Nuclear Technologies and Climate Adaptation in Africa

IAEA
International Atomic Energy Agency
Atoms for Peace and Development

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Executive Summary

Climate change is already severely affecting all continents and the ocean – and Africa in particular. Africa has contributed very little to greenhouse gas (GHG) emissions, however, key sectors are already experiencing damaging consequences, including biodiversity loss, reduced food production, loss of lives and reduced economic growth [1]. Furthermore, African marine and freshwater fisheries are significantly threatened; growing seasons will shorten and reduced yields for staple crops across the continent are expected. Increased temperatures and changing rainfall patterns may lead to a shortage of irrigation water and affect the generation of energy through hydropower. The increasing frequency and intensity of severe weather events exposes millions of people to acute food insecurity and reduced water security. Sudden losses of food production and access to food compounded by decreased diet diversity are increasing malnutrition in many communities.

In addition to the global goal of reducing GHG emissions, effective measures are also needed to adapt to their current and expected effects. This requires commitments across a broad range of sectors spanning agriculture, energy, industry, health and the environment. Scientific evidence plays a key role in adaptation planning. Decision-making needs to be based on sound scientific, technical and socio-economic data. Technologies, including nuclear technologies and techniques, can support the climate change adaptation process. However, their successful transfer and application goes beyond the exchange of technological solutions. It requires enabling policy and regulatory environments, and, moreover, human and institutional capacities to deploy these specific technologies and techniques.

Climate adaptation covers a wide range of structural, social and institutional options intended to build resilience and reduce vulnerabilities in multiple areas spanning marine ecosystems, water resources and food production. In turn, the IAEA's expertise is relevant for these areas, as nuclear techniques complement conventional climate adaptation and climate science technologies and approaches.

The overall objective of the IAEA's work on climate adaptation is ***to contribute to climate change adaptation efforts through research and technical cooperation in nuclear science and technology***. The IAEA pursues an integrated approach to the causes and effects of climate change and contributes to climate adaptation and climate science in a number of thematic areas.

Through its Marine Environment Laboratories, the IAEA promotes both research and technical cooperation addressing harmful algal blooms, ocean acidification, and blue carbon, and transfers the relevant nuclear technologies to Member States. This is particularly relevant to African countries, as the Intergovernmental Panel on Climate Change (IPCC) estimates with high confidence that African coastal and marine ecosystems are highly vulnerable to climate change.

Similarly, extreme hydrological variability across Africa is projected to increase under all climate scenarios, posing a wide range of cross-cutting risks to water-dependent sectors, forcing countries to devise policies under high uncertainties. Understanding the quality, availability and origin of water resources is key information for their sustainable use. The IAEA promotes the use of isotope hydrology, which uses isotopes to track the movement of water through the hydrological cycle and to trace the original source of groundwater. Isotope hydrology has been applied in generating new knowledge to address changes in precipitation patterns, reductions in surface water bodies, groundwater vulnerability to climate change and deteriorating water quality worldwide.

Food systems across the African continent are also affected by climate change, as the inhabitants of drylands are vulnerable to shocks, especially those resulting from droughts and other extreme weather events. Africa faces severe food security challenges associated with dryland agriculture including the urgent need to boost agricultural production to enhance crop productivity, and to address insect pests, livestock productivity and health, and food safety issues. This requires improved crop varieties, increased soil fertility, better soil and water management and improved crop protection practices, while preserving the environment.

Major problems at the heart of food insecurity in Africa are related to land degradation and water scarcity, which affects the productivity of land especially that of poor smallholder farmers. The IAEA supports better agricultural water and nutrient management in dryland agriculture through the use of isotopic techniques. This helps to measure the available water in the soil and to determine the right amount of water and nutrients needed at the right time to enhance the production of high-value crops. This knowledge can be transferred to assist smallholder farmers to improve the production of various crops, thus improving the socio-economic situation of local communities.

Improved genetic capacity for stable and enhanced crop production is a key prerequisite for global food security. The IAEA, in collaboration with the Food and Agriculture Organization of the United Nations (FAO), has been implementing breeding programmes to develop new crop varieties that can better cope with extreme conditions. For example, farmers in Namibia now have new crop varieties of cowpea and sorghum that are more tolerant to drought and pests.

Control and management of insect pest populations is very important to enhance food security. The sterile insect technique (SIT), when deployed as an important component of an area-wide integrated pest management approach, can prevent the establishment of, and contain and eradicate, an invasive population without raising public opposition or leaving an ecological footprint. This technique is currently being used against tsetse flies, fruit flies and false coddling moth.

