T.[4]***

*[1]Soil and Water Management & Crop Nutrition Laboratory, Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture, Department of Nuclear Sciences and Applications, International Atomic Energy Agency, Vienna, Austria*
*[2]Department of Agricultural and Food Sciences, University of Bologna, Bologna, Italy*
*[3]Soil and Water Management & Crop Nutrition Section, Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture, Department of Nuclear Sciences and Applications, International Atomic Energy Agency, Vienna, Austria*
*[4]School of Natural Resources, University of Nebraska Lincoln, Nebraska, USA*

Efficient agricultural water management is a prerequisite for sustaining agricultural productivity, and better management of agricultural water involves measuring soil moisture.

Cosmic Ray Neutron Sensors (CRNS) is a nuclear technology used for estimating soil moisture (SM) content at the landscape level (up to 20 to 30 ha). The CRNS is a valid, robust technology and has demonstrated its ability to support agricultural water management.

CRNS technique is based on the detection of natural neutrons. Incoming cosmic rays interact with elements of the earth's atmosphere and produce fast, high-energy neutrons that eventually penetrate the soil and then scatter back into the atmosphere. These scattered neutrons lose energy due to collisions mainly with hydrogen atoms - which come mostly from soil moisture - and become low-energy neutrons (epithermal neutron). The CRNS measures these low-energy neutrons near the soil surface. Because the neutrons are spatially distributed and scatter across large distances in the air, they can monitor soil moisture over vast areas.

*Figure 1. Traditional (left) and novel (right) Cosmic Ray Neutron Sensors at the SWMCN Laboratory research site in Seibersdorf, Austria.*

The current commercial CRNS uses Helium-3 ($^3He$) for thermal neutron detection and liquid/plastic scintillators for the fast neutron. The $^3He$ used today in industry is artificially produced from the radioactive decay of tritium which comes from the residual activities of atmospheric nuclear weapons tests of the last decades. Given its very low natural abundance, $^3He$ price is high and is rising.

To overcome this challenge of high price of $^3He$, novel CRNS technology is now being developed by the scientific community. This new technology uses a composite detector made of commercial detectors, including inorganic scintillators. Besides avoiding the need for $^3He$, this approach makes the novel CRNS also lighter (plastic material), smaller and easily recyclable.

First studies on the use of this novel technology are now available highlighting how the new sensor could be a valid alternative and robust solution for the application of the CRNS technology for soil moisture measurements in agriculture (e.g. Germany and Italy) (Stevanato et al., 2019). In 2021, the SWMCN Laboratory has initiated the performance assessment of this new CRNS technology by comparing it to the traditional technology at its research sites (Figure 1). First results of this comparison are expected in the summer months.

## Effect of nitrogen process inhibitors on soil ammonia emission

***Mirkhani, R.[1,2], Heiling, M.[1], Zaman, M.[3], Jabbarimalayeri, H.[1], Shorafa, M.[2], Van Laere, J.[1,4], Heng, L.[3], Dercon, G.[1]***

[1]*Soil and Water Management and Crop Nutrition Laboratory, Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture, Seibersdorf, Austria*
[2]*Soil Science Department, University of Tehran, Iran*
[3]*Soil and Water Management and Crop Nutrition Section, Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture, Vienna, Austria*
[4]*Division of Soil and Water Management, Faculty of Bioscience Engineering, University of Leuven, Belgium*

Nitrogen (N) is an essential nutrient for crops, that is commonly applied as fertilizer, but it is also subject to many transformations in soil leading to ammonia ($NH_3$) volatilization, nitrate leaching and greenhouse gas emission. Ammonia volatilization (AV) is a major pathway of nitrogen fertilizer loss. The global average N loss from applied urea fertilizer, through the AV process, is estimated to be close to 14% (Bouwman et al., 2002).

The AV process is influenced by meteorological conditions, soil properties and field management practices. Ammonia volatilization can be reduced if N fertilizers are applied when soil and air temperatures are low, or when rain occurs, or when the fields are irrigated soon after fertilizer application. Incorporating N fertilizer into the soil after its application will also reduce or prevent $NH_3$ volatilization.

In this study, our objective was to understand the role of N process inhibitors on $NH_3$ volatilization. Nitrogen process inhibitors are chemical compounds that temporarily retard conversion of fertilizers to the forms that can be lost through different pathways. By extending the time, the active N component of the fertilizer remains in the soil as either urea-N or ammonium-N, an inhibitor can improve N use efficiency (NUE) and consequently enhance crop yield and reduce environmental impacts. There are two main types of N process inhibitor that are added to stabilize N fertilizers:

- Urease inhibitors (UI) slow down the hydrolysis of urea
- Nitrification inhibitors (NI)inhibit the biological oxidation of ammonium to nitrate

A field experiment was established at the SWMCN laboratory in Seibersdorf, Austria to determine the effect of different N fertilizers coated with N process inhibitors on maize yield and $NH_3$ volatilization in summer 2020. The soil at the experimental field site is a moderately shallow Chernozem with significant gravel content. A randomized complete block design with four replica was used in this study. Treatments were: $T_1$ (control treatment - without N fertilizer), $T_2$ (Urea only), $T_3$ (Urea + UI), $T_4$ (Urea + UI + NI-1), and $T_5$ (NPK + NI-2). Urea was applied through two split applications in the $T_2$ treatment (at 20 DAP and 34 DAP). In $T_3$, $T_4$, and $T_5$ treatments, N fertilizers were applied only once (at 20 DAP). All treatments received 120 kg N $ha^{-1}$, except for treatment 1, 60 kg $ha^{-1}$ $P_2O_5$ and 146 kg $ha^{-1}$ $K_2O$. Supplemental irrigation was only applied in the early stages of growth, to ensure that the crop could establish.

Ammonia volatilization was measured with semi-static chambers (Figure 1). The detailed description and validation of these chambers were reported in the studies conducted by Jantalia et al. (2012), Martins et al. (2017 and 2021) and Zaman et al (2021). The chamber consists of a transparent polyethylene terephthalate bottle (a 2-L bottle) with the bottom removed and subsequently fixed on the top of the bottle. A vertically hung polyurethane foam strip (250 mm long, 25 mm wide, and 3 mm thick) pre-soaked in a solution of sulphuric acid (1 mol/L) plus glycerol (4%, v/v) is placed inside the chamber to capture $NH_3$. A small plastic pot (80 ml) is used inside the chamber to keep the foam strip moist during sampling periods. A basket made of wire was used as a support for the plastic pot and the foam inside the chamber. Measurements were taken every two days during the first month, then every three days for the second month. This simple and low-cost method could be assembled easily (https://www.iaea.org/newscenter/news/fighting-air-pollution-with-a-1-tool).

The results with regards to maize yield were reported in the previous newsletter published in January 2021, showing a clear impact of the N process inhibitors on maize yield.

