



Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

IN ACTION

Nuclear applications in agriculture

On-the-ground success

Part III





Joint FAO/IAEA Division brings nuclear techniques to climate-smart agriculture

The global climate is changing, altering the frequency and intensity of extreme weather events and seriously impacting food security. Rising sea levels, ecosystem stress, glacier melt and altering river systems exacerbate the vulnerability of particular social groups and economic sectors. Climate change is also altering the distribution, incidence and intensity of terrestrial and aquatic animal and plant pests and diseases. Most developing countries are already subject to an enormous disease burden, and both developing and developed countries could be affected by newly emerging diseases. Making global agricultural systems resilient to these changes is critical for efforts to achieve global food security.

The Joint FAO/IAEA Division helps countries develop capacity to optimize their use of nuclear techniques to confront and mitigate impacts of climate change on agricultural systems and food security – nuclear techniques that can increase crop tolerance to drought, salinity or pests; reduce greenhouse gas emissions and increase carbon sequestration from agricultural systems; track and control insect pests and animal diseases; adjust livestock feed to reduce emissions and improve breeding; optimize natural resource management through isotopic tracking of soil, water and crops; and provide information essential for assessing ecosystem changes and for forecast modelling.

The Joint Division provides technical support and policy advice to support Member States in targeting their R&D and implementing national regulations that address their climate vulnerabilities.

The Joint FAO/IAEA Division helps Member States apply nuclear and related techniques to sustainably increase agricultural productivity, taking into account national and

local specificities and priorities. Its focus on climate-smart agriculture includes the following applications.

Resilience and adaptation to climate change

- Mutation breeding for drought, salinity and pest tolerance of agricultural crops
- Insect sterilization for area-wide integrated pest management
- Identification of sources of land degradation in agricultural landscapes
- Optimization of livestock reproduction, breeding and local feed utilization

Greenhouse gas reduction

- Identification of sources of nitrous oxide production for emission reduction
- Evaluation of soil quality and carbon sequestration
- Optimization of animal feeding practices and manure management

Development of smart agricultural practices

- Assessing land degradation, soil erosion and carbon, water and nutrient movement dynamics
- Determining uptake and utilization of rumen microbial protein
- Optimizing animal breeding programmes

Assessing impact of climate change

- Assessing impacts of climate change on land degradation and sediment redistribution
- Identifying sources of nitrous oxide production
- Tracking migratory bird movement to ascertain risks of disease transmission
- Monitoring agrochemical inputs to reveal application efficiency of climate-smart agricultural practices.

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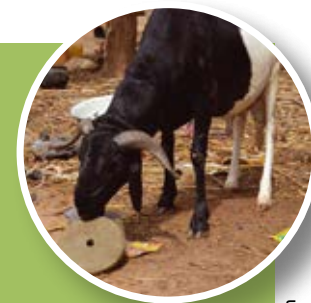


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BURKINA FASO

Genetic analysis in Burkina Faso guides farmers in improving sheep and goat productivity



The sheep and goat populations of Burkina Faso face many challenges – limited feed in the Sahelian north, infestations of deadly trypanosome-carrying tsetse flies in the south, and a long dry season in the whole country. The area is home to three breeds of sheep and goats. The Sahelian sheep and goats in the north are large animals, which means they produce more meat and milk, but the north's harsh terrain does not provide enough feed. The *Djallonke*, from the greener south, may be smaller, but they have natural resistance to the trypanosome infections. And the *Mossi*, a cross of the *Sahelian* and *Djallonke*, emerged from farmers' efforts to maintain the size of the northern breed and disease resistance of the southern breed, but their rather indiscriminate crossing only produced mixed results. Now that is changing. A genetic evaluation and characterization assisted by the Joint FAO/IAEA Division has given farmers a visual guideline to know which animals to breed. All they have to do is look at the animal, especially its size – *and its ears!*

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Burkina Faso is a West African country with 17.3 million people, the great majority of whom rely on agriculture, mainly livestock rearing. Livestock, which is responsible for 7.5 percent of national GDP, is almost totally in the hands of resource-poor pastoralists and smallholder farmers. Developing the livestock sector, especially focusing on improving the productivity of sheep and goats, would make a great contribution toward reducing poverty.

A two-level approach has been taken to determine the best way to support the farmers of the area in improving the productivity of their sheep and goats. This includes crossbreeding to capture both the size of the Sahelian and the disease resistance of the Djallonke sheep and goats while also developing a low-cost feeding programme to maintain the animals during Burkina Faso's long dry season. The Joint Division, working with four national laboratories, set up a programme to improve national capacity to conduct genetic evaluations and, in turn, use increased knowledge of the genetic composition of the breeds to improve productivity. First step called for establishing baseline data on the purebred Sahelian and Djallonke breeds.

To do so, the Joint Division provided local technicians with easy-to-use DNA testing kits along with training in sample collection and DNA extraction. As a result, more than 6 000 sheep and 10 000 goats were characterized, of



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which 123 sheep and 133 goats were genotyped. With this data, the national team from the *Institut de l'Environnement et de Recherches Agricoles* (INERA) formulated a training module to guide farmers in crossing the two breeds, so they would end up with better producing and trypanosome-resistant sheep and goat crossbreeds.

Of course, following the genetics would be complicated for a smallholder sheep or goat herder to comprehend. So instead of explaining the genetic details, scientists and extension workers just asked the farmers to look at their crossbred animals, especially at their size and their ears. Researchers had discovered that when the animals are the appropriate crosses, they will not only be larger – their ears will be slightly longer than the *Djallonke* but shorter than the *Sahelian*. Those larger, medium-eared and well-conditioned animals are therefore the crosses that should be kept and bred.

Mineral lick-blocks from local crop residue provide dry season feed

Looking ahead, as the farmers do their breed selection, they will be building herds of animals that are naturally trypanosome resistant and are larger than *Djallonke*, meaning they have potential to produce more meat and milk. However, this brings with it another problem. If these larger animals are going to produce better, they will need more and better feed, especially during the dry season.



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Thus, the Joint Division worked with the animal nutrition lab of INERA, studying what the animals were already eating and what feeds and forages were available. With this information, the project team developed a programme to produce “multi-nutrient mineral blocks” (MMBs) – lick blocks that contain urea, vitamins, minerals and other micronutrients along with local crop residues. This calls for taking locally available feedstuff, combining it with a mineral mixture and pressing it into small-volume blocks that can provide animals with nutrients during the dry season. Once the nutritionists determined what should go into the blocks, they handed the formula over to several farmer cooperatives that now make the blocks to sell to farmers on a full-cost recovery basis.

Looking ahead, the improved nutrition of the MMB-fed animals is likely to double their market value, as compared with those who live on poor quality grasslands. At the same time, breeding for trypanosome resistance will save millions of dollars by reducing animal mortality and reducing the need for veterinary drugs.

As next steps, work is underway to improve artificial insemination laboratory capacities at *Université de Ouagadougou*, so the national team can take the improved sheep and goat breeds to the field faster and even to neighbouring countries, thus providing additional income opportunities to farmers.

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Veterinary labs receive emergency toolkits for handling disease outbreaks

From the outside, it looks like an ordinary 50x50x50 cm box, but inside that box is an emergency toolkit, packed with an array of critical laboratory testing materials to support African veterinary laboratories in the rapid detection of highly pathogenic avian influenza viruses. Of course, it is one thing to support veterinary laboratories with a toolkit, it's quite another to decide what that toolkit should contain. Created by the Joint FAO/IAEA Division, it called for a lot of pre-testing and prior knowledge of the laboratory environments in recipient countries, in order to ensure it would contain everything a lab would need to perform proper diagnosis of avian influenza. The take-up of the instant diagnostic package in kit format was so positive that the Joint Division expanded its support by also providing companion biosecurity cases containing all of the personal protective equipment, sampling materials and disinfectants needed for field gathering and secure shipment of samples for testing in veterinary laboratories.

The increasing incidence of transboundary animal and zoonotic disease outbreaks, with emergence and re-emergence of new animal diseases, can often be traced to changes in climate, changes in agricultural practices and increasing global trade. When a new animal disease emerges, laboratories are often caught without the capacity for rapid diagnosis, making its control a real challenge. That is what the emergency toolkits developed by the Joint Division are all about. Developed for diagnosis of avian influenza, they now sit at the ready in laboratories across West Africa, while others have been prepared and remain on standby, ready to be shipped immediately from the Joint Division laboratory in Seibersdorf, Austria, when and where needed.

While a complete toolkit is certainly an ideal approach for an effective response to an emerging disease, setting up such a kit requires that its contents cover the necessary lab procedures, travel and store well, and work with whatever lab equipment and machines the target labs are working with. There can be no margin for error when the emergency toolkit is needed. The Joint Division therefore did extensive pre-testing and also asked laboratories to conduct tests at their ends of some of the toolkits contents. Through this concerted effort, they determined that, for example, some reagents included for some specific tests were not as

delicate as feared and would work well without the need to maintain a cold chain during shipping and storage.

To increase its effectiveness in emergency situations, the toolkit has been developed in a way that it can be used for several different diseases with just minor and simple modifications. However, when it comes to diseases such as Ebola, it becomes more challenging because of the potential biosafety aspect of samples containing the Ebola virus.



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Ebola biosecurity kit evolved with practical field testing

When spread of Ebola outbreaks led to deaths of thousands of people, including health workers and lab personnel, proven biosafety protection equipment was urgently needed in laboratories and in the field. Thus, the Joint Division was challenged to find the most appropriate protective items, such as coveralls, masks, gloves, goggles, shoes and disinfectants, and also to determine how to dispose of the protective gear and lab materials after their use.

Based on specifications from a European mobile lab project, the proposed items were evaluated during a live training session in Cameroon that put the participants together with experts. There it became clear that some components of the kit were not suitable for their intended use, others not needed and others were missing, all of which had to be rectified. Now, on request, the Joint Division sends experts along with the toolkits to train local professionals in biosecurity in the field and in the use of these kits, and also to perform advanced biosecurity checks of the laboratory environment where the kits will be used.