Similarly, climate change has compounding impacts on animal production and animal health. It affects the emergence and re-emergence of transboundary animal and zoonotic diseases, and the availability of adequate quantity and quality of livestock feed. The IAEA, in collaboration with the FAO, is supporting the use of nuclear and nuclear-related/derived immunological and molecular diagnostic tools and techniques in the surveillance and early diagnosis of diseases that are most likely to emerge or re-emerge in response to climate change, to enable adequate disease prevention and control measures in IAEA Member States.

Livestock farming is a major component of dryland agriculture. Serving as a global 'food basket', drylands are climate change hotspots, suffering not only from water scarcity but also a range of endemic and emerging pests and diseases. Crops in drylands are infested by insect species that cause pre- and post-harvest food losses. The use of agrochemicals to control these pests and associated diseases in both crops and animals leaves residues that are of consumer and trade concern. The IAEA, in partnership with the FAO, is assisting more than 30 countries in Africa to establish food safety laboratories using a range of traditional and innovative nuclear and isotopic techniques. These techniques are used to test and control chemical hazards and promote market access.

2012–2021

238 **PROJECTS**

45 **COUNTRIES**

€54m **DISBURSEMENTS**

Supporting African countries on climate adaptation is at the core of an increasing number of bilateral and multilateral development partners. Within this context, the IAEA provides assistance to its African Member States in building capacity to deploy nuclear technologies to support climate adaptation action. From 2012 to 2021, the IAEA has supported 45 African countries through 238 technical cooperation projects[1] in climate change adaptation, disbursing approximately €54 million.

[1] In addition, 53 new projects in climate change adaptation were launched in Africa in 2022.

The IAEA avails itself of mechanisms such as Coordinated Research Projects and its Technical Cooperation (TC) Programme, in collaboration with the African Regional Cooperative Agreement for Research, Development and Training related to Nuclear Science and Technology (AFRA) network, and the establishment of partnerships with key stakeholders.

The IAEA's main regional partner is the African Union (AU) with which it has Practical Arrangements aimed at cooperating for the safe, secure and peaceful use of nuclear technologies for sustainable development in Africa. The IAEA stands ready to continue supporting its Members States in Africa towards the identification of meaningful partnerships towards the achievement of the SDGs and the implementation of the Paris Agreement in areas such as sustainable land use, climate-smart agriculture, food production systems, analysis of GHG emissions, water management, ocean and coastal protection, all areas of vital importance for the continent.

01

NUCLEAR TECHNOLOGIES FOR CLIMATE CHANGE ADAPTATION


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1. Nuclear Technologies for Climate Change Adaptation

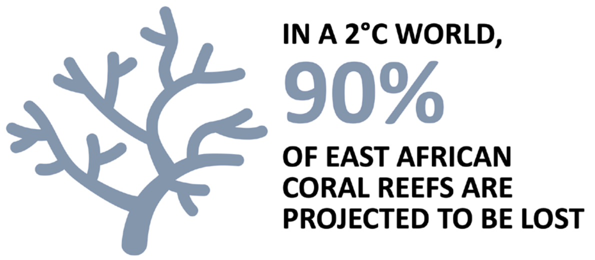
Climate change is already severely affecting many regions of the world – and Africa in particular. The adoption of the Paris Agreement in 2015 with the specific goal of "holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels" was a landmark achievement. The COP26 summit, in Glasgow in late 2021, brought parties together to review previous commitments and the status of their implementation, and to accelerate action towards the goals of the Paris Agreement and the UN Framework Convention on Climate Change.

To achieve the 1.5°C/2°C goal, countries have committed themselves to mitigate climate change by reducing anthropogenic GHG emissions. Projections show that there is a 50:50 chance of average global temperature reaching 1.5°C above pre-industrial levels in the next five years [2].

Globally, climate change is expected to lead to an average temperature increase, more frequent extreme meteorological events and a geographical shift of climatic zones. Droughts in some regions will become more frequent, longer and more severe. A hotter global climate will also influence the availability and quality of fresh water. Taken together, the consequences of climate change are bringing about broad and deep social and economic consequences, impacting the lives and livelihoods of billions of people.

Africa has contributed among the least to GHG emissions; however, key sectors have already experienced damaging consequences attributable to anthropogenic climate change, including biodiversity loss, reduced food production, loss of lives and reduced economic growth [1].