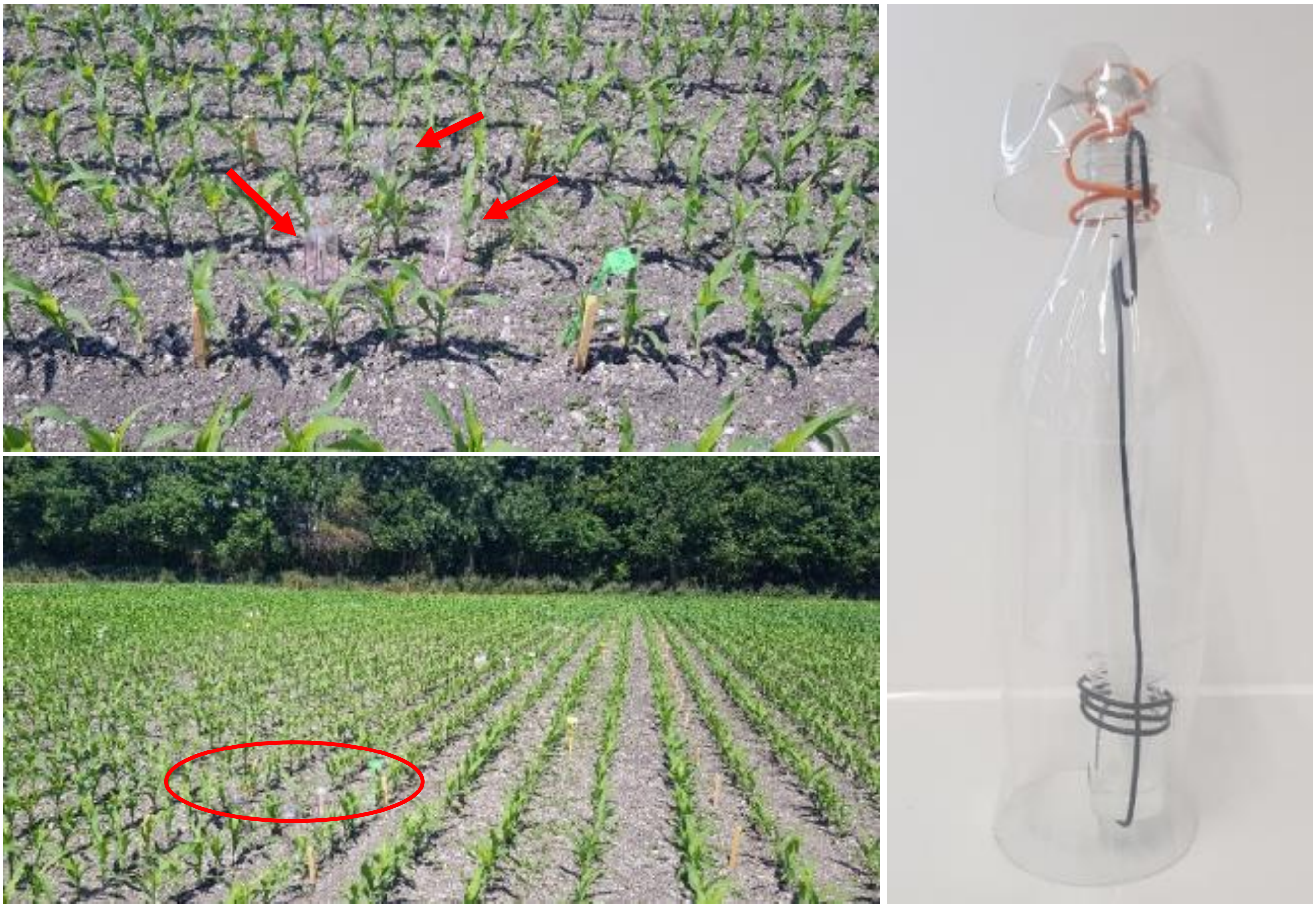


*Figure 1. Semi-static chambers to measure the $NH_3$ volatilization.*

The cumulative $NH_3$ emission data (the cumulative emissions for each treatment minus the background emission from the control treatment-$T_1$) showed that different fertilizer treatments had a significant ($p \leq 0.05$) effect on $NH_3$ volatilization (Figure 2). The cumulative $NH_3$ emissions from urea alone (Treatment 2) was 27 kg N $ha^{-1}$, corresponding to a high emission factor of 22% of the applied N. Our study showed that addition of the urease inhibitor to urea (Treatment 3) reduced $NH_3$ losses to 21 kg N $ha^{-1}$, i.e. a reduction by 21% compared to the urea treatment alone. However, statistical analysis showed that this decrease was not significant, probably due to the application of urea in two splits in Treatment 2. Treatment 4, including urea, urease (2-NPT) and nitrification (MPA) inhibitors, further reduced $NH_3$ losses to 16 kg N $ha^{-1}$, or by 41%, as compared to urea alone, but this time the difference with urea alone (Treatment 2) was significant (at $p<0.05$). This finding may suggest that treatment 4 might be a potential approach to minimizing $NH_3$ volatilization from urea application under the studied agro-ecological conditions.

The cumulative $NH_3$ emissions from treatments 3 and 4 corresponded to an emission factor of 18% and 13% of the applied N, respectively. Compared to the $NH_3$ loss associated with urea-based treatments, $NH_3$ loss from treatment 5, including NPK and nitrification inhibitor (DMPP), was relatively low, corresponding to an emission factor of 7%. Despite the same total N amount, the lower $NH_3$ emissions of treatment 5 could be explained by the lower $NH_4^+$ concentration in NPK compared to the urea-based treatments.

This study showed the importance of N process inhibitors in reducing $NH_3$ volatilization. The ranking of the treatments (Figure 2) is close to the ranking of maize yields, reported in the 2021 January Newsletter, with, besides the control treatment, treatments 2 and 3 having the lowest maize yield, and treatments 4 and 5 the highest yields.

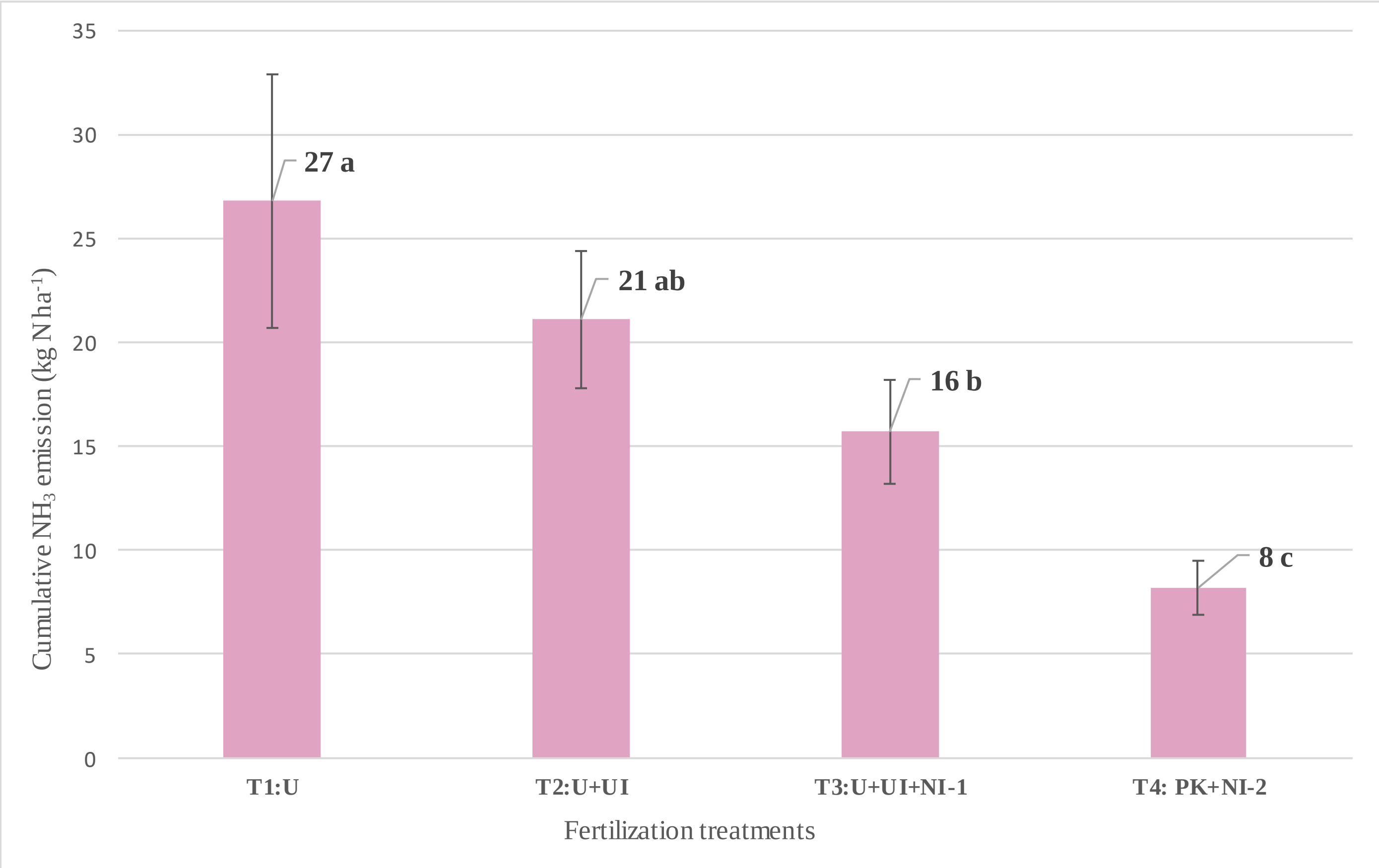



*Figure 2. Cumulative $NH_3$ emissions of different fertilization treatments (U: urea-in two splits; U+UI: urea+2-NPT; U+UI+NI-1: urea+2-NPT+MPA; NPK+NI-2: NPK+DMPP). The vertical bars indicate the standard deviation. A mean comparison between fertilization treatments from Tukey's HSD-test indicates a significant difference at $p<0.05$. The same letters indicate groups that were not significantly different from one another.*
** 2-NPT: N-(2-nitrophenyl) phosphoric acid triamide*
** MPA: N-[3(5)-methyl-1H-pyrazol-1-yl) methyl] acetamide*
** DMPP: 3,4-dimethylpyrazole phosphate*
** NPK (Total Nitrogen 15%: 6.9% Nitrate + 8.1% Ammonium)*

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# Supporting the FAO Global Soil Laboratory Network (GLOSOLAN) in the use of Mid-Infrared Spectroscopy (MIRS) for estimating soil properties

***Heiling, M.*[1]*, Albinet, F.*[2]**

*[1]Soil and Water Management & Crop Nutrition Laboratory, Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture, Department of Nuclear Sciences and Applications, International Atomic Energy Agency, Seibersdorf, Austria*
*[2]Independent Data Science Consultant, France*

In 2020, the SWMCN Laboratory became member of the FAO GLOSOLAN's Working Group on Dry Chemistry, with emphasis on soil spectroscopy. Besides improving the mathematical processing of soil spectroscopy data for estimating soil properties, the SWMCNL also started recently in 2021 to assist in the development of sample preparation protocols for soil spectroscopy analysis, in particular in the mid-infrared range (also called Mid-Infrared Spectroscopy or MIRS).