The emergency toolkit has been described as a clever way to kick-start labs into doing accurate diagnoses. The suitcase for emergency intervention increases lab capacity to collect samples properly from the field and bring them back for analysis in a safe and secure way. These are all elements of an ongoing programme that began in 2003 to enhance West Africa's capacity to respond to animal disease emergencies. At that time, many countries did

not have the diagnostic tools, protective equipment or the trained personnel needed to run molecular techniques for rapid diagnosis of animal diseases.

In the ensuing years, the situation has improved greatly. The equipment has become less expensive and more robust, the reagents have become less expensive and more stable, and many scientists in the concerned countries have obtained training in utilizing them. The Joint Division conducts ongoing courses and workshops to introduce or re-train lab personnel in using the machines and conducting the tests, including training for laboratory biosafety. Equal to following a standardized process for disease diagnosis, it is critical that country scientists work in safe conditions. If they are in emergency situations, the Joint Division is ready to provide support. Through training with Joint Division experts, the lab personnel now know what to expect, they know what they need to do and they feel more confident that they can do the job well and do it safely.



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Scientific methods test farmers' indigenous knowledge to identify sheep and goat breeds resistant to parasites



Each year, sheep and goat farmers around the world lose an estimated US \$10 billion due to gastrointestinal parasites that infect their animals, leading to loss of weight and wools and even death – a problem that is now escalating as parasites become resistant to the drugs used to eliminate them. In developing countries, sheep and goat owners are mostly resource-poor or marginalized farmers who cannot always afford the antiparasitic drugs. They are also more likely to keep a small number of animals of indigenous breeds that have adapted to the local conditions and, in some cases, are said to have developed a natural resistance to the parasites. The Joint FAO/IAEA Division has been exploring farmers' reports of natural resistance, seeking scientific evidence that can be used to improve breeding programmes and enhance and quicken benefits to farmers. Working in ten countries in Africa, Asia and Latin America to identify parasite-resistant features of local animals, the exploration included everything from checking their eyes for anaemia to checking the 60 000 DNA markers of their genomes for variations that indicated resistance.

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The effort to identify sheep and goats with natural resistance to parasites began with a challenge. Each of the ten countries involved in the Joint Division's study identified one breed that farmers considered tolerant or resistant and one breed farmers considered susceptible. Twenty young animals of both the tolerant and susceptible breeds were selected and "challenged", meaning they were purposely infected with parasites. Researchers monitored them at field stations, noting their weight and wellness – if tolerant to parasites, they should have a normal level of red blood cells and gain weight; if susceptible, they should lose weight and become anaemic. They also counted the number of parasite eggs in their faeces to determine if the worms had taken residence in the animals' stomachs. Interestingly, with only a few exceptions, most of the indigenous knowledge as to animal susceptibility or resistance was correct.



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Countries involved in this research included Argentina, Bangladesh, Brazil, Burkina Faso, China, Ethiopia, Indonesia, Iran, Nigeria, Sri Lanka.

Armed with this knowledge, the second test was a field trial. The goal was to identify any individual animals within the breed that were "very tolerant or resistant" or "very susceptible", and to identify a visible clue – something obvious to help farmers determine which animals to breed for what is called "genetic gain". At this level, weighing the animals to measure their growth for meat production and recording wool yield would give some information to farmers but not enough for making good breeding



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decisions. It was also prudent for farmers to collect faecal samples so the lab could identify how many parasite eggs they contained.

Identifying animals with natural parasite resistance has value beyond a local farmer's herd. It can be the beginning of large-scale breeding programmes. Until now, developing countries have not exploited the potential of animals with natural resistance due in part to lack of infrastructure and skilled scientists. Thus, this programme, which screened more than 5 000 animals in the ten participating countries, helped establish sound animal selection programmes and fill in the blanks in performance data.

DNA markers identified for parasite resistance

Once the screening had identified the best animals using faecal eggs and blood testing, the project moved to the genetic level. Samples were sent to the Joint Division laboratory in Seibersdorf, Austria, for analysis, seeking to identify variation in DNA markers that would indicate resistance. Using specialized software to perform meta-analyses of genomic and phenotypic data, researchers could identify components in the genome associated



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with parasite resistance or tolerance. Adding the genetic information to the mix enables researchers to identify the most resistant males, select them for breeding, and use modern reproductive technologies such as artificial insemination or embryo transfer for faster dissemination of the desired traits well beyond local farmers' fields.

In Argentina, the institutional farms recorded a clear reduction in the parasite loads of sheep by selecting rams with fewer parasite eggs in their faeces. The process has now gone through four generations of sheep selection and the technology is being transferred to private breeders. Herders may still need to use deworming drugs if animals do not have absolute resistance, but just cutting the deworming from three times a year to just one time drastically reduces the costs for farmers and the threat of parasites building resistance to drugs. Having the genetic information means farmers also know the breeding value of a male sheep or goat and can use that in breeding for sustainable improvement of animal productivity.

The scientific journal *Nature/Biotechnology* published the important technical findings of this research in an article "Sequencing and automated whole-genome optical mapping of the genome of a domestic goat (*Capra hircus*)".

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Laboratory network that helped win rinderpest battle expands efforts to control other animal diseases



When the avian influenza virus was spreading across Asia into Africa in the early 2000s, veterinary extension services gathered virus samples from the field, but often had to send them abroad for diagnosis because their national labs were not prepared to conduct the specific tests needed. Problems arose because they were sending live virus samples, which many airlines refused to ship. Even when airlines did agree, the costly and time-consuming shipment protocols meant diagnoses were delayed, slowing desperately needed response activities. Compare that to a suspicion of avian flu in Togo in 2015. When that arose, Togo sent its suspicious samples to a competent laboratory in neighboring Ghana and received results quickly. This enormous advance is the result of VETLAB, a Joint FAO/IAEA Division network of veterinary diagnostic laboratories in Africa and Asia, initially established during the global effort that eradicated rinderpest – a deadly cattle disease.

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VETLAB won its first battle. A laboratory network established to connect technical supports in the global battle against rinderpest, VETLAB was certainly in the winner's circle when the disease was declared eradicated in 2011. The unprecedented victory against a disease that had plagued the livestock sector for millennia owed much of its success to the networking of laboratories able to use efficient nuclear-related technology to facilitate surveillance and diagnosis in the field. However, in reality, rinderpest

was just one battle in the ongoing fight to prevent and control an array of transboundary animal and zoonotic diseases – diseases that not only impact animal and public health, they devastate farmers who depend on animals for their livelihoods and disrupt world food trade.

So, instead of just congratulating VETLAB for a job well done, the Joint Division not only maintained the network, it expanded its membership to other African labs and also



VETLAB Funders

South Africa's African Renaissance and International Co-Operation Fund (ARF) and the IAEA's Peaceful Uses Initiative (PUI) with support from the IAEA Technical Cooperation Department.

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to labs in Asia. Now membership includes and connects laboratories in 40 African and 17 Asian countries. The Joint Division supports them in improving their screening and diagnostic capacities, and upgrading their equipment and facilities. It also runs proficiency tests of laboratory capacity to diagnose specific diseases and conducts training to help the labs achieve accreditation from the International Standards Organization (ISO). ISO accreditation attests a lab's expertise and capacity to perform specific laboratory tests and is required by importing countries that want assurance that animals or animal products they receive comply with global food standards.

Early diagnosis is the key element in stopping the spread of transboundary animal diseases. During the rinderpest campaign, when VETLAB members were working together in a highly focused environment, they opened valuable lines of communication, were able to share and define common needs, collaborate and reach conclusions together. Now the VETLAB networking exchange, an endeavor which evolved so naturally in VETLAB's earlier days, remains a main fabric of the programme.

The Joint Division brings veterinary laboratory scientists together through workshops and coordination meetings, offering a unique opportunity for countries facing similar challenges to coordinate activities such as training, information dissemination and the design of disease control strategies. During a meeting of Asian laboratories, Mongolia requested technologies to test for *peste des petits ruminants* (PPR), a viral disease that affects small ruminants. Although the disease is not currently found in Mongolia, the country recognizes the need to be vigilant because it is bordered by countries where PPR is present.

"Leading laboratories" provide regional support

Within its membership, VETLAB identified the leading laboratories of Ethiopia, Botswana, Cameroon and Ivory Coast to provide regional support. The Joint Division specifically works with these laboratories to improve their facilities and increase the number of tests they perform so they, in turn, can conduct tests for neighboring countries with labs that have not yet received accreditation. Botswana's National Veterinary Laboratory and Cameroon's *Laboratoire National Vétérinaire* host disease diagnosis training courses for labs in the region. Cameroon tested



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and quickly diagnosed the swine samples sent from Chad as an African swine fever infection, a highly contagious pig disease. The rapid response enabled Chad to focus its national control measures.

As VETLAB laboratories continue to improve and expand accreditation for more diseases, there will be fewer reports of delays in diagnosis such as happened with avian flu in 2000. In fact, when avian flu appeared in West Africa in 2015, a technical expert from the Joint Division went to Ghana to install needed diagnostic equipment in the national laboratory and to train the staff in using it. They knew quickly what strain of flu they were dealing with and, with that information, were able to prepare proper control measures.

Member States participating in VETLAB

Africa (40 MS): Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Democratic Republic of the Congo, Cote D'ivoire, Egypt, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, South Africa, Sudan, United Republic of Tanzania, Tunisia, Uganda, Zambia, Zimbabwe.

Asia (17 MS): Bangladesh, Indonesia, Iraq, Japan, Lao People's Democratic Republic (Laos), Malaysia, Mongolia, Myanmar, Nepal, Oman, Pakistan, Philippines, Sri Lanka, Syrian Arab Republic, Thailand, Viet Nam, Yemen.

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COSTA RICA

Costa Rica's agricultural waste converted into charcoal to filter and dispose of polluting agricultural chemicals



Burning agricultural waste in a controlled environment to make charcoal and then using that charcoal to filter leftover agrochemicals before disposing of them is just one of the steps taken to clean up chemical contamination that pollutes the soil and water of central Costa Rica. In addition to promoting use of these "bio-beds", Costa Rican farmers are being trained in Good Agricultural Practices (GAP) – practices that address environmental, economic and social sustainability for on-farm processes, and result in safe and quality food and non-food agricultural products. For example, GAP stresses the proper handling and use of agrochemicals but also the environmentally friendly disposal of any chemicals the farmer has left over. All this is part of a Joint FAO/IAEA Division project to support food and environmental safety in Costa Rica by providing specialized testing equipment and training laboratory personnel so they can oversee a campaign to clean up the environment and establish an ongoing monitoring programme to ensure it is kept clean.