If global warming is not limited to 1.5°C, there will widespread consequences for the livelihoods, economies and ecosystems of the African continent. For example, in a 2°C world, over 90% of East African coral reefs are projected to be severely degraded by bleaching and African marine and freshwater fisheries will be significantly threatened. Growing seasons will shorten and reduced yields for staple crops across the continent are expected. Not enough or insufficient quality water due to increased temperatures and changing rainfall patterns may lead to a shortage of irrigation, drinking and service water. It may also have detrimental impacts on shipping and supply chains as well as affect electricity generation.



For many countries, including African countries, the Paris Agreement's global goal of "enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change" is not an abstract future aspiration, but a necessity, grounded in today's reality. Agriculture, for example, is intimately and inextricably linked to climate, and the impacts of climate change on agriculture are already severe in many parts of the world. If current trends continue, depending on the location, agricultural yields could decrease significantly due to high temperatures, water shortages, extreme weather events and less land that is suitable for production.

Increasing weather and extreme climate events have exposed millions of people to acute food insecurity and reduced water security, with many of the largest impacts observed in many locations and communities in Africa. At the same time, sudden losses in food production and restricted access to safe and nutritious food, compounded by decreased diet diversity, have increased malnutrition in many communities, especially for indigenous peoples, small-scale food producers and low-income households, with children, elderly people and pregnant women particularly affected.

The risks and effects of climate change also threaten the achievement of many other UN Sustainable Development Goals (SDGs). The predicted or already existing risks and impacts of climate change will disproportionately affect the most vulnerable countries and populations. Many developing countries and vulnerable and marginalized groups or individuals in societies, such as women, minorities, indigenous peoples, young adults and children do not have the necessary capacities and abilities to respond to the effects and impacts of climate change.

The window for reducing GHG emissions and achieving the 1.5°C/2°C goal is rapidly closing. Effective measures are needed to adapt to current and expected effects of a changing climate. This requires commitments across a broad range of sectors, spanning agriculture, energy, industry, health and the environment. Scientific evidence plays a key role in adaptation planning. Decision-making on adaptation needs to be based on sound scientific, technical and socio-economic data. Technologies, including nuclear technology and techniques, can support the climate adaptation process. However, successful transfer of knowledge and technology goes beyond the exchange of technological solutions. It requires enabling policy and regulatory environments, and, moreover, human and institutional capacities to deploy these specific technologies and techniques.

Climate adaptation includes a wide range of structural, social and institutional options intended to build resilience and reduce vulnerabilities in multiple areas. IAEA expertise and experience is relevant for many of these areas, including land use and management, climate-smart agriculture, food production systems, analysis of GHG emissions, management of water resources, coastal protection and ocean change monitoring. Nuclear techniques in these areas complement conventional climate adaptation and climate science technologies and approaches. The IAEA provides an integrated approach to the causes and effects of climate change and contributes to climate adaptation and climate science in a number of thematic areas, and 42% of its active climate change adaptation projects take place in Africa.

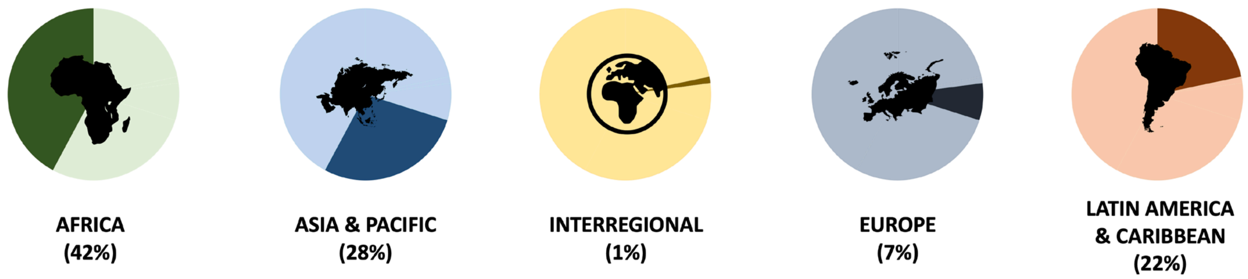
The overall objective of the IAEA's work on climate adaptation is ***to contribute to climate change adaptation efforts through research and technical cooperation in nuclear science and technology***.

A Theory of Change (ToC), illustrating the key categories of results derived from the IAEA's work in the thematic areas of nuclear science and technology for climate adaptation has been developed. It links these results to medium- and long-term objectives related to climate change adaptation and mitigation as envisioned in the SDGs and the Paris Agreement[2].