Soil spectroscopy is the study of the interaction between soil and electromagnetic radiation. It is based on the principle that molecular vibrations and electronic transitions associated with soil constituents absorb light while interacting with radiation. For the first time since the discovery of this technology, institutions and experts from around the world are now joining efforts to use this technology to support decision making on soil protection globally[1].

Soil Spectroscopy can be used to estimate soil properties, after calibration by soil property measurements through conventional chemistry. Therefore, it can be considered a more cost-effective way forward in assessing soil properties and soil mapping.

Sample preparation for soil spectroscopy is relatively easy (mainly physical preparation, by drying, milling and homogenizing). However, the subsample taken for analysis must represent the original sample accurately, otherwise the results of the analysis can be questionable.

As it is assumed that the error resulted through sampling and sample preparation is considerably higher than that of the MIRS measurement itself, the SWMCN Laboratory has started to conduct a soil sample preparation comparison to assess the influence of reducing the sample volume on derived spectral information. Based on the recommendations of the Kellogg Soil Survey Laboratory (KSSL), belonging to the United States Department of Agriculture (USDA), ten soils, with a wide range of texture and organic matter content, were sieved to 2 mm, sub-sampled by quartering or after hand-mixing for 2 minutes. Aliquots of 5 mL soil sub-samples were ball-milled using a Retsch MM200 mill at 25 Hz for 15 minutes (Figure 1). To evaluate the impact of the sample preparation method, the MIR spectra of the processed samples are now being compared. Simultaneously, the impact of the use of different mid-infrared spectrometers on the spectral data will be assessed. The question to be answered is how the spectral data can be transferred from one to another spectrometer with distinctive instrumental settings. By being able to transfer spectral data from one to another measurement setting in a simple systematic way, soil estimation models developed on one instrument can then be used for spectral data derived on another instrument. This will improve global collaboration between laboratories. Final results will be reported in the next Newsletter.

To support Member States in soil analyses, the SWMCNL is now able to receive soil samples from all over the world. Information on how to ship soil samples to the SWMCNL in Austria can be found in the FAO online tool: Soil Import Legislation (SIMPLE) database for Austria. Simplifying the shipment procedure of soil samples is essential to promote and facilitate international inter-laboratory comparisons and analytical support.


*Figure 1. Ball-milling soil samples for MIRS analysis.*

[1] Dry chemistry (spectroscopy) | Global Soil Partnership | Food and Agriculture Organization of the United Nations (fao.org)

# Stable isotope discrimination in different carbon pools in banana plants

*Vantyghem, M.[1,2,4], Allaert, J.[2], Merckx, R.[2], Swennen, R.[3], Hood-Nowotny, R.[4], Dercon, G.[1]*

[1]*Soil and Water Management & Crop Nutrition Laboratory, Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, Department of Nuclear Sciences and Applications, International Atomic Energy Agency, Vienna, Austria*
[2]*Division of Soil and Water Management, Faculty of Bioscience Engineering, KU Leuven, Belgium*
[3]*Laboratory of Tropical Crop Improvement, Division of Crop Biotechnics, KU Leuven, Belgium*
[4]*Institute of Soil Research, Department of Forest and Soil Sciences, University of Natural Resources and Life Sciences Vienna, Austria*

The PUI (Peaceful Uses Initiative) project on Enhancing climate change adaptation and disease resilience in banana-coffee cropping systems in East Africa has, among others, the objective to develop isotope based and other methods to measure drought stress in coffee and banana in the field. In the first year of the project, a field experiment in Tanzania has shown that carbon isotope discrimination, measured as $\delta^{13}C$, is a very good method for detecting drought stress in banana in the field. We developed a leaf sampling approach specific for banana and suitable for field conditions. The $\delta^{13}C$ value of a banana leaf is however a time-integrated measure: it is a combined measure of all carbon in a leaf and therefore represents the whole lifetime of the leaf. It might be interesting to have more time-specific information, especially short-term information. Therefore, we have more recently been looking into different carbon pools within the leaves, namely the α–cellulose fraction, which is highly immobile and which should represent the conditions at time of leaf development, and the water-soluble organic matter (WSOM), which consists of recent photo-assimilates and as such, should represent current stress conditions. These were compared with the $\delta^{13}C$ of the whole leaf and of the phloem sap, another short-term indicator for drought stress.

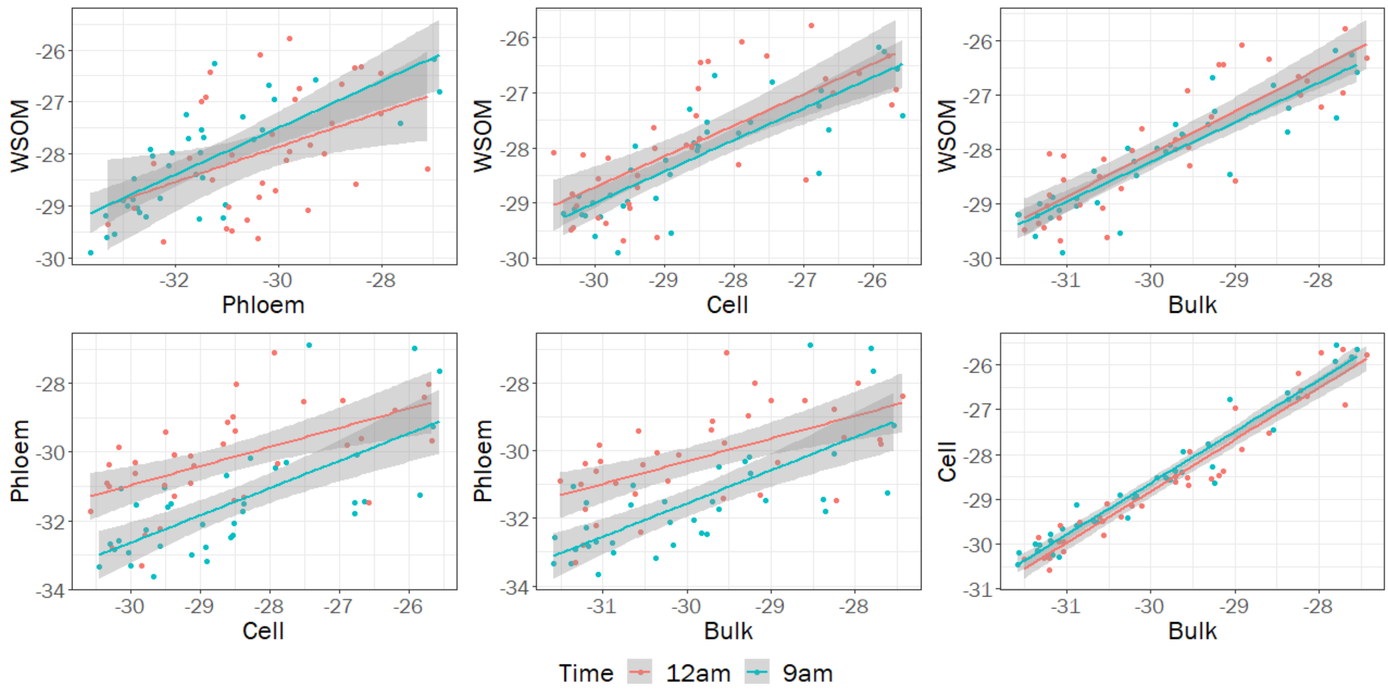


*Figure 1. Relationships between the $\delta^{13}C$ values (‰) of different carbon fractions: Water Soluble Organic Matter in the leaf (WSOM), Phloem sap (Phloem), α-cellulose in the leaf (Cell) and Bulk leaf (Bulk) in the banana plants, at 2 times per day.*

Figure 1 shows the relationships we found between these different fractions, in banana plants sampled in a greenhouse experiment. It becomes clear that $\delta^{13}C$ values of the α-cellulose fraction in the leaf strongly correspond to the bulk leaf $\delta^{13}C$ values. This is in accordance with our expectations. We assumed that a bulk leaf mostly consists of non-mobile carbon in a leaf (such as α-cellulose) and therefore represents the stress level at time of leaf development. What is however surprising, is the relationship between phloem $\delta^{13}C$ and α-cellulose and bulk leaf $\delta^{13}C$. One would expect that generally, phloem $\delta^{13}C$ values at noon are less negative than in the morning. At noon, more photosynthesis occurs, resulting in more stress. Therefore, sugars in phloem sap should have a less negative $\delta^{13}C$. Bulk leaf and or α-cellulose are very stable carbon pools, we would expect the $\delta^{13}C$ values in these fractions to be the same in the morning and afternoon. This is indeed the case. The relationship between phloem $\delta^{13}C$ and bulk leaf or α cellulose at noon is shifted upwards compared to the morning. The phloem $\delta^{13}C$ values have increased, but the $\delta^{13}C$ values of α-cellulose and bulk leaf samples have not. However, we would expect this difference between morning and noon to be the largest in the more stressed plants (with less negative $\delta^{13}C$ values, upper right corner). Here, we see the opposite, namely that the difference between morning and noon is largest for non-stressed plants (more negative δ[13]C, left bottom corner). One possible explanation could be the time lag of the phloem δ[13]C value. Transportation to the phloem takes time, and therefore the signal at noon might actually represent the stress level of the morning.