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Keeping the agricultural landscape clean and safe is not only important for the local environment and public health, it also impacts a country's compliance with food safety standards and its ability to export its produce to other countries. Almost 85 percent of Costa Rica's vegetables – for both local consumption and export – come from the Cartago region in the country's central valley. However, toxic residues from the indiscriminate use of agrochemicals and fertilizers have contaminated Cartago's water, soil and the environment, raising public health concerns, and adversely impacting wildlife and fish in the area. Costa Rica's water resources are especially prone to agrochemical contamination because of high rainfall that can reach 16 000 mm per year. Problems arise because the rain washes unabsorbed pesticides off the plants, contaminating both soil and water.

Partnering with the Costa Rica Environmental Pollution Research Center (CICA), the Joint Division initiated a two-level solution: training farmers in GAP with a focus on raising community and government awareness of the detrimental effects of improper agrochemical use,

and providing state-of-the-art lab equipment to monitor residues and contaminants in food, soil and water. Farmers apply what they learn in GAP training to protect their water supply and environment as well as the health of their families and neighbours. At the same time, laboratory personnel receive scientific support and training on the use of equipment provided through the Joint Division, improving their ability to pinpoint existing contamination and to test for presence of herbicides, insecticides and fungicides throughout the Cartago region.

The equipment provided to CICA included a high-tech liquid chromatograph coupled with a mass spectrometer (LC-MS-MS) that, together with nuclear and isotopic techniques, enable the testing and characterization of even the smallest amounts (parts per billion) of pollutants. As part of their training in analytical and monitoring techniques for food safety, lab personnel have learned to take random samples from the field or processing plants, and scientists have developed methods for extracting the samples, meaning extracting toxic agricultural chemicals from the foodstuff for testing. They can now use the state-of-the-



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art LC-MS-MS to analyse the extract and ensure that the foodstuff complies with international safety standards and is safe for the population to eat.

The Joint Division also helped buy and install a gamma irradiation unit at the Technological Institute of Costa Rica and trained scientists in its use. The gamma irradiation unit has a wide range of uses, including irradiating foods to eliminate harmful microbial (bacterial) contaminants, developing higher yielding, disease-resistant or drought-tolerant plants and thereby improving food production, and developing applications for health care and human ailments.

Project links laboratory with the field

The project, which began in 2012, provided critical links between the field and labs. When an initial survey carried out by CICA's lab confirmed the presence of dangerous contaminants in water resources and the environment, its conclusions became the fodder for a successful awareness-raising campaign. It proved to farmers that the environmental and public health situation had reached such a point that their use of GAP was critical for cleaning up the environment and keeping it clean. Once educated on the environmental and public health situation created by indiscriminate and uncontrolled agrochemical use, the farmers were convinced of the health, environmental and economic benefits of adopting good agricultural practices.

CICA's follow-up assessments have shown that large numbers of farmers in the Cartago area are now following GAP in their use of agrochemicals. They are also using their on-farm bio-bed purification systems – which were developed with technical support from the Joint Division – to minimize contamination from their leftover chemicals. Initial data of contamination before and after GAP adoption shows that residues of the insecticide chlorpyrifos dropped 80-fold in river sediment and the residues of the insecticide cypermethrin dropped two-fold. As the farmers could see for themselves, not only has adoption of GAP helped provide cleaner drinking water and a better environment, it has provided an inexpensive way for them to optimize their safe use of and, in turn, reduce their need for expensive agrochemicals.



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JAPAN

Information technology critical in response and follow-up to Fukushima nuclear accident



As the Fukushima nuclear accident unfolded in March of 2011, the global community could follow the emergency response and monitor the situation, thanks, in part, to the widespread availability of mobile communication technology. The Joint FAO/IAEA Division posted rolling reports and updates, compiled and shared monitoring data, and posted a Q&A segment to ensure all Member States and partner organizations had access to the same information and advice regarding safety. In addition, in response to Japan's request for support, within two weeks of the emergency onset, the Joint Division sent experts to the field to help with technical issues related to food safety and agricultural countermeasures, providing advice on sampling and analytical methods and data interpretation to ensure that reliable, continuous updates could be provided. Building from this, in the aftermath of the emergency, the Joint Division hosted technical meetings and initiated a research project to develop a portfolio of documents and communication tools to ensure any future such incidents will be met with efficient and agreed protocols and guidelines for monitoring, reporting and determining safe radiation levels for agricultural production, and for disseminating information in an easy-to-digest format.

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The Fukushima nuclear accident occurred almost exactly 25 years after the Chernobyl accident in the Ukraine, during which the world had seen a proliferation of technological developments to enhance emergency communication and response. The causes of these accidents were very different – Chernobyl resulted from a flaw in the reactor's design and a test that went wrong, while Fukushima resulted from an earthquake and resulting tsunami waves that inundated the power plant. However, the lessons from Chernobyl, such as the importance of monitoring and sampling agricultural produce and establishing post-accident countermeasures in the context of food and agriculture, helped in the response.

The Japanese government, aided by modern IT and the Internet, went well beyond what was required to ensure the thoroughness of studies and monitoring reports.

Having IT tools also enabled the Joint Division to examine and re-distribute the monitoring information coming from Japan, collecting and disseminating all data through

one coordinated international database. This proved so advantageous that, post-accident, it led to an initiative to develop and enhance methods of sharing such information,



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in readiness, should an accident occur again. This would mean that any government, organization or even individual with an interest in the knowledge and outcomes of the monitoring could have online access.

Almost immediately after the accident, the Joint Division sent a field mission to Japan, to help with technical issues related to food safety and agricultural countermeasures. It provided advice on sampling and analytical approaches, and the interpretation of data to ensure that reliable, continuous updates could be provided. These data were used to establish local and national strategies to deal with the developing situation. During the accident, a lot of effort was necessary to ensure that those who needed information received it in a form that was easy to understand.

Building on their experience, the Joint Division experts initiated the development of a visionary programme that could manage large volumes of data and, at the same time, automatically put samples on a map, which would help visualize patterns. Not only would this mean that all who needed agricultural data or who were following the accident received the same information, it would also mean less margin for error – as could occur when trying to copy and resend information on hundreds or even thousands of samples through email or spreadsheets. Now, five years after the accident, that vision is becoming a reality.

Radioactivity in food and drinking water – safety protocols clarified

As the work moved from dealing with the emergency itself to taking a look at the consequences of the emergency, the Joint Division recognized the need to act quickly and harvest lessons learned from the emergency response. It put together a research project with experts from 12 countries to develop their database further, look at ways to improve protocols for sampling analysis, and develop an online food safety tool to support countries in making decisions concerning food restrictions.

A host of standards and guidelines already existed that could be followed, such as IAEA safety standards on nuclear emergencies, WHO guidelines for radioactivity in drinking water and Codex Alimentarius standards for levels of radioactivity in food in international trade. But these were all designed for specific audiences and, during the Fukushima emergency, some countries were confused as



to which ones they should follow. Thus, the Joint Division collaborated with nuclear safety experts to clearly set out the different kinds of standards and what they are intended for, and to introduce a method to calculate when and where to set reference limits for residual levels of radioactivity in the environment, including when a nuclear emergency has ended but radioactivity persists over a wide area.

The resulting technical document (TECDOC), “Criteria for Radionuclide Activity Concentrations for Food and Drinking Water”, was drafted with support of experts from 37 Member States. It already stands as an authoritative reference and explanation of different international standards relating to radiation levels of food and drinking water, and includes a framework to help individual countries develop radionuclide reference levels that are consistent with global standards.

Without doubt the response by Japan and the international community to the Fukushima accident was efficient and responsible. The teamwork evident – from the initial days of the Joint Division staffing the IAEA’s Incident and Emergency Centre and undertaking field missions, to its technical meeting and coordinated follow-up research projects that are producing overarching guidelines and communication dissemination tools – indicates that Fukushima was more than a one-off wake-up call. The TECDOC, the new protocols, and the concerted partnerships among the international organizations are now in place with the hope that they will not be needed but the satisfaction of knowing they will be there if they are.

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AUSTRALIA, NEW ZEALAND

New Zealand can import winter tomatoes thanks to Australia's food irradiation facility



The Bowen region is Australia's largest winter producer of vegetables. Tomatoes are by far its biggest crop, totalling US \$120 million a year. Yet, even though it could offer consumers access to fresh tomatoes in the winter, its export market has been extremely limited. The problem is the Queensland fruit fly, an aggressive pest that Australia once controlled with pesticides that are no longer allowed. However, thanks to a protocol in place that links Australia to New Zealand, tomato exporters have another option: irradiation. Australia irradiates the tomatoes to ensure there are no pests and New Zealand accepts irradiation as proof of insect control. The Joint FAO/IAEA Division has worked with Australia and other countries to bring irradiation to the fore as a suitable replacement for chemical treatments.

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The timing is perfect. As Australia's tomatoes are ripening, New Zealand's tomatoes are going out of season. And because the two countries have agreed that irradiation is a safe and appropriate way to meet insect pest control requirements, New Zealand can import irradiated winter tomatoes and a host of other fresh produce from Australia's orchards and fields.

Australia was the world's first country to use irradiation as a phytosanitary measure in international trade. It started in 2004 with exports of mangoes and expanded to several other foods over the years. When its produce is sold in New Zealand, it is labelled as irradiated, and the amount sold is increasing steadily. In 2014, New Zealand consumers purchased some 2 000 tonnes of produce irradiated to protect their environment from invasive pests.

Irradiation has been used for decades to control bacterial growth and food-borne illnesses and to prevent spoilage. But Australia's battle against the Queensland fruit fly is indicative of the more recent adoption and acceptance of irradiation as a viable way to combat the spread of insect pests that can hide in fresh fruits and vegetables destined for export markets. Initially used mainly on dry herbs and spices to combat food poisoning organisms, the process was declared safe for an array of foods in the 1980s by FAO and the World Health Organization (WHO). Further, it

is increasingly recognized as a viable way to cut back on the need for potentially harmful and expensive chemical pesticides.