The key outcomes that are supported through the IAEA's activities can be grouped into the following five major categories:

- Strengthened Member State capacity in nuclear science and technology to support climate adaptation.
- Enhanced biodiversity and protection of the natural environment.
- Increased efficiencies and productivity in the use of natural and agricultural resources.
- Availability of tools and strategies for enhanced consumer protection.
- Reliable information to strengthen evidence-based decision-making.

Distribution of active IAEA climate change adaptation projects by region



[2] The outcome pathways at the level of long-term, high-level outcome are adapted from the Adaptation Fund's Theory of Change derived from the Agenda for Sustainable Development and Paris Agreement in its Medium Term Strategy 2018-2020; and Green Climate Fund's initial adaptation and mitigation logic models (document no. GCF/B.07/11).

02

EXPERIENCES AND CHALLENGES IN AFRICA

2. Experiences and Challenges in Africa

2.1. Marine Ecosystems

Ocean Acidification

The IPCC estimates with high confidence that African coastal and marine ecosystems are highly vulnerable to climate change [3]. The ocean is the Earth's most important carbon storage reservoir, containing around fifty times more carbon than the atmosphere. Its surface layer helps regulate atmospheric carbon dioxide (CO_2) concentration and has absorbed about one-third of human-released CO_2. This excess of CO_2 changes the seawater chemistry, and the chemical and physical ocean changes due to the elevated CO_2 are expected to continue at unprecedented rates. The phenomenon is known as ocean acidification and is now observed everywhere across the globe. Ocean acidification is a serious threat to ocean health and marine organisms that depend on a stable and nurturing environment. Ocean acidification destroys habitats of fish like coral reefs, it inhibits the growth of fish and affects their fitness; shellfish and shelled zooplankton, the food for many fish, form thinner shells and become more vulnerable as a result. Fisheries, aquaculture, tourism and biodiversity can all be affected by ocean acidification, and billions of dollars in losses are anticipated by the end of the century.

1/3

OF HUMAN-RELEASED CO_2 IS ABSORBED BY THE OCEAN

Coastal communities in many African countries rely heavily on the sea for economic, social and nutritional services. Ocean acidification has the potential to negatively affect marine ecosystems important to these communities. Fisheries and aquaculture currently contribute around US $24 billion to the economy in Africa, employing more than 12 million people across the continent. The fisheries sector is particularly important for rural coastal African populations, which are among the

At the IAEA Environment Laboratories in Monaco, scientists use isotopes to study biological processes to understand how marine organisms react to ocean acidification and warming. (Photo: IAEA)

What are isotopic techniques?

Stable isotopes are non-radioactive forms of atoms with unique properties that can be used in a broad range of applications by measuring their amounts and proportions, for example, in water, food and soil samples. Naturally occurring stable isotopes of water and other substances are used to trace the origin, history, sources, sinks and interactions in water, carbon, and nitrogen cycles, and for provenance of goods and materials. Stable isotopes can also be used as tracers, deliberately added to a system that is to be studied, such as in agriculture or nutrition, to make it easier to distinguish the different sources. Stable isotopes have many applications, including in water and soil management, environmental studies, food safety testing, ocean and climate change, nutrition assessment studies and forensics. Naturally occurring radionuclides are used for tracing the cycling of carbon and organic matter in freshwater and marine ecosystems, including carbon sequestration in the oceans.

most vulnerable in terms of both food and job security. Due to the growing population and low level of per capita income, demand for fish in Africa is expected to increase by 30% by 2030. Ocean acidification, combined with other global and local stressors, may make it difficult to meet this need.

The IAEA Ocean Acidification International Coordination Centre (OA-ICC) promotes international collaboration on ocean acidification. The OA-ICC organizes training and provides access to data and resources to advance ocean acidification research. The Centre promotes the development of data portals, standardized methodology and best practices. The OA-ICC works to raise awareness of the issue among various stakeholders and to highlight the role of nuclear and isotopic techniques in assessing its impacts. To achieve these objectives, the OA-ICC works with many international partners and supports global and regional ocean acidification networks, including the Ocean Acidification Africa (OA-Africa) regional hub.

Addressing harmful algal blooms and ocean acidification

The IAEA has assisted in building capacity to monitor harmful algal blooms and ocean acidification in several African countries. Monitoring the toxins exuded by harmful algal blooms and their impact on seafood safety and the environment is achieved using Receptor Binding Assays (RBA). This technology has been established in Algeria, Kenya, Mauritius, Morocco, Namibia, Nigeria, South Africa, United Republic of Tanzania, and Tunisia. Capacity to monitor ocean acidification has also been built in the above countries as well as in Côte d'Ivoire, Gabon, Ghana, and Sudan.