Similar sampling was undertaken in early 2021 in the field in Tanzania (Figure 2). Sample and data analysis is still ongoing, but these results should allow us to further elaborate on these carbon dynamics in banana plants in the greenhouse. Moreover, a greenhouse experiment has been planned for the summer of 2021 in Seibersdorf, where we will investigate carbon dynamics in banana mother and daughter plants.

Banana plants typically reproduce through the formation of so-called suckers or daughter plants. These will conduct their own photosynthesis, but also receive carbon assimilates from the original mother plant, to which they remain connected. Understanding and quantifying this carbon flux from mother to daughter plant will allow us to better understand δ[13]C values in daughter plants as well as improve our knowledge on carbon dynamics within banana plants and impact of drought stress on those dynamics.

*Figure 2. Sampling banana leaves for α-cellulose, WSOM and bulk leaf δ[13]C analysis in field experiment in Arusha, Tanzania*

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

***Van Laere, J.[1,2], Hategekimana, I.[2], Merckx, R.[1], Dercon, G.[2]***

*[1]Division of Soil and Water Management, Faculty of Bioscience Engineering, University of Leuven, Belgium*
*[2]Soil and Water Management and Crop Nutrition Laboratory, Joint FAO/IAEA Centre of Nuclear techniques in Food and Agriculture*

Dry spells are an increasing problem in Central Africa, also potentially affecting staple crops such as cassava[2]. Therefore, strategies to cope with drought are becoming key to improve cassava production under a changing climate. Variety selection and balanced fertilizer application are the two strategies that can be used to mitigate drought impact on cassava yield. In particular, potassium may be an important element in this endeavor, as this nutrient is known to influence stomatal regulation, photosynthesis and assimilate transport[3].

In November 2020, an experiment with 120 cassava plants was initiated in the SWMCNL greenhouses. For this experiment, two varieties were used: a local Rwandese variety, called Gacyaricyari, and an improved high-yielding variety, Narocass1, developed by NARO in Uganda. All cassava cuttings were provided by the Rwanda Agriculture and Animal Resources Development Board (RAB). Cuttings were planted in 7 L pots, filled with a fine sand substrate (to be able to control nutrient availability), and covered with a plastic mulch to reduce evaporation.

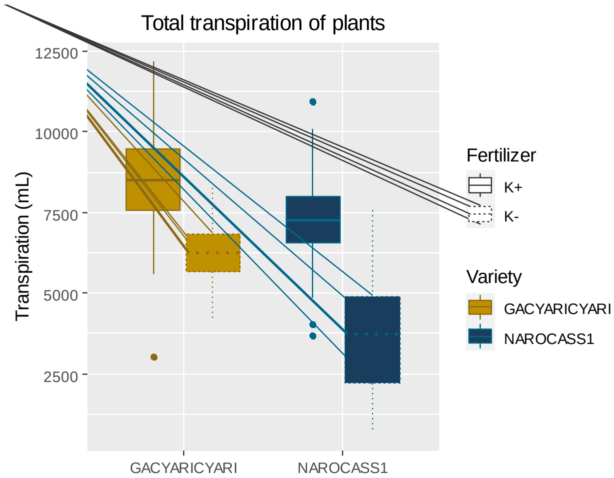


*Figure 1. Total transpiration of cassava plants from start of experiment to before the start of the drought treatment at 5 months after planting. Each group contains 25 plants. Blue color represents Narocass1 variety, brown color Gacyaricyari. Full edges indicate K+ fertilizer regime, while dotted edges indicate K- regime.*

[2] Daryanto S, Wang L, Jacinthe P-A (2016) Drought effects on root and tuber production: A meta-analysis. Agric Water Manag 176:122–131. https://www.sciencedirect.com/science/article/pii/S0378377416301810
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Half of the plants received a fully balanced nutrient solution, but with a low potassium (K-) concentration, while the other half received the same solution high in potassium (K+). At 5 months after planting a drought treatment (50% of pot capacity; W-) was applied to half of the plants, while the other half received optimal watering (90% of pot capacity; W+). Growth of the plants was followed closely by measuring the length, number of nodes and living leaves once a week, while stomatal conductance was measured just before inducing drought.

Although only the first results of until the initiation of drought[4] are published in this contribution to the newsletter, influence of variety and, more important, potassium on water use and the physiology of the cassava plants could be observed.

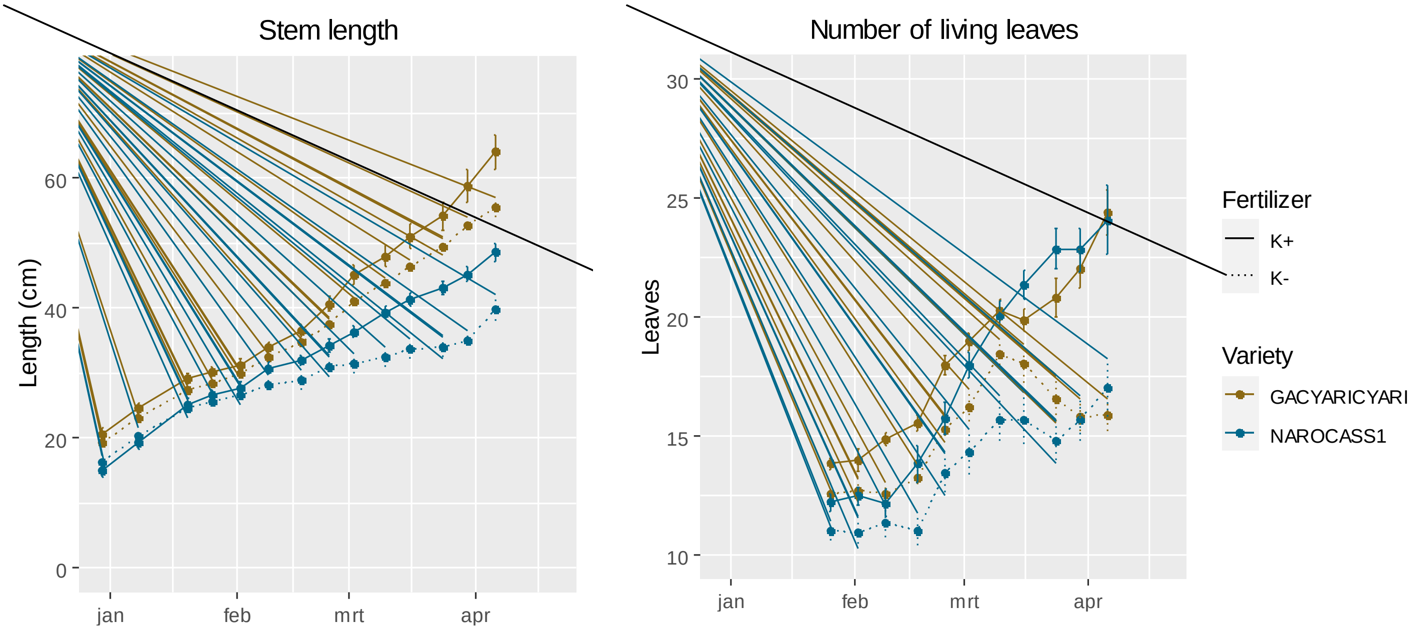


*Figure 2. Evolution of stem length and number of living leaves were measured weekly to follow the growth of the plants. Data from before start of drought. Dots represent averages of 23 plants, with standard error. Blue colour represents Narocass1 variety, brown colour Gacyaricyari. Solid lines indicate K+ fertilizer regime, while dotted lines indicate K- regime.*