The technique has had slow uptake in the ensuing years because retailers feared that consumers equated the term "irradiation" with "radioactivity", even though, in reality, food irradiation harnesses the energy in beams of photons, electrons or X-rays – a process similar to airport security screening. The food never comes into contact with radioactive material. The beams do the work.

Irradiation controls pests without use of chemicals

Pests are also controlled with cold and heat treatments or with chemical fumigants, but these can reduce the quality of the food or leave chemical residues. That does not happen with food irradiation. In addition, irradiation may extend shelf life. Because of this, it has been used for foods prepared for astronauts, for hospital patients with depressed immune systems and to ensure that food rations prepared for displaced people in need of emergency shelter are stable enough to be transported and stored at ambient temperatures because refrigeration isn't always an option in an emergency.



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The Joint Division supports countries in realizing the potential of the technique and setting up irradiation facilities. Many countries have such facilities, and eight now have accredited facilities that irradiate fruits and vegetables commercially to prevent the spread of pests. In addition to technology, the Joint Division has also aided in the development of 16 treatment standards and produced a set of guidelines to promote harmonization of standards from country to country. It has also published a Manual of Good Practice in Food Irradiation and offers a comprehensive e-learning course that anyone can log into. All of these elements – the technological support, the publications and the online resources – are meant to increase public and trade understanding of the advantages of irradiation over chemical and fumigation pest control techniques and other



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such treatments, and to facilitate the increasing use of the technology in addressing trade restrictions.

Approval of Australia's food irradiation facility was granted in 2004, and it now treats about US\$1.5 billion worth of fruit and vegetables produced by Queensland growers each year. About 70 percent of the production is sold within Australia, but still requires irradiation because sales are to states that need to keep out the Queensland fruit fly. And, as for those winter-ripening tomatoes, New Zealand imported 430 tonnes of irradiated tomatoes from Australia in 2014, the first full year it was permitted.

Countries with irradiation facilities to combat pests in fresh fruits and vegetables

Australia, China, India, Mexico, South Africa, Thailand, USA, Viet Nam



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PAKISTAN

Farmer training and cost-effective testing for veterinary drug residues improve Pakistan's reputation in international food trade

Imagine having to tell a poor farmer that a full pail of fresh milk must be thrown out. The problem is, in many parts of the world, this scenario actually should happen more often than it does. It all has to do with how and when a farmer administers veterinary drugs to a dairy cow before milking. Administering drugs to maintain the health and welfare of dairy cattle may be necessary but, if not done properly, chances are that the drug will also be present in the milk. Scientists do risk assessments to determine how much veterinary drug residue it takes to cause harm to humans – not just drugs in a smallholder's pail of milk but drugs that are given at large livestock facilities that can end up in meat and other animal products, meaning they will not comply with food safety standards. In Pakistan, which has dealt with exports being rejected for noncompliance, the Joint FAO/IAEA Division is working on farms and in laboratories to raise awareness of the potential health and trade problems that can result from improper use of veterinary drugs. The goal is to keep all consumers safe and also help the country's livestock sector meet international food safety standards.

Both smallholder farmers and larger livestock operations use veterinary drugs to treat animals when they are sick or to keep them from getting sick. The higher the threat of disease, the more need to administer drugs. Problems arise when farmers do not have correct advice on what drug to buy, or do not follow instructions on how and when to administer the drugs or how long to wait until the drugs have cleared the animal's body. Misuse comes with consequences. The organisms causing the disease being treated can develop resistance, which means the farmer will have to increase dosage or find different or more powerful drugs. Or the drugs remain in the animal's body and these residues, although often at only trace levels, are health hazards and impediments to trade.

During fiscal year 2014–2015, Pakistan's agriculture sector grew 2.9 percent, but the livestock sector grew 4.1 percent and now contributes more than 11 percent to the national GDP. As agriculture in general and livestock in particular have grown, the sectors have faced some harsh realities,

such as the EU's rejection of 134 food export consignments due to the presence of contaminants. When this happened, it raised concern in Pakistan of the need to provide training for farmers working with livestock but also to improve its food safety control system.

To make this happen, the Joint Division worked together with Pakistan's Nuclear Institute for Agricultural Biology, National Institute for Genetic Biotechnology and the National Veterinary Laboratories of Islamabad to develop cost-effective methodologies to test for veterinary drug residues. With the Joint Division's support, the laboratories have improved their testing capabilities by, for example, optimizing existing facilities instead of buying commercial tools. They have gone through proficiency testing, improved their ISO accreditation, and are authorized to provide eight analytical services to test for compliance – services they make available to the private sector. To date, more than 45 private and public institutions involved in food production and export can benefit from the laboratory testing capabilities.



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Pakistan calls for farm-to-fork diligence in food safety

According to the principle of food safety, the ultimate responsibility is with the producer. But in reality, when looking at the food sector as a “farm-to-plate” industry, it becomes obvious that problems can happen anywhere. The farmer may produce food safely, but contamination can enter the picture during transport, during storage, at home or even at the market. Thus the project created awareness at both field and laboratory levels of the importance of laboratory accreditation as well as production that meets international standards, something that had not been specifically addressed for veterinary drug residues before the project. Through organizing classes, workshops and farmers’ days, it not only raised awareness of the importance of food safety for farmers and agriculture students, it also facilitated their ability to share their new knowledge with others.

For farmers, solutions lie in knowing the rules and following directions. For example, smallholder dairy farmers must learn when and how to administer drugs, and how to



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manage their livestock so they do not contaminate the milk. At the same time, as laboratories increase their competencies, they will be able to ensure that Pakistan’s name becomes associated with high quality products in international trade.

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AFRICA, ASIA, LATIN AMERICA

Research into fruit fly taxonomy adds knowledge of cryptic species on the family tree



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Getting to know members of the Tephritid family can be quite a colourful experience. Tephritidae is the family name of fruit flies, one of the most damaging insect pests of horticultural products worldwide. Over the centuries, taxonomists have broken the Tephritidae into some 500 genera and then further into 5 000 species – most of which have colourful wings, interesting mating rituals and territorial personalities. But today, for some species of economic and quarantine importance, questions arise as to whether taxonomists have been correct in how they have identified the species – whether they are actually distinct biological species or variants of the same species. The Joint FAO/IAEA Division conducted coordinated research aimed at resolving some of the taxonomic questions surrounding major “cryptic” species complexes, meaning questions about closely related species within a genus. The study led to accurate taxonomic alignment of the species and provided valuable information needed for effective application of the sterile insect technology (SIT) and facilitation of international trade.

This is the story of three fruit fly complexes and a suspected complex of significant economic importance. These pests, all of which can cause major yield losses and by their very presence keep a horticultural sector from exporting, are known scientifically as *Anastrepha fraterculus* (South American fruit fly complex), *Bactrocera dorsalis* (Oriental fruit fly complex), *Ceratitidis FAR* (fruit fly complex from the African region), and *Zeugodacus cucurbitae* (formerly *Bactrocera cucurbitae*), the melon fly suspected complex.

Accurate fruit fly taxonomy makes it possible to assess which species are present or absent in a given area which, in turn, provides a scientific basis for countries to set up their import regulations according to international phytosanitary standards, and to develop appropriate and effective fruit fly surveillance and control methods. For example, using the sterile insect technique (SIT), a species-specific and cost-effective environmentally friendly method of controlling fruit flies, requires a substantial initial capital investment. Thus, before embarking on such an endeavour,

it is essential for governments and industry to know exactly which species are present in the area of interest.



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For example, over the years, taxonomists identified and named several closely related species of *Bactrocera dorsalis*, to a point where it became the "dorsalis complex". The *Bactrocera* species are native to Southeast Asia, but when one of its species arrived in East Africa from Sri Lanka in 2003, taxonomists identified it as a new species, naming it "*B. invadens*" because it spread quickly and aggressively across more than ten African countries. In response, regulatory authorities of importing countries required exporters from the African countries to certify that their horticultural produce originated from *B. invadens*-free areas or that the produce was free of the pest – but this required stringent post-harvest treatments that were not readily available for this supposedly new species. As a result, the exporting African countries dealt with years of trade restrictions that seriously affected their mango and banana exports.

The Joint Division, with participating scientists from 20 countries, decided to take another look at the fruit fly complexes, including the case of *B. invadens* and other suspected species. With the availability of new, more precise tools to identify species, the scientists began the processes of comparing morphology, e.g. of wings, antennae and organs; checking at the genetic level for consistency; and checking propensity for mating compatibility, all of which are accepted designations for identifying species.

Study tunes in on what may be evolution in the making

With research going on in several laboratories, the researchers reached extremely valuable conclusions. For example, they found the *B. invadens* and *B. dorsalis* were morphologically and genetically close and mating propensity was high. In other words, they proved these two species were actually the same *dorsalis* species – *B. invadens* did not really exist as a separate species. This insight will now enable the African fruits growers and export industry to use technologies already available for pre- and post-harvest control of *B. dorsalis*. In fact, the researchers determined that four of the species in the *dorsalis* complex – *B. dorsalis*, *B. papayae*, *B. philippinensis* and *B. invadens* – were all the same biological species. Looking forward, this means that growers and industry will be much better able to target their control programmes and provide phytosanitary certification to importers.

The research conducted on the *Ceratitidis* FAR complex from the African region identified five different species.



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C. capitata, *C. fasciventris*, *C. anonae* and *C. rosa* were confirmed as individual biological species thus, for the most part, *Ceratitidis* taxonomy remains unchanged, although they did identify a new species related to *C. rosa*. – It will be known simply as R2 until taxonomically described and a proper Latin name has been chosen. As for the *Zeugodacus cucurbitae*, it was concluded that the melon fly does not represent a cryptic species complex in regards to its geographic distribution or its host range.