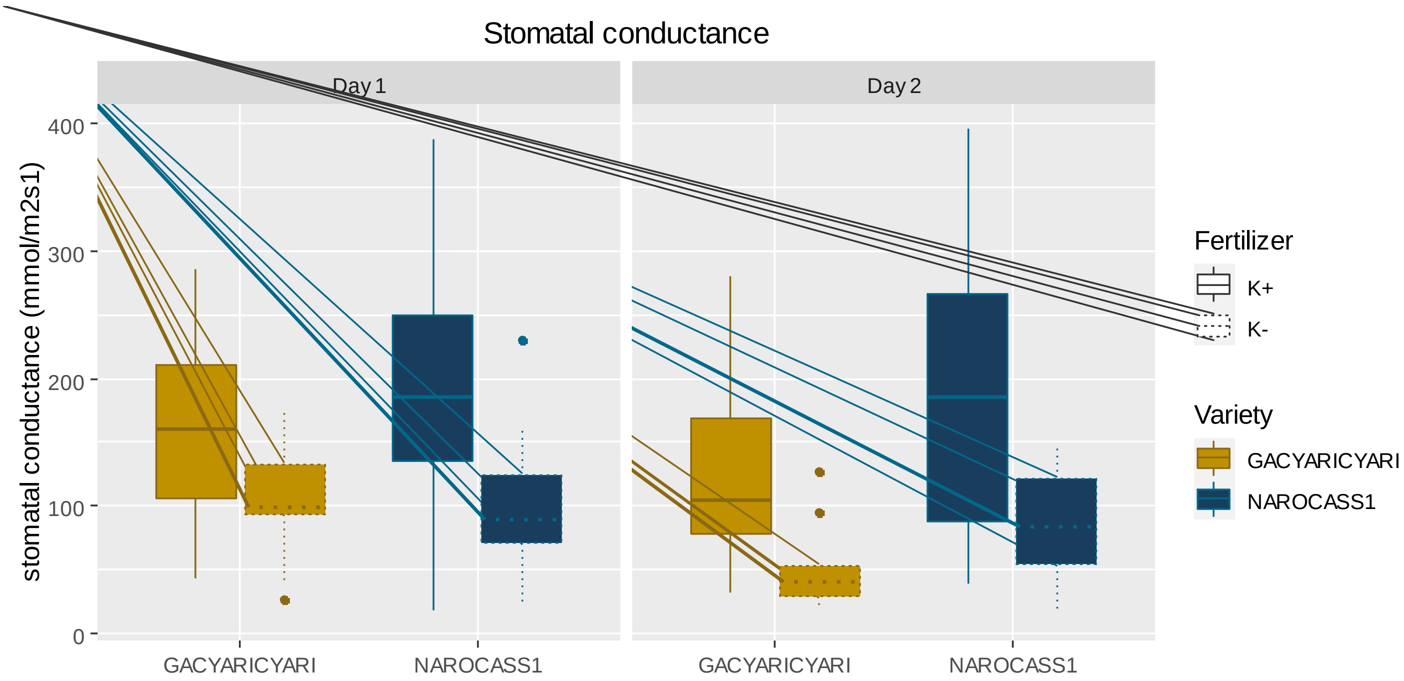


*Figure 3. Stomatal conductance of the different treatment groups at 5 months after planting (before drought). Each group contains 10-12 observations. Measurements were done at two consecutive days and on each day, half of the plants was measured. Blue boxes mean Narocass1, brown boxes mean Gacyaricyari. Full edges mean K+ fertilizer regime, while dotted edges indicate K- regime.*

[4] Drought treatment started at the deadline for submission of this newsletter

Before initiation of drought, water use was influenced both by variety ($p<0.001$) and potassium availability ($p<0.001$), with Gacyaricyari using more water than Narocass1 and plants on K+ regime using more water than on K- regime (Figure 1).

In general, Gacyaricyari (local variety) has a significantly ($p<0.001$) higher stem length as compared to Narocass1 (improved variety) (Figure 2). Further, potassium has a significant effect ($p<0.001$) on stem growth, affecting the length of both varieties. The most important observation is that the number of transpiring leaves on the plant is significantly ($p<0.001$) determined by potassium availability, and this is for both varieties, having more leaves on plants with the higher potassium level. The clearly observed role of potassium in the conservation of the leaves, even under optimal water conditions, may be an important fact, in terms of water use and in particular drought tolerance.

Further, analysis of variance shows that Gacyaricyari has a significantly ($p<0.05$) lower stomatal conductance, compared to the Narocass1, whereas potassium application significantly ($p<0.001$) increased the stomatal conductance (Figure 3).

So, under optimal watering conditions, not only more leaves are available due to potassium application, but stomatal conductance is also higher. These preliminary findings show the significant role of potassium in the physiology of cassava plants, related to water use. Plants that stay green longer, because of the higher potassium availability, may be able to mitigate the impact of dry spells better.

During the drought phase of the experiment, these physiological parameters are continued to be followed up. The observed differences in plant physiology will further be linked with stable isotope data. Stable isotope data will be obtained during the summer of 2021 by analyzing $^{13}C$ and $^{18}O$ contents of dried leaf material (bulk/cellulose/sugars), as $^{13}C$ and $^{18}O$ are related to water use efficiency and stomatal conductance, respectively. Stable isotopes can then be related to the measured water use efficiency and other related physiological measurements. Once these relations are understood, this study will help improve interpretation and application of stable isotope techniques to assess and enhance water use efficiency in cassava cropping systems. More information on this experiment will be provided in the next Newsletter.

## Calibration and Validation of the AquaCrop Water Productivity Model for Cassava (*Manihot Esculenta* Crantz)

***Coppye, C.[1], Diels, J.[2], Raes, D.[2], Dercon, G.[3], Heng, L.[4], Wellens, J.[5]***

[1]*Faculty of Bioscience Engineering, University of Leuven, Belgium*
[2]*Division of Soil and Water Management, Faculty of Bioscience Engineering, University of Leuven, Belgium*
[3]*Soil and Water Management and Crop Nutrition Laboratory, Joint FAO/IAEA Centre, IAEA, Austria*
[4]*Soil and Water Management & Crop Nutrition Section, Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture, Department of Nuclear Sciences and Applications, International Atomic Energy Agency, Vienna, Austria*
[5]*Department of Science and Environmental Management, Faculty of Science, University of Liège, Belgium*

Increasing yield and water use efficiency is becoming increasingly important when cultivating crops in climate vulnerable regions. The Food and Agriculture Organization of the United Nations (FAO) addressed this by developing an easy-to-use water productivity model: AquaCrop. This crop model simulates the evolution of attainable crop biomass and harvestable yield based on the soil water content in the root zone. To facilitate the ease-of-use of AquaCrop, the model only needs a relatively small number of parameter values and mostly intuitive input variables (Steduto, 2009). Experts worldwide have previously collaborated to calibrate AquaCrop for some essential crops including cotton, maize, wheat, peas, etc. (FAO, 2009). To date, cassava (*Manihot esculenta* Crantz), a perennial tuber crop cultivated in the tropics and subtropics, has not yet been calibrated (Lebot, 2008). However, it is the primary food source for over 800 million people and a reliable multipurpose crop that grows well in poor soils and with unpredictable rainfall (FAO, 2016).

In 2021, through a MSc study, AquaCrop is parameterized for cassava (*Manihot Esculenza* Crantz) using two calibration datasets. One from cassava experiments performed by Veltkamp (1985) in Colombia from 1978 to 1980, and one from experiments conducted by Ezui et al. (2017) from 2012 to 2013 in Togo. Some parameters were estimated using literature sources and our understanding of crop physiology, others were calibrated.

During simulations, all parameters were held constant across the different cassava cultivars, except for the maximum rooting depth, the start of senescence and the reference harvest index. With these calibrated parameters, AquaCrop was able to simulate the canopy cover and biomass evolution relatively well. For the biomass simulations of the calibration datasets, an average index of agreement (d) of 0.95 and an average root mean square error (RMSE) of 1.7 Mg dry matter/ha was attained (Figure 1). Root yields were simulated less accurately as reference harvest indices were missing for all cultivars, and no cassava plants in the experiments were cultivated entirely stress-free (Figure 2). This resulted in an RMSE value of 2.9 Mg/ha.

The new cassava model was validated afterwards with the dataset of Adiele et al. (2021) from experiments performed in 2016 to 2018 in Nigeria. As the same cultivar was used in these experiments as in Ezui et al. (2017), the model did not need cultivar specific calibration. Biomass accumulation in the validation dataset was estimated adequately (RMSE = 4.4 Mg/ha), but yields were overestimated for three out of the six experiments. The reason behind this is the inability of AquaCrop (version 6.1) to always correctly simulate the crop's regrowth after a period of dormancy.

Despite the simple input parameters, AquaCrop has proven to be robust and accurate. Differences between observed and simulated values are often the cause of simplification made by the AquaCrop model, like excluding the quality of sprouting or the occurrence of pests. Using different cassava varieties and locations in our calibration led to lower d values and higher RMSE values compared to models that only use one variety and/or location. However, for most trials, AquaCrop achieved better results than other models currently available.

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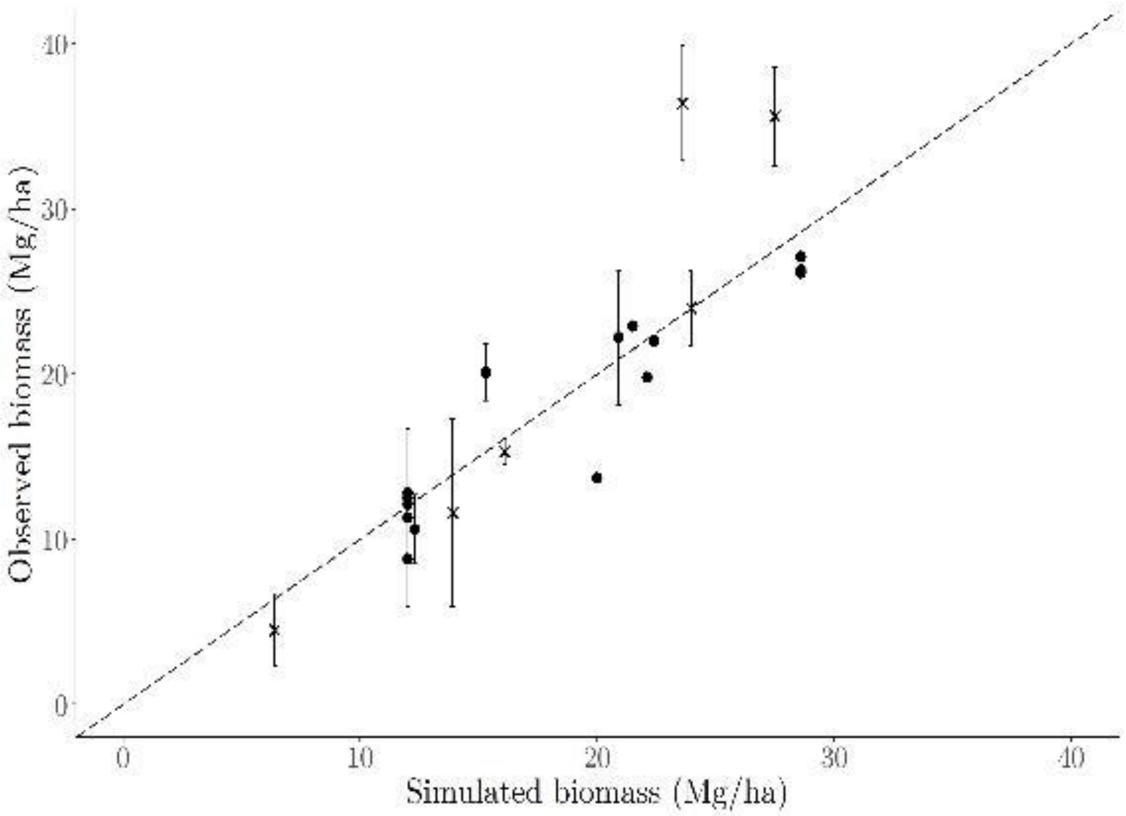


*Figure 1. Overview of simulated over observed final biomass (Mg/ha) for the validation dataset. Trials on the 1:1 line are perfectly simulated. Standard deviations, when larger than the dots and available, are represented by error bars. • represent experiments from the two calibration datasets, × represent experiments from the validation dataset.*

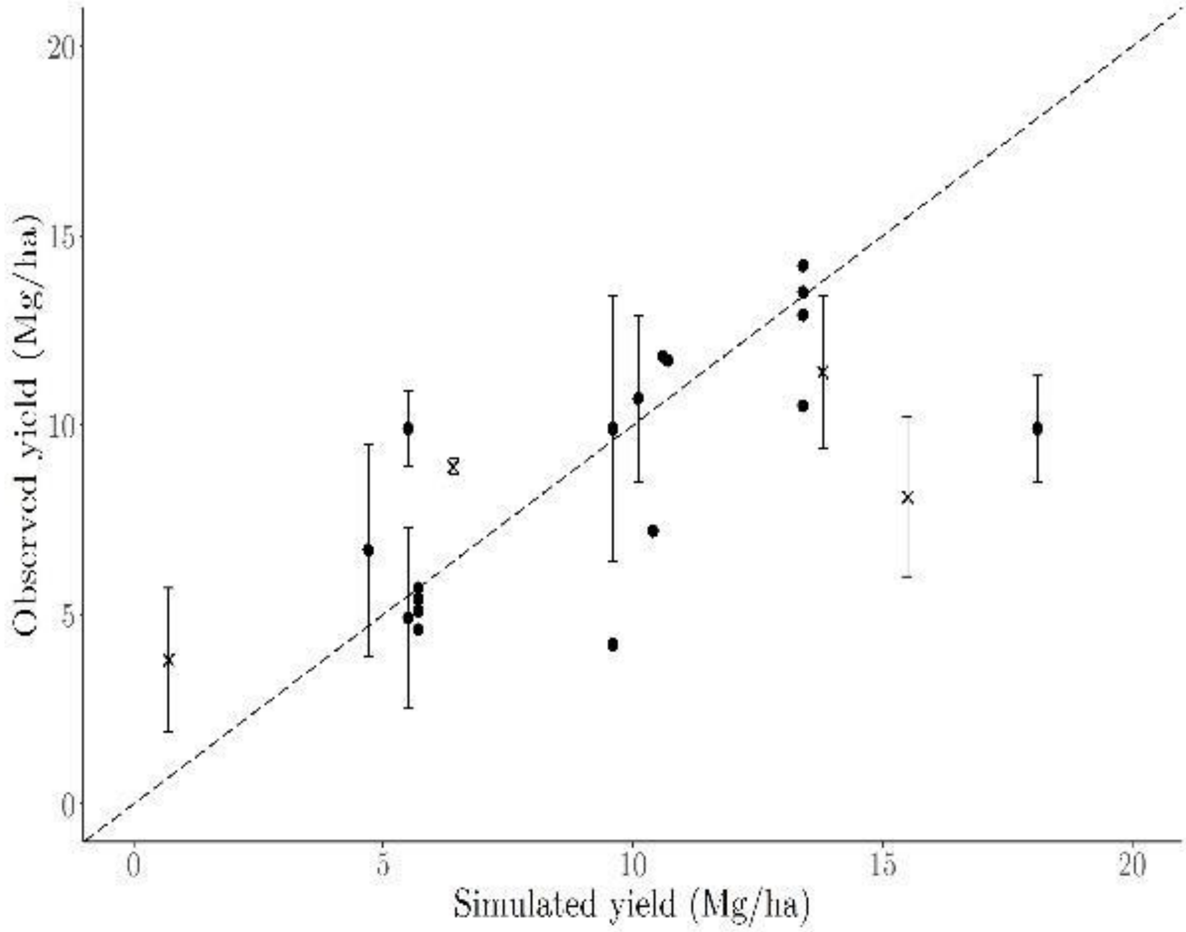


*Figure 2. Overview of simulated over observed final root yield (Mg/ha) for the validation dataset. Trials on the 1:1 line are perfectly simulated. Standard deviations, when larger than the dots and available, are represented by error bars. • represent experiments from the two calibration datasets, × represent experiments from the validation dataset.*

## Influence of ammonium fertilization and clay amendments on caesium dynamics in soil

***Rohling, M.[1,2], Eguchi, T.[1,3], Heiling, M.[1], Toloza, A.[1], Gerzabek, M.H.[2], Putyatin, Y.[4], Dercon, G.[2]***

[1]*Soil and Water Management & Crop Nutrition Laboratory, Joint FAO/IAEA Center of Nuclear Techniques in Food and Agriculture, International Atomic Energy Agency, Vienna, Austria.*
[2]*Institute of Soil Research, University of Natural Resources and Life Science (BOKU), Vienna, Austria.*
[3]*Agricultural Radiation Research Center, Tohoku Agricultural Research Center, National Agriculture and Food Research Organization (NARO), Fukushima, Japan.*
[4] *Institute for Soil Science and Agrochemistry (BRISSA), Minsk, Belarus*

Nitrogen (N) forms the major yield limiting factor in many regions of the world. Due to nitrate ($NO_3^-$) leaching into groundwater, many N-fertilizers are applied as $NH_4^+$ as this can occupy the exchange sites of clay minerals and thus be retained in soils. However, in case of radioactive contamination of soil by radiocaesium, $NH_4^+$ and $Cs^+$ are competing for exchange sites on clay minerals, so that $NH_4^+$ application can cause the release of $Cs^+$ into the soil solution and subsequently facilitates $Cs^+$ uptake by plants. Furthermore, $NH_4^+$ can also be oxidized to $NO_3^-$ through nitrification-processes, whereby the competition between $NH_4^+$ and $Cs^+$ gets lost.

Under the CRP D1.50.19 on remediation of radioactive contamination in agriculture, the SWMCN Laboratory started in 2021, in close collaboration with NARO and BOKU, R&D activities aiming to better understand the dynamics of radiocaesium ($Cs^+$) in soils in dependence of ammonium ($NH_4^+$) fertilization, and how clay amendments (e.g. zeolite) can influence the relationship between radiocaesium and ammonium.

To elucidate the interactions between $Cs^+$, $NH_4^+$, and $NO_3^-$ and clay amendments, $Cs^+$, $NH_4^+$ and $NO_3^-$ concentrations in the exchangeable and soil solution fractions are investigated over 5 weeks. The soils are either fertilized with 300 kg $NH_4^+$/ha or not fertilized and partly treated with zeolite as clay amendment (0, 10 and 40 t/ha).

Preliminary results, focusing on the interaction between $NH_4^+$ and clay amendments for an Andosol soil from Japan, show that the concentration of $NH_4^+$ in soil solution is highest without clay amendment (zeolite) and decreases with incremental increase of clay amendment (zeolite) applied (Figure 1). However, the results inversed after 3 weeks, so that $NH_4^+$ concentration in soil solution is 8 times higher in the 40 t/ha variant than in the untreated variant, which would result, based on modelling results, in a 3-fold increase in $Cs^+$-concentration in soil solution. This is of particular interest, as the clay amendment used for this experiment is commonly applied in Fukushima and surrounding area as a countermeasure against $Cs^+$ uptake of crops and to increase soil productivity after removal of severely polluted topsoil. This result implies that zeolite application could increase fertilizer use efficiency of $NH_4^+$, however, this can also lead to challenges with the synchronization between N supply and demand by the crops. To further elucidate these dynamics, five soils will be investigated in due course of this CRP D1.50.19 study, i.e. Andosol, Cambisol, Gleysol (all sampled in Japan), Chernozem (1 soil sampled in Austria), and Anthrosol (1 soil sampled in Belarus).