And finally, the study of the *Anastrepha*, specifically the South American fruit fly complex and its one species, the "*fraterculus*", proved quite surprising. Four morphotypes with their geographical distribution were defined as "distinct biological species". This might be an indication that the *fraterculus* complex has been in the act of separating into distinct species, and that the researchers have actually tuned in during its process of evolution. As a follow-up, scientists will meet again in 2016 to sort out issues on three Brazilian morphotypes and the description of the new species, and to choose a name for the new "*fraterculus*".

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USA: CALIFORNIA AND FLORIDA

Prevention rather than crisis reaction protects US horticulture industry from medflies



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As far as the horticulture industry is concerned, one piece of fruit in a traveller's backpack or a shipment of fruit arriving at a seaport both portend disaster if the fruit also contains hitchhiking larvae of the Mediterranean fruit fly (medfly) – larvae that could escape inspection at port of entry and initiate an infestation. In the past, California and Florida, the main USA horticulture-producing states, used a reactive approach to control medfly outbreaks, such as ground and aerial insecticide-bait spraying – but this was only partially effective and there were concerns about negative public health and environmental impacts. In the mid-1990s, at the recommendation of a technical advisory committee in which staff of the Joint FAO/IAEA Division had a leading role, California and Florida both initiated the sterile insect technique (SIT), calling for area-wide preventive and continuous aerial releases of sterile male medflies over high-risk areas – an endeavour that has substantially reduced overall cost and prevented establishment of the pest.

Until the mid-1990s, California and Florida controlled medfly outbreaks mainly through using insecticide-bait sprays. Yet, checks of surveillance traps increasingly found adult flies, indicating new infestations of the pest. The inadequate results of the reactive approach and concerns about its negative environmental and health effects led the two states to initiate a preventative medfly control operation – the sterile insect technique (SIT) – with the advice and technical guidance of the Joint Division.

SIT calls for rearing, sterilizing and releasing an enormous number of male medflies near where an infestation is or might occur. The males mate with wild females but there are no offspring. In the case of California and Florida, setting up a preventative SIT programme, and ensuring the weekly availability of millions of sterile medflies to release over the large areas at risk proved to be a challenge. The solution came from the largest insect rearing facility in the world – the El Pino facility of the Moscamed Programme in Guatemala. Now, the hundreds of millions of sterile male insects needed to effectively cover the areas at risk are

shipped weekly from Guatemala and delivered for release in the two states.

When California and Florida used a reactive approach – with increased insecticide-bait applications – medfly outbreaks were becoming ever more frequent and severe



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as a result of more infested fruit entering the states. It meant exporters often faced costly quarantine restrictions from countries that only accepted shipments from medfly-free areas. Also at that time, insecticide-bait-based control programmes that used broad-spectrum organophosphate insecticides, such as Malathion, were facing serious public opinion opposition. In urban areas of Los Angeles, residents were extremely concerned about the insecticides wafting onto public property as well as their lawns and cars.

SIT is cost effective, safe and efficient

In researching the situation, studies determined that the reactive insecticide-bait approach in California had a direct average cost of approximately US\$33 million a year, which included the insecticide and labour costs, but mainly represented market losses due to quarantine restrictions. They also determined that a preventive SIT approach, calling for continuous release of sterile male flies over targeted high-risk areas, would have an overall annual cost of approximately US\$13 million for weekly shipments of the sterilized male medflies from Guatemala, the packing, holding and aerial release, and associated labour costs. Not only were expenses cut by more than half, there would be multimillion dollar savings by avoiding restrictions to trade of horticultural products.

Seeing the financial, human health and environmental advantages, the departments of agriculture and the horticultural industries of California and Florida adopted the preventive SIT approach. The numbers vary according to



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the pest situation, but in California, this calls for releasing from 30 to 150 million sterilized male flies each week over an area of up to 6 500 km². In Florida, it is 25 to 100 million flies each week over an area of up to 1 640 km². In addition to reducing cost, it is safer – with greater protection to human health and less impact on the environment due to reduced insecticide residues.

The SIT preventive pest control is a suitable strategy to protect pest-free areas from the entry and establishment of insect pests. And, because the sterilized males will seek wild females upon release, SIT is an ideal preventive control method for a wide area that has multiple potential pest entry points. SIT also relies on surveillance traps to provide on-the-ground early detection and to assess effective eradication of small populations in outbreaks.

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MEXICO, GUATEMALA, USA

At Mexico-Guatemala border, sterile insect technique has controlled the northward march of medflies since 1982



Imagine an area of nearly 200 000 km² that needs to be monitored on a daily basis – monitored for the presence of a destructive insect smaller than a fingernail. It has been more than four decades since the governments of Mexico, Guatemala and the United States agreed to work together to stop the spread of the Mediterranean fruit fly – an agreement which evolved from three bilateral agreements signed in 1975 and 1981 into the one single Trinational Moscamed Cooperative Agreement signed by the three governments in 2015 plus a memorandum of understanding with Belize. In their years of working together, the countries have kept the medflies out of their orchards and fields but also, with the support of the Joint FAO/IAEA Division, have continued to improve the technology, including the use of the sterile insect technique (SIT), insecticide-bait applications and on-the ground surveillance. It is all done with annual financial contributions by the three countries and significant numbers of trained personnel who work in the mass-rearing and sterilization facilities and in the field to keep the four countries safe from what could amount to billions of dollars in annual damages to production and trade – if the insects were allowed a foothold.

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No one really knows for sure when or how the medfly began its odyssey from its original homeland in East Africa to become one of the most reviled and feared insect pests on the planet. Theories include Ethiopian coffee traders who inadvertently took the flies to North Africa, and sailors who purchased fly-inundated citrus fruits in North Africa and brought them to Europe.

As for the Americas, medflies arrived in Brazil in 1901, possibly through trade with Portugal and, in subsequent years, invaded most of South America. In 1955, they reached Costa Rica in Central America, possibly through trade with West African colonies, and then spread to southern Guatemala in 1976, on a northward trajectory that put the high value fruit and vegetable industry of Mexico, the United States, Guatemala and Belize in their sight.

At the same time, the Joint Division was developing and testing a daring method for medfly control. Known as the sterile insect technique (SIT), it had been used since the

1950s for the suppression and eradication of screw-worm flies but never for medflies. The Joint Division initiated research to use the SIT technique for medflies at its laboratories in Seibersdorf, Austria, where it reared and sterilized the number of insects needed for field testing. In 1969, pilot testing was undertaken on two Mediterranean islands off the coast of Italy, Procida and Anacapri, releasing the sterilized male insects to mate with wild females – and thus produce no progeny. The pilot was declared a success in 1971.

Although still a visionary idea, by the time medflies were detected at the border of Guatemala and El Salvador, the countries were able to transfer the technology from Seibersdorf and adopt it in an attempt to quash potential disaster. A medfly mass rearing and sterilization facility was constructed in Metapa, Chiapas, in southern Mexico, with the first sterile fly releases in 1978. Four years later, after releasing billions of sterilized flies, the medfly was proclaimed eradicated from approximately 1 million



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hectares of Chiapas, a state on Mexico's South Pacific Coast that borders Guatemala. Years later, a second and larger rearing facility, El Pino, was constructed in Guatemala, which greatly contributed to the goal of protecting the medfly-free areas in Guatemala and preventing the northern spread of the pest.

Building from success, focus switched from eradication to maintaining a containment barrier on Guatemalan territory away from the Mexican border and to the gradual medfly eradication from Guatemala. Today, that biological barrier has served its purpose and the programme continues to release sterilized male medflies – as many as 1.3 billion each week – to maintain it.

Technological advancements bring down SIT costs and increase impact

Over the decades, improved technology has increased efficiency and brought costs down. Joint Division researchers developed a medfly strain that only produces males, so instead of rearing, sterilizing, packing, transporting and releasing both males and females, the programme only produces males. This not only substantially cuts costs, it increases the induction of sterility in the population by forcing sterile males to seek wild females.

On-the-ground surveillance is regarded as the eyes of a programme. Baited traps are set and, when checked, they tell programme managers and growers if there are medflies in the area, where they are and how many – critical

information for where, when and how many sterilized flies to release. Traditionally, traps baited with parafferomone lures were set to attract males. But in the early 2000s, the Joint Division supported the development of a female biased trapping system using food attractants with a mix of the proteins females need to mature their eggs. The females tend to respond earlier to the protein lure than the males respond to the parafferomones, which gives more advanced warning of need to step up control. In addition, a recently developed organic and environmentally friendly insecticide can be used for effective medfly control over large areas prior to the targeted release of sterile male medflies – the step that leads to eradication of the medfly population.

Today, the facilities in Mexico and Guatemala rear and sterilize over 1.5 billion medflies per week and have expanded their production to other species of fruit flies of economic significance. Keeping the USA and Mexico medfly free has created conditions for the development of their multibillion dollar horticulture industries and has paved the way to increase production and export of fruits and vegetables from Guatemala and Belize.

This long lasting collaboration with the Joint Division resulted in the recognition of the Moscamed Programme as a Collaborative Centre of the IAEA in 2010. Through this partnership, harmonized SIT and associated technologies continue to be transferred to hundreds of technicians in countries that participate in international training courses hosted by the programme, and the technologies have been advanced through joint research and development.

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COSTA RICA

Stinging wasps replace chemical pesticides becoming control agents in fighting stable flies



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Costa Rica's position as the world's largest producer of pineapple brings with it a parallel problem for the country's livestock and dairy industry. Its pineapple processing plants are surrounded by mountains of pineapple residue, and that residue provides a breeding ground for the aggressive, blood-sucking "stable fly", a fly that can wreak havoc on cattle and affect their productivity. In an effort to control the fly without resorting to chemical sprays, the Costa Rica Institute of Agricultural Technology Research (INTA-MAG) with the support of the Joint FAO/IAEA Division identified another way to do the job – using a wasp. Not just any wasp. This wasp is a "biocontrol agent", a natural enemy of the stable fly that does no harm to the environment. The extensive experience of the Joint Division in the use of irradiation in biocontrol and in insect mass rearing has made this an ideal partnership.

The stable fly got its name from its habitat. Known scientifically as *Stomoxys calcitrans*, the stable fly hangs out almost anywhere that horses, cattle and other agricultural animals can be found. A bit smaller than the common housefly, its stinging, blood-sucking bite stresses the dairy and livestock cattle it attacks and can lead to anemia, weight loss and reduced milk production.