The three Japanese soils are of particular interest, as the Fukushima Daiichi nuclear accident still requires elucidation about appropriate measures to counteract radioactive soil pollution. The soils selected from Japan vary in texture and content of 2:1 clay minerals, as these characteristics strongly influence the capacity of binding $Cs^+$ in soils. This approach will assist in attaining more precision in implementing the soil remediation measures.

One of the sampled Japanese soils contains only little 2:1 clay minerals and is therefore additionally treated with three different clay amendments, i.e. zeolite but also smectite and vermiculite. Zeolite was already used as a countermeasure for $Cs^+$ soil pollution, as it is affordable and shows synergies with agricultural practice when it comes to nitrogen-use efficiency. Similar synergies exist for smectite, as it is practically used to increase water retention. Moreover, at high exchangeable $K^+$ condition, smectite has a considerable amount of frayed edge sites, which show an increased selectivity for $Cs^+$. Opposed to those clay minerals, vermiculite is less affordable and investigations on it are of purely scientific interest.

The soil types sampled in Europe, on the other hand, are of particular interest, as they are still affected by the Chernobyl nuclear accident. The sampled Anthrosol from Belarus is located at 40 km from Chernobyl, an area affected by radioactive soil pollution. The Chernozem soil (sampled in Austria) represents an important and fertile soil of central Europe, which is also present in the area affected by the Chernobyl nuclear accident.

It is expected that these investigations will help to provide advice for countermeasures against $Cs^+$ uptake while considering agricultural practice and affordability but also soil properties given at sites, which are highly affected by $Cs^+$ pollution.

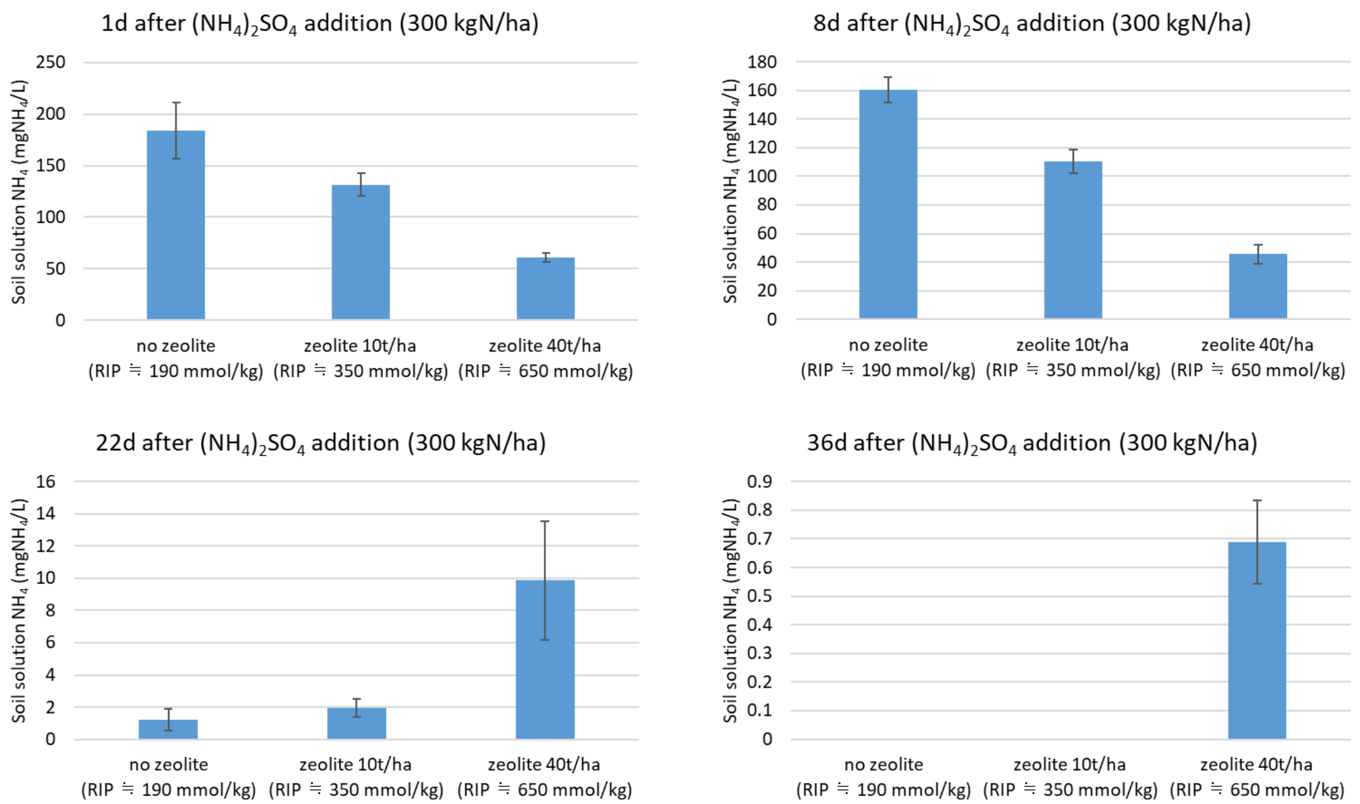


*Figure 1. Influence of zeolite application (0 t/ha, 10 t/ha, 40 t/ha) on $NH_4^+$ in soil solution after $(NH)_4SO_4$ addition to an Andosol (Japan).*

# Optimizing remediation decisions in response to large-scale nuclear emergencies affecting food and agriculture

***Abrams, F.[1,2], Hendrickx, L[1,2], Sweeck, L.[1], Camps, J.[1], Van Orshoven, J.[2]***

[1]*Belgian Nuclear Research Centre (SCK•CEN), Boeretang 200, 2400 Mol, Belgium*
[2]*Division of Forest, Nature and Landscape, Faculty of Bioscience Engineering, University of Leuven, Belgium*

## Optimizing remediation efforts under uncertainty

Choosing the optimal measures for the remediation of agricultural fields after a nuclear accident, can significantly reduce the long-term consequences for people, environment, trade, and the economy. A decision support system can aid with the efficient allocation of resources as well as the increase in transparency and robustness of the decision-making process. This research proposes a multi-criteria decision aiding system to rank the remediation measures per agricultural parcel, to optimize the remediation process.

However, one of the main challenges for such decision aiding system is the role of uncertainty in the decision-making. Uncertainty can have effect on different parts of the multi-criteria decision aiding process. First, measurement uncertainty can occur on the different criteria, the uncertainty relates to the methods used to evaluate the criteria. For example, if the concentration of $^{137}Cs$ in the soil is measured, the method of measurement is inherently accompanied by a level of uncertainty. Second, ulti-criteria decision analysis uses a weighted aggregation to the criteria, reflecting its importance. The weights assigned to the criteria, are determined by a stakeholder panel, however if disagreement exists between decision makers, it can lead to a more uncertain decision. Therefore, the uncertainty of the criteria and the decision space (criteria weights) after a nuclear accident are always accompanied by a certain level of uncertainty. In addition, because of trade-offs between different remedial actions (cheap but less effective compared to costly but very effective), make decision-making difficult. A decision support system should help the decision maker in addressing and acknowledging the consequences of this uncertainty and trade-offs.

A hypothetical contamination situation was modelled to form the basis of the Multiple-Criteria Decision-Making (MCDM) process. The PROMETHEE II framework 5 was used for determining the optimal remedial technology on a hypothetical agricultural field. By evaluating the remedial actions on seven criteria (Table 1), the most optimal alternative for this specific field and socio-economic context can be found (Figure 1).

*Table 1. Criteria used for evaluating the remedial measures.*

| Criteria | Description |
|---|---|
| **Reduction efficiency** | Reduction of radioactivity in agricultural products (compared to doing nothing) [%] |
| **Direct cost of alternative** | The total implementation cost. The full remediation cycle is included from investigation to monitoring and waste treatment. [€/ha] |
| **Indirect cost/benefit of alternative** | Expected change of yield of the agricultural parcel. [Low - High based on expert assessment] |
| **Local impact** | Changes to the landscape/ way of life of the people from the surrounding communities. Measured by increased discomfort because of the production of dust, noise, etc.<br>[Low - High based on expert assessment] |
| **Environmental impact** | Risk or actual impact on the living and or non-living environment due to the remediation effort. [Low - High based on expert assessment] |
| **Feasibility** | How easily can the remediation strategy be implemented successfully. "How difficult it is to allocate the workers and arrange the technical resources? [Low - High based on expert assessment] |
| **Incremental dose** | Internal and external radiation exposure dose to the workers who need to implement the remediation technique. [Low - High based on expert assessment] |

[5] PROMETHEE II is a commonly used outranking MCDM framework, more details can be found in (Betrie et al. 2013)