Costa Rica's dairy and livestock sector has a particular problem with the stable fly because of the country's position as the world's largest producer of pineapple. The stable fly lays its eggs in pineapple residue and, when the new flies emerge, they fly off in the direction of the nearest cattle or dairy farm. Efforts to control the stable fly with pesticides can have public health or environmental impacts.

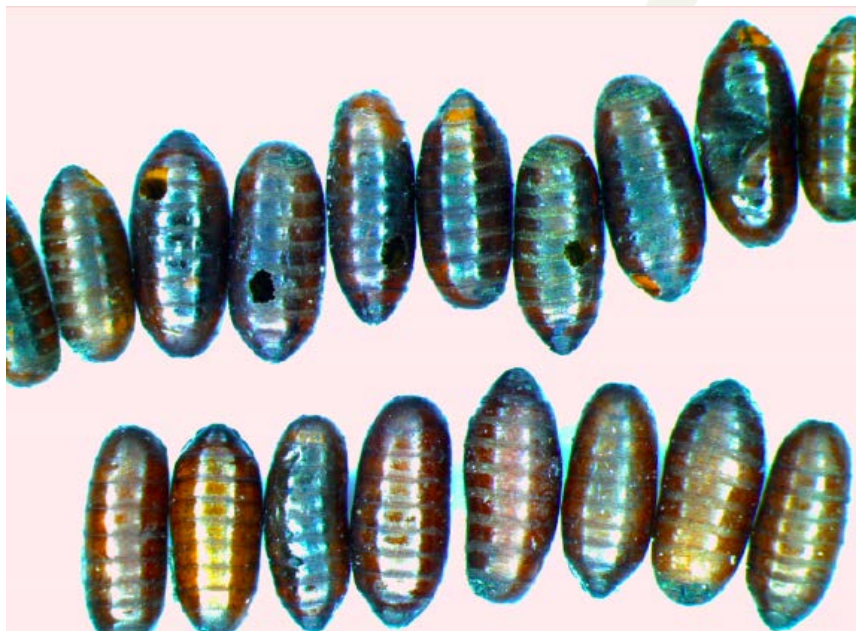
Now, there is a new player in the control game, the *Spalangia*, a tiny parasitoid wasp. Parasitoid, not to be confused with parasite, refers to an insect that attacks other insects, which is exactly what this little wasp does. It lays its eggs in stable fly pupae. Upon hatching, the wasp larvae feed on their host – they consume the stable fly pupae. This means that the wasp is born but the stable fly never

emerges. It all happens naturally, hence the *Spalangia* is called a "biocontrol agent".

The Joint Division has provided scientific support in the development and use of nuclear techniques to enhance biocontrol against insect pests. For example, it supported



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the Moscamed Program in Mexico in developing the mass production and release of other wasp species to control fruit flies that threaten the country's horticulture sector. Now, in supporting the Ministry of Agriculture (MAG) of Costa Rica in adapting the methodology for stable flies, it facilitated the establishment of a facility to rear the needed numbers of *Spalangia*, allowing testing of the method at pilot level in dairy and beef farms.

Irradiating stable flies provides extra safeguard for wasp release

In order to make this happen, researchers from INTA-MAG, with support of the Joint Division, rear stable flies and wasps side-by-side. This method requires bringing a colony of stable flies into the facility and using its pupae to rear the wasps. When the wasps become adult, they are released in areas where pineapple processing facilities are in proximity to dairy and beef farms. Once the process is started, the wasps naturally seek out stable fly pupae to lay their eggs, so the process of controlling the stable flies continues quite naturally.

There is also a prequel to this scenario. When the INTA-MAG laboratory rears the wasps using the stable fly pupae, it cannot be sure that wasps will lay their eggs in every single pupa, meaning there is a chance that some stable flies themselves will actually emerge. Thus, the researchers use gamma rays to irradiate all of the stable fly pupae before the wasps come to lay their eggs. That way, even if a few stable flies emerge, they will be sterile, so no progeny, which further assures an effective biocontrol programme.



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This has proven to be a safe and cost-effective approach, reducing the need for potentially dangerous and costly chemical insecticides. In addition, animal health, and milk and meat production improve when they are no longer under attack by stable flies. Building on its successful implementation, the Costa Rican Ministry of Agriculture is putting the information produced and techniques developed into a national action plan to suppress stable fly infestations in affected areas throughout the country. Looking ahead, the stable fly is found worldwide and breeds on residues other than pineapple, meaning there are many countries that will be able to take advantage of this methodology for pest control. And as for *Spalangia*, they neither sting nor bite livestock or humans.

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BANGLADESH

Bangladesh plant breeding programme adds variety to the seasonal planting calendar



In Bangladesh, villagers have often faced “*monga*” periods, a seasonal famine when food is scarce and prices of whatever food is available are high. Today, thanks to a crop-breeding programme that takes the calendar as well as the soil and climatic conditions into consideration, many villages in the country’s northern region no longer struggle during the long *monga* periods. Farmers can now plant and harvest new crop varieties with synced maturation and growing seasons, allowing them to use their fields for more than just rice. Developed by the Bangladesh Institute of Nuclear Agriculture (BINA) and with support of the Joint FAO/IAEA Division, the breeding programme of course included rice, the major crop, but also groundnuts, mung beans and lentils. The positive socio-economic impact of being able to plant a diversity of crops helps sustain local agricultural production and food security but also represents billions of US dollars added to the national economy.

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As researchers worked on developing new crop varieties for the farmers of Bangladesh, they kept an eye on the calendar. If they could develop a rice variety that would mature faster than the conventional rice currently being used, then farmers could use the extra days of the growing season to plant other crops and vegetables. And that’s just what they did.

Conventional rice takes around 140 to 150 days to ripen, but the Binadhan-7 mutant variety, developed by BINA in 2007 with support of the Joint Division, matures in 110 to 120 days. That means farmers have 20 or more extra days to plant other crops to carry them through the *monga* periods, foods that can also improve family nutrition, such as winter vegetables, pulses and oil seeds. In a 10-year period, Bangladesh increased its enormous annual rice harvest from 26.8 million tonnes in 2003–2004 to 33.8 million tonnes in 2012–2013. Now, with the shortened maturation season, the farmers can plant the newly developed crops that not only are adapted for the local climate, they have inbred resistance to the new pests and pathogens emerging with the changing climate, and they can be planted and mature after the rice is harvested.

Bangladesh is one of the world’s most successful countries in terms of mutation breeding. The Joint Division has supported it all along the process and continues training scientists from BINA on specific screening techniques developed at the Joint Division’s laboratory. BINA has had its own irradiating equipment and laboratory since the 1970s. Of the 64 improved mutant varieties it has developed since it began doing its own mutation breeding, 58 were developed using nuclear technology. Fourteen of those improved varieties have been introduced since 2012.

Bangladesh breeding programme adapts crops to new climate reality

Because Bangladesh is a low-lying country, its rice paddies have become dangerously high in salt. Since a lot of the increase in salt is due to changing climate conditions, Bangladesh has followed salinity-tolerant protocols in developing new rice varieties that will maintain yields even in salty conditions. This is especially a problem in the country’s coastal areas where more than 1 million hectares are affected by saline soil conditions. No longer able to cultivate their traditional crops, farmers have been able



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to adopt new varieties developed specifically for salinity tolerance. With these new varieties, 40 to 50 percent of the land inundated with salt can now be cultivated. Without them, the land would be fallow.

Varieties are developed by exposing thousands of seeds to gamma radiation, which causes mutations. The goal is to identify those mutations that may prove beneficial. When seeking plants with salinity tolerance, the seeds are grown in hydroponic solutions that have varying degrees of salt concentration. This same system can be used for a variety of crops – all that changes is the amount of salt and the pH. The Joint Division has developed techniques for rapid screening of seedlings in the greenhouse while still in the hydroponic solution. Seedlings that present mutations that might work well within the Bangladesh agricultural scenario also go through soil testing in the greenhouse before actual field testing.

The Joint Division has advised and supported BINA's mutant breeding programme since 1972, providing laboratory equipment, training and fellowships for lab personnel. In 2013, BINA's senior staff, many of whom were



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approaching retirement age, asked the Joint Division for support in training younger staff, which resulted in the Joint Division developing specialized training courses. In addition, BINA and the Joint Division have expanded the horizon of their activities and now work together on soil and water management, pest control and technology transfer to support farmers in Bangladesh and its neighbouring countries.

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CUBA

Cuban rice variety bred for tolerance to salinity and rice mites stays relevant in Cuba's fields and its cuisine for almost 20 years

Cuban cooking represents a blend of many cuisines, including Spanish, African, Caribbean and Native American, with one ingredient connecting them all – rice. Rice is the central ingredient of so many dishes that per capita rice consumption in Cuba is estimated as high as 60 kg a year. That means each person in the country eats more than 1 kg of rice a week. To meet this demand, Cuban farmers dedicate 200 000 ha of land to rice production and, since 1997, an enormous percentage of that rice has been INCA LP-7, a mutant variety developed by Cuba's National Institute of Agricultural Science (INCA) with support by the Joint FAO/IAEA Division. INCA LP-7 not only thrives in the Cuban climate, it is tolerant to salinity and resists the panicle rice mites that plague Cuba's rice fields.

When the mutant rice variety INCA LP-7 was introduced to Cuban farmers in 1997, it was the result of seven years of development, representing a successful collaboration between the Joint Division and INCA. The development goal was to breed a high-yielding and saline-tolerant mutant variety that would also be resistant to *Steneotarsonemus spinki*, a microscopic panicle rice mite that had just appeared in Cuba. Cuba actually was the mite's first stop in America. Upon arrival in 1990, it first lowered Cuba's rice yields by between 30 and 60 percent and then spread throughout the Caribbean and Central America.

When introduced, not only was INCA LP-7 the first Cuban variety resistant to the mite, it met all of the other yield and saline tolerance goals, and, above all, it was a variety that Cuban farmers and consumers would accept. Today, it is almost 20 years old, which is quite old in today's world. Farmers and researchers constantly seek varieties that are adapted to new or changing environmental conditions, yet INCA LP-7 has stayed at the top of the market all this time – appreciated for taste, but also for its reliable good yield under stress conditions.