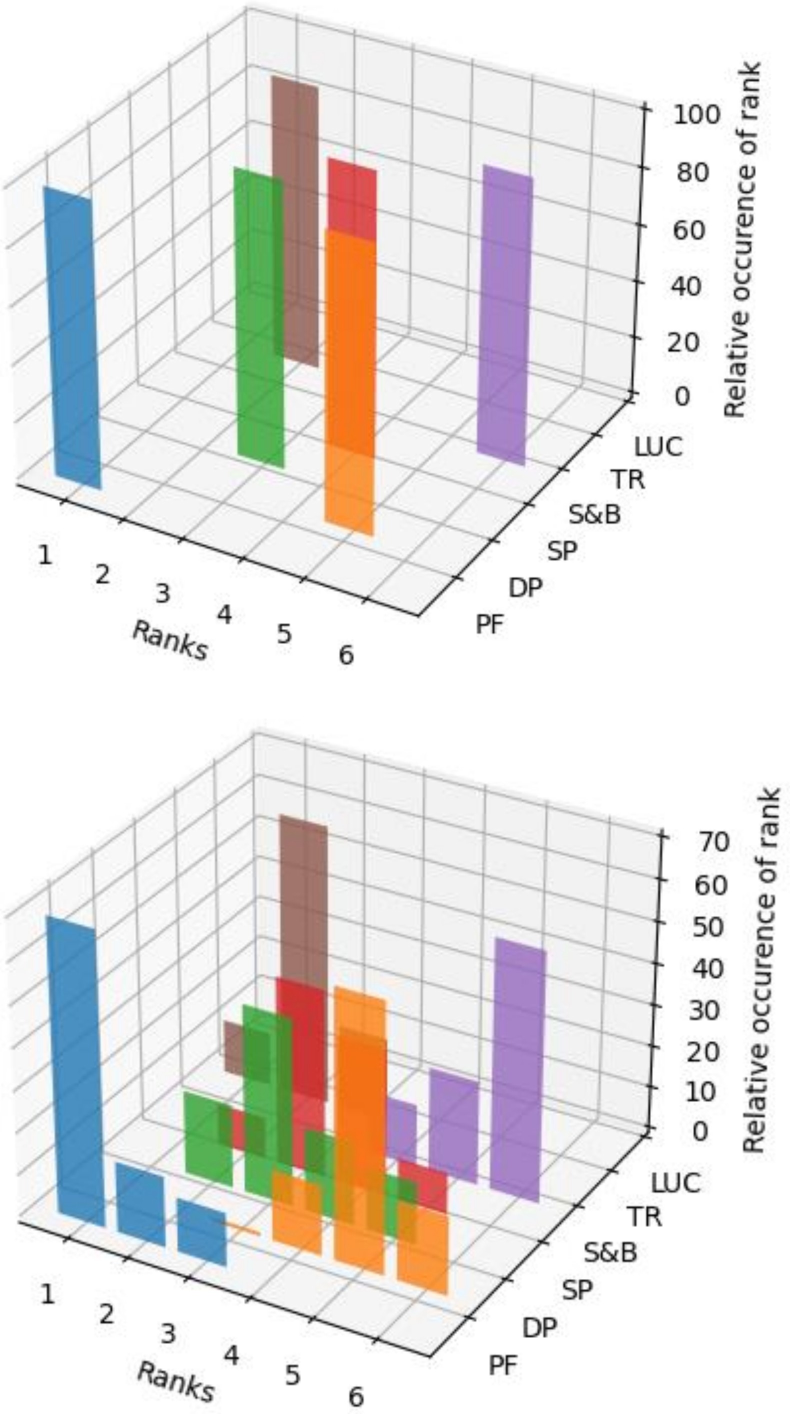


*Figure 1. 3D plot of the rank acceptability indices of the different alternatives following the multi-criteria decision analysis, without (top) and with uncertainty (bottom). The abbreviations of the alternatives are: PF=Potassium Fertilization, DP= Deep Ploughing, SP= Shallow Ploughing, S&B= Skim and Burial ploughing, TR = Topsoil Removal, LUC = Land Use Change.*

The use of multi-criteria decision analysis (MCDA) helps determine the optimal remediation technology for the specific criteria. The ranking of the remediation actions, without considering uncertainty, can be seen in Figure 1 (top). It can be observed that less intrusive technologies are ranked better for this specific set of weights. However, with the additional uncertainty the resulted ranking becomes spread over ranks as seen in Figure 1 (bottom). This analysis can help us understand that different remedial actions are actually equally good from the MCDA perspective, therefore decision making becomes less straightforward. Compared to uncertainty analysis, a sensitivity analysis can help us to specifically focus on one parameter and look at the effect of this parameter on the ranking of the measures.

## The OREFA platform

As part of the CRP D1.50.19 on Remediation of Radioactive Contaminated Agricultural Land, an interactive web platform was set up to easily distribute information and to engage more with the public (Figure 2). On the platform we will introduce you to our research, how multi-criteria decision aiding systems can help us make better decisions. Are you a remediation expert, decision maker or interested in emergency preparedness? Help us determine the needed criteria by filling out our survey. Have a look on our web platform and learn more about MCDA to support remediation efforts after a nuclear accident.

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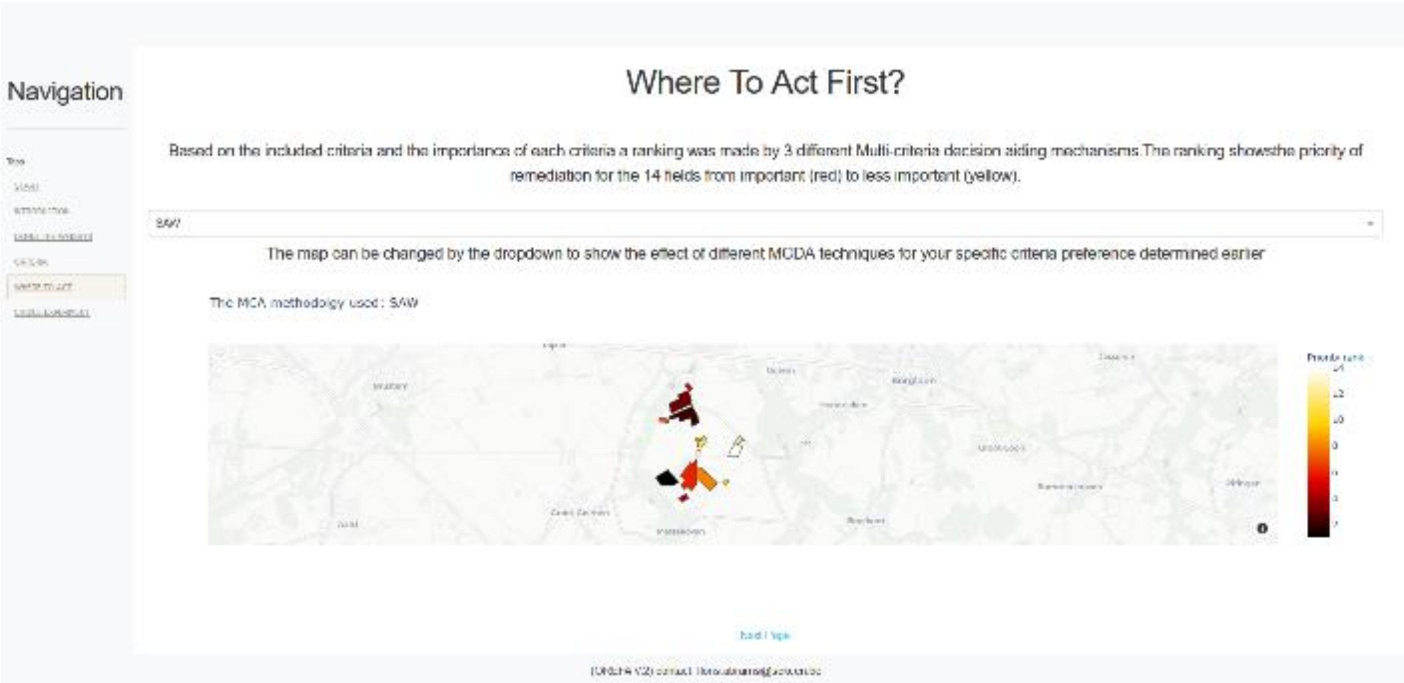


*Figure 2. Screenshot of the OREFA web-based platform.*

# Publications

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# Websites and Links

- Soil and Water Management and Crop Nutrition Section:
  http://www-naweb.iaea.org/nafa/swmn/index.html
- Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture:
  http://www-naweb.iaea.org/nafa/index.html
- http://www-naweb.iaea.org/nafa/news/index-ss.html#swmcn
- Food and Agriculture Organization of the United Nations (FAO):
  http://www.fao.org/about/en/
- FAO Agriculture and Consumer Protection Department
  http://www.fao.org/ag/portal/ag-home/en/
- FAO Land & Water:
  http://www.fao.org/land-water/en/ l
- New communication materials outlining successes in the area of nuclear techniques in food and agriculture:
  http://www-naweb.iaea.org/nafa/resources-nafa/IAEAsuccessIV_stories_Rev6.pdf
  http://www-naweb.iaea.org/nafa/resources-nafa/ProgBrochure-2014.pdf
  http://www-naweb.iaea.org/nafa/resources-nafa/LabBrochure-2014.pdf

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