Until INCA LP-7 was introduced, no rice had ever produced more than 3 tonnes per hectare, but INCA LP-7 yielded 5 to 7 tonnes. It proved to be well adapted to the increased periods of drought currently affecting Cuba as well as the changes in soil due to the intrusion of salty water in coastal areas.



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Mutation breeding meets Cuban farmer needs

The work to develop this variety began with rice seeds already popular with Cuban farmers. They were brought to the Joint Division laboratory in Seibersdorf, Austria, for “mutation induction” to derive new improved characteristics. The treated seeds were planted in Cuba’s fields, and seedlings were screened for any mutations that could be beneficial to Cuban rice farmers. Some mutations, such as colour or strength of the stem, are easy to see but others, such as resistance to mites or tolerance to saline soil, only emerge over time.

This exposure to mutagens, whether physical or chemical, speeds up the evolutionary process so that rare mutations can be detected, even in the comparatively small samples of seeds that breeders can handle. The process of irradiating seeds and selecting new mutant varieties with valuable agronomic traits, to achieving regulatory acceptance and, finally, to planting by Cuban farmers is an arduous path of planting and studying performance.

Cuban farmers still plant INCA-LP7 on more than 50 000



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ha, which is more than a quarter of all the rice planted in the country. In addition, the higher yields provide farmers with additional income estimated at Cuban pesos 44 000 per year (US\$1 660), and increased harvests have helped Cuba cut back on the amount of rice it must import. Also, INCA-LP7’s resistance to rice mites has enabled farmers to expand their planting season. This variety has now been shared with farmers in Columbia who also will benefit from its taste, tolerance and yield.

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INDONESIA

Three mutant varieties of sorghum introduced in Indonesia hold promise for both food and energy security



Although still regarded as a minor crop in Indonesia, sorghum holds great promise for the country's food security and industrial development. A grain crop, it sustains people, feeds animals, powers cooking stoves and can be made into paper. It also grows well in poor soils of hot, drought-prone areas, which is often the situation in Indonesia. In 2015, the Indonesian National Atomic Energy Agency (BATAN), with the support of the Joint FAO/IAEA Division, introduced three new mutant varieties of grain sorghum to the country's farmers: one variety was developed for consumption, one for producing ethanol fuel, and one to be processed into flour as a commercial food ingredient.

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It's been thousands of years since sorghum was first domesticated in northeastern Africa. Over the millennia, it has spread around the world becoming a staple crop for millions of the world's poorest and most food insecure people, while also becoming the world's fifth major cereal in terms of production and acreage. In Indonesia, smallholder farmers grow traditional sorghum varieties but never considered it a major crop. However, now with the introduction of three new mutant varieties developed specifically for the Indonesian environmental reality, it has great potential to become a much more important contributor to the agricultural sector.

As a crop, sorghum produces grains that are high in fibre, iron and protein, but low in fat and cholesterol. In addition, all of its parts are utilized. The grains are for human consumption or can be processed into starch. Sugars in sweet sorghum stalks can become liquid sugar or syrup, or be fermented into bioethanol, the stalk fibres can be processed into pulp, paper or construction materials, and the stem waste and leaves becomes feed for poultry and small ruminants. Combining its array of uses with the fact that sorghum can grow in Indonesia's drought-prone east or in the acid soils of the western part of the country, indicates why BATAN's Center for Isotope and Radiation Application (CIRA) and the Joint Division joined to support sorghum's potential in Indonesia.

Plant mutation researchers take their success to the field

Researchers irradiated sorghum seeds with CIRA's gamma irradiator, using seeds provided by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and China. The Joint Division provided technical assistance connected with the research and development of sorghum in Indonesia in the form of equipment, experts, scholarships, scientific visits and training courses. Through a process of mutation induction, development of a mutant



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population, and screening and selection of the best mutant plants, the researchers developed and released three new sorghum mutant varieties – Samurai 1, Samurai 2 and Pahat – that are not only drought tolerant, they are early maturing, high yielding and ideal for dry-season cultivation. This means that in addition to providing food, feed and fibre, they have a big potential to increase marginal land productivity, improve soil fertility, stimulate sustainable agriculture development and promote economic growth.

These new varieties also hold great promise for supporting Indonesia's efforts to reduce its dependence on rice and imported wheat, and to support farmers and small-scale industries in an effort to ensure future food and energy security. For example, Samurai 1, the first variety developed for bioethanol production, is already grown on 6 500 of a total of 11 000 ha in seven provinces and is envisioned to produce more about 1 148 litres of ethanol per hectare. Samurai 2, a variety suitable for consumption, can produce 8.5 tonnes of sorghum per hectare, which is 30 percent higher than traditional varieties. The third variety, Pahat, is currently grown by a private company that process flour from the grain – flour used in sorghum food products such as cookies and couscous now available on local markets.

For now, these mutation varieties are so new that Indonesian researchers themselves are introducing their advancements to the farmers. Working closely with local governments and farmer cooperatives, the researchers arrange sorghum field days to promote sorghum cultivation and introduce farmers to the technology needed to grow it.



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BENIN

Benin farmers inoculate their legumes to improve soil fertility and yield



The farmers of Benin constantly struggle with poor soil fertility which requires them to use expensive fertilizers in order to have a good crop yield – fertilizers that they often cannot afford. But now, through work supported by the Joint FAO/IAEA Division, more than 5 000 farmers have been trained to improve their soil fertility by inoculating their legume crops – inoculating them with a dose of bacteria needed to facilitate the process of nitrogen fixation. The Government of Benin supports a laboratory that produces the inoculum locally and makes it available to farmers. Since this concept was brought to Benin, yields have increased dramatically for both grain legumes and cereal crops. The process decreases the amount of nitrogen fertilizer required for cereal crops, which means farmers spend less on production.

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The process of nitrogen fixation has long been known as one way for nature to improve soil fertility in farmers' fields. Legumes planted in a field absorb nitrogen (N) from the air and convert it, through a natural biological process involving nodules that form on its roots. They then leave that nitrogen behind in the soil after they are harvested, meaning for the next season's planting, farmers need much less nitrogen fertilizer for the subsequent crop. Except, there is often something missing from this scenario. For nitrogen fixation to work, the right bacteria must be present in the soil to make those nodules grow in the first place.

The Joint Division has promoted cropping systems that add nitrogen to the soil through nitrogen fixation since the 1960s. The process calls for introducing legumes into crop rotations and inter-cropping. Farmers who have adopted this system have seen enormous increases in their yields as they have alternated legumes with their cereal grain crops.

The Joint Division, through work in its laboratory in Seibersdorf, Austria, has also identified the specific bacteria needed for legume roots to produce the nodules that fix nitrogen – bacteria that will initiate the process of helping the roots form nodules. Researchers can quantify this process with an isotopic technique that calls for the addition of ^{15}N isotope fertilizer to the soil to measure

how much nitrogen the legume absorbs from the fertilizer and the soil, and how much from the air, so the amount of fertilizer can be adjusted if needed. Scientists also use this method to determine which legumes perform best in improving soil fertility and increasing crop yield in any specific cropping system.



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Maize yield increases 50 percent

In Benin, maize is by far the most important crop, grown by 90 percent of family farmers and occupying more than a third of the 2.2 million hectares of arable land in the country. By initiating crop rotations between maize and nitrogen-fixing legumes such as soybean and groundnut, maize yield has increased 50 percent. In addition, the legumes chosen for the rotation did more than add nitrogen to the soil, with yields of both soybean and groundnut doubling. Even animal productivity and health have improved with this process, because the animals are fed with the legumes grown in more fertile soil, so their feed is also more nutritious.

The lab in Benin that produces the inoculum has grown to keep up with demand from satisfied farmers and to accommodate other farmers who want to initiate the process in their fields. The laboratory also has become a hub to train scientists from other African countries in inoculum production.

Since this programme began, more than 5 000 farmers have been trained at the Faculty of Agronomic Sciences at Benin's University of Abomey-Calavi. Farmers are encouraged to use inoculant technology along with



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nitrogen fixation to improve soil fertility and increase crop yields. The area of nitrogen-fixing legumes included in cereal cropping systems increased from 2 200 ha in 1999 to 30 000 ha in 2016. Not only has planted area increased, the Benin farmers who improve their soil's fertility through nitrogen fixation now save a cumulative US \$4 million on fertilizer costs each year.

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SUDAN

Improving Sudan's vegetable production with small-scale irrigation technologies



Agriculture is the principal source of income and livelihoods for 60 to 80 percent of the population of Sudan, where 90 percent of the arable land is rainfed. Climate change and rainfall variability, water scarcity and the inaccessibility of other water sources have contributed to crop failures making it difficult for small-scale family farmers to maintain adequate livelihoods, particularly in the Kassala region in the eastern part of Sudan. As part of a pilot project aimed at saving water and increasing yields, the Joint FAO/IAEA Division and the Sudan Agricultural Research Corporation, have introduced small-scale family drip irrigation systems to subsistence farmers in the Kassala region to overcome water stress when growing vegetables. This system, which monitors soil water using nuclear techniques, enables farmers to schedule their crop irrigation when and where it Kassala is considered the food basket of Sudan. But without sufficient and continuous water supply, those crops are in peril every growing season. The Joint Division began working with the vegetable farmers in the area in 2014 to introduce family-scale drip irrigation systems that use much less water and also lead to better and more sustainable production. Initially, the work was undertaken with just a few "champion" women farmers who could pass on what they learned to neighbours and friends.

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Drip irrigation is not a new technology, but this project is a great example of adopting what is already available and adapting it to the needs of a specific farming region. In this case, the two elements were a neutron probe, which the scientists used to determine the water requirement so that every drop will be used by the crops, and the nitrogen-15 isotopic technique to trace the movement of applied nitrogen fertilizer and hence determine the efficiency with which it is being used by crops.

Combining the water and nutrient information gathered at the research farms, this was adjusted to meet the local needs. In addition to providing farmers with the simplified drip irrigation system, scientists also train farmers in how to set up the drip system and schedule irrigation for different crop types.

As a result, onion yield increased from 20 tonnes per hectare using local surface irrigation to 27.4 tonnes per hectare using local drip irrigation, while at the same time,



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the quantity of water applied decreased from 16 000 m³ per hectare using local surface irrigation to 9 600 m³ per hectare using the family drip system. This meant water use decreased by 63 percent while yield increased by 43 percent. The net profit per hectare increased from US\$2 440 under surface irrigation to US\$3 820 under the family drip system.

The success of these "champion" farmers has resulted in the work spreading from village to village. Now, the Sudanese Red Crescent, through financial support from the United Nations Refugee Agency (UNHCR), is introducing more farming communities to the technology in an effort to help more farmers adapt to climate change and, ultimately, improve livelihoods and relieve poverty in the country. And since this is used for vegetable fields, which are usually the responsibility of women, more than half of the participating farmers are women.



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SRI LANKA

Isotope techniques trace erosion source to Sri Lanka's terraced tea plantations



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The Central Highlands of Sri Lanka present a picture perfect snapshot of green hillsides, with beautifully terraced fields and gardens that produce a considerable amount of world class tea, rubber, spices and vegetables. These fields, cumulatively, are responsible for around 20 percent of national GDP. Yet a closer look at the area reveals problems. The area is highly prone to soil erosion, which at one point reached almost 40 tonnes of soil per hectare lost each year. In a search for solutions, the Joint FAO/IAEA Division, in collaboration with the Sri Lanka Atomic Energy Board and Natural Resources Management Centre, brought in isotopic techniques to help pinpoint the specific areas where appropriate conservation measures should be taken to improve soil management – measures that led to a 42 percent reduction in annual soil losses.

The landscape of the Dolosbage sub-catchment in Sri Lanka's Central Highlands, which is extremely prone to erosion, is made up of plantations, orchards, crop fields, livestock pastures and even small home gardens. Not only does the area lose soil to erosion, it also loses all of the nutrients in that soil, which the plants and plantations need to thrive.

The problem multiplies when the eroding soil enters water reservoirs and the nutrients, especially nitrogen and phosphorous, become feed for the algae in the water. Known as algal bloom, as the algae grow, they consume the oxygen that fish need to survive. Also, as the sediment load increases in the reservoir, it decreases the amount of water that the reservoir can hold and shortens the lifespan of the dam.

Because the study area was a large catchment with a mixture of land uses, it was obvious that any attempt to help solve the area's erosion problems had to be done at landscape level. It was equally imperative to identify the main sources of the erosion. Working with its Sri Lankan partners, the Joint Division used fallout radionuclides (FRNs) to conduct land degradation assessments and compound-specific stable isotopes to identify its source, a relatively new concept for Sri Lanka.

Simple changes cut erosion and improve soil quality

When the researchers conducted studies on the sediment built up in the reservoirs, they found that most of the problems with soil erosion in the area originated in the terraced tea plantations. Poorly designed contours and the lack of good barriers along the terrace edges allowed rainwater to cascade off each level, picking up speed as it headed downhill and taking soil with it on its way. They also observed that the soil in the tea plantations was degraded, which inhibited its ability to absorb water. Researchers shared results of the studies with farmers, industry and local communities through field days and brought all groups together to seek solutions.

Working together, they identified and undertook appropriate conservation measures, such as changing the shape of their fields, planting vegetation under the tea plants to stop soil from moving, and putting stones in critical places to keep rain water from cascading down the terraces. They also planted medium-sized leguminous trees, such as *Gliricidia sepium*, to stabilize soils and prevent erosion, with roots that both bind the soil and are nitrogen fixing. Now, in addition to containing the soil, they improve its quality, which makes it better for plant nutrition and increases its ability to absorb



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and conserve water. These relatively simple restorative measures reduced annual soil erosion from 39.5 tonnes per hectare to 23 tonnes per hectare.

Bringing the farmers into the network of industry and community leaders will continue to be important moving ahead, because the farmers now know steps they can take personally to minimize soil erosion, and how to monitor their fields to ensure that nothing is changing. The results impressed the decision-makers of the Government of Sri Lanka's Council for Agriculture Research Policy, which is now providing extra funding to support more work in the area.



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Using FRNs and CSSIs to measure and track erosion

FRN refers mostly to measuring caesium-137 (^{137}Cs) in the soil, which came to the earth as fallout following the atmospheric nuclear testing of the 1950s and 1960s. Since it was not there before those days and because it bound strongly to soil particles, it now can be used as a marker to compare what has changed in the natural landscape. This allows scientists to quantify the soil loss and to trace eroded soil back to the specific place where it started, and enables agriculturalists to target their solutions to the area that needs to be treated. CSSIs are naturally occurring soil organic biomarkers that also can be used to identify sources of sediments.

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MOROCCO

Erosion in Moroccan watersheds can be reduced up to 60 percent through the use of isotopic techniques

The erosion that plagues Morocco's hillsides affects more than the agricultural fields that are losing soil. The eroding soil that sweeps down the hillsides eventually ends up as sediment in water reservoirs, leaving them with less water storage capacity. The Joint FAO/IAEA Division, working with Morocco's nuclear institution and other partners, adapted and introduced a package of isotopic techniques to identify the most erosion-prone areas. Having this information allowed for development and introduction of targeted conservation agriculture solutions. Initial pilot studies indicate that the steps taken have reduced soil loss in Morocco's Tetouan watershed of the Tangier-Tetouan region and in the Oued Mellah watershed of the Casablanca-Setta region by around 40 and 60 percent, respectively, and, in turn, greatly reduced the sedimentation of the local reservoirs.

Each year, as much as 100 million tonnes of fertile soil is lost from world agricultural systems through soil erosion. In economic terms, the on- and off-farm soil erosion costs for farmers and the world's land systems are estimated at US\$400 billion per year. Moreover, a quarter of the world's population relies on food produced on degraded lands, which means crops have lower yields and the food produced has lower nutritional value.

In Morocco, soil erosion effects up to 40 percent of the total land area. Half of its 20 million hectares of watersheds are affected by high erosion risks, losing around 100 million tonnes of soil each year. Moreover, the eroding soil ends up in reservoirs, which reduces their water storage capacity by 75 million m³ per year. This means Morocco is losing the ability to store an amount of water capable of irrigating 10 000 ha of arable land each year. In addition, the topsoil that erodes down the hillsides is rich in nutrients, so when it enters the reservoirs, those nutrients feed the growth of algae in the water, which affects water quality and fish populations.

Morocco's mountainous regions deal with a great deal of soil erosion, due to difficult climatic conditions that combine

long drought periods and short intense rainfall, poor soil development due to the steepness of slopes, and a history of unsustainable land management practices, such as overgrazing, deforestation and improper planting schemes. Armed with information about the physical problems, the Joint Division initiated a programme to introduce a package of nuclear techniques that would enable local institutions to identify Tetouan's areas most prone to erosion. The study

Partners

The Joint FAO/IAEA Division works with the *Centre National de l'Energie des Sciences et Techniques Nucléaires (CNESTEN)*, the *Institut National de Recherche Agronomique (INRA)*, *Ecole Nationale Forestière d'Ingénieur (ENFI)*, the *Centre de Recherche Forestière (CRF)* and the French *Institut Vétérinaire et Agronomique (IAV)* as well as in collaboration with decision makers such as the *Haut Commissariat des Eaux et Forêt et à la Lutte Contre la Désertification (HCEFLCD)* and the *Ministère de l'Agriculture et des Pêches Maritime*.



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combined two isotopic techniques: fallout radionuclides (FRNs) and compound specific stable isotopes (CSSIs), which are further explained in the FRNs-CSSIs box below.

Using the pinpoint accuracy of FRNs and CSSIs to reduce erosion and establish soil monitoring

The use of FRNs and CSSI tools to pinpoint erosion sources in the Tetouan watershed area gave researchers the information needed for finding solutions. In this case, the solutions called for introducing farmers to non-tillage soil conservation and planting cereal crops together with fruit trees and with shrubs such as “Atriplex”, that have root systems known to hold soil. With these changes, the Tetouan area saw its soil losses reduced from 54 tonnes per hectare per year to 32 tonnes and Oued Mellah watershed from 10 tonnes per hectare per year to 3.5 tonnes. Now, moving ahead, those same tools can be used to manage and monitor the watershed's soil resources. The project also developed and posted a set of guidelines for using FRNs to assess erosion, which was downloaded more than 2 000 times in its first few months online.

The work in Morocco was part of a 4-year undertaking by the Joint Division that focused on increasing understanding of the causes of soil degradation and providing tools for controlling erosion in ten African countries: Algeria, Benin, Côte d'Ivoire, Madagascar, Mali, Senegal, Tunisia,

Using FRNs and CSSIs to measure and track erosion

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Uganda and Zimbabwe, as well as Morocco. During the four years, the Joint Division and its national partners provided capacity building and training in FRNs and CSSIs techniques. It also sponsored four regional training courses and several individual fellowships, and further developed regional analytical facilities such gamma spectroscopy and weather monitoring systems. At the request of the countries themselves, a second phase of the project will reinforce capacity building, add more analytical equipment and expand the types of agro-ecosystems investigated.

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- » Improved mutant varieties to increase farmer income and livelihoods
- » Superior irradiated vaccines to reduce livestock mortality and increase productivity
- » Sustainable market access through increased and validated food quality



- » Mutation breeding to improve crop yield and enhance nutritional value
- » Sterile insects to reduce food loss caused by major insect pests
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- » Improved water and nutrient use efficiency to reduce water pollution and scarcity
- » Minimized agrochemical runoff in agriculture to ensure safe drinking water
- » Optimized agricultural practices in water-related ecosystems for effective water management



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- » Enhanced nutrient-use efficiency of crops to minimize use of agrochemicals



- » Minimized greenhouse gas emission to strengthen climate resilience
- » Improved crop varieties to strengthen adaptability to climate change
- » Control of transboundary animal diseases under changing climatic environments
- » Sterile insect techniques to control insect pests invading in previously inhospitable areas



- » Radio- and stable isotopes to assess soil erosion and combat land degradation
- » Mutation induction to increase plant biodiversity
- » Remediating impact of nuclear and radiological contamination



- » Coordinated global research network for nuclear science and application in agriculture
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