(Photo: Dean Calma/IAEA)

Mbweni, Zanzibar. (Photo: Gloria Salgado Gispert)

The IAEA has supported action in Africa through two separate coordinated research projects focusing on ocean acidification: 'Ocean Acidification and the Economic Impact on Fisheries and Coastal Society', which included representatives from Ghana, Kenya, and Namibia; and 'Evaluating the Impacts of Ocean Acidification on Seafood – A Global Approach', which includes representatives from Egypt, Kenya, and Morocco.

In addition, the IAEA has provided support to Member States on ocean acidification through its TC Programme, with projects such as 'Applying Nuclear Analytical Techniques to Support Harmful Algal Bloom Management in the Context of Climate and Environmental Change' and 'Supporting a Global Ocean Acidification Observing Network towards Increased Involvement of Developing States'.

Blue Carbon

The goal of reducing GHG emissions to limit global average temperature rise can be supported by their removal from the atmosphere via various mechanisms. Although it induces ocean acidification, the global ocean, by taking up CO_2 from the atmosphere, serves as a buffer for the global climate system by acting as a net sink of anthropogenic CO_2. The term blue carbon refers to the carbon that is captured by the ocean and stored as organic carbon (C_{org}). Vegetated coastal ecosystems, such as seagrass meadows, tidal marshes and mangrove forests, have high carbon sequestration rates due to their rates of productivity, the accumulation of organic matter in their sediment and their high efficiency in preserving C_{org} under anoxic conditions for centuries or millennia. The burial rates per unit area in blue carbon systems are about an order of magnitude greater than those of terrestrial forests and are considered as potential major players in nature-based solutions for climate mitigation and adaptation strategies. This is in addition to the myriad functional roles and ecosystem services of these habitats, such as coastal protection, support for biodiversity and protection of water quality and clarity. Decades of degradation of these habitats worldwide, leading to the loss of their carbon sequestration capacity, makes their preservation and, where possible, creation and restoration, a matter of urgency.

BLUE CARBON

REFERS TO THE CARBON THAT IS CAPTURED BY THE OCEAN AND STORED AS C_{ORG}

The accurate assessment of the sequestration rates of C_{org} in blue carbon habitats is key to considering these ecosystems as part of mitigation strategies, but current knowledge is incomplete and subject to substantial uncertainties. Nuclear techniques are being used to address this gap in information. Determination of C_{org} sequestration rates can be achieved using natural and artificial radionuclides present in the environment, with carbon-14 at millennial timescales and using lead-210, caesium-137 and plutonium isotopes at decadal/centennial timescales. This provides a time frame relevant for management actions within the UN SDGs and the UN Decade of Ocean Science for Sustainable Development framework, enabling the determination of C_{org} sequestration and its variation over time due to natural or human activities. Radionuclides can also provide a unique assessment of whether natural or anthropogenic disturbances may have caused losses of carbon, for instance via sediment resuspension and erosion processes. Shorter-lived radionuclides such as polonium-210, thorium-228, thorium-234 and beryllium-7 are used as tracers of sedimentation dynamics at time scales of weeks, months, or even a few years, to estimate carbon sequestration capacity of vegetated coastal ecosystems relevant for blue carbon policy frameworks that support the quantification and financing of carbon emissions reductions. Nuclear and derived techniques are also instrumental in the assessment of the role of carbonate and macroalgae in the carbon cycle, the determination of carbon provenance, in understanding factors that influence sequestration in blue carbon ecosystems and their corresponding budgets, and in support of management actions to promote blue carbon strategies.

The IAEA, through its Marine Environment Laboratories, studies many of the main aspects of blue carbon science and transfers the relevant nuclear technology to Member States. The IAEA is currently involved in blue carbon projects in mangrove forests, seagrass meadows and saltmarshes worldwide. In addition, the IAEA is also engaged in an innovative project coordinated by Oceans 2050 to assess the carbon sequestration capacity of seaweed farms across the world [4]. Countries in Africa where this work is ongoing include Madagascar, the Seychelles, and United Republic of Tanzania. A regional project in Africa has been recently launched to establish capacities to assess the importance of carbon sequestration in aquatic systems for climate change mitigation, environmental conservation and economic purposes.

Chwaka Bay, Zanzibar. (Photo: Gloria Salgado Gispert)

2.2. Water Resources

The African continent is facing extreme variability in rainfall and river discharge. This is projected to increase under all climate scenarios, posing a wide range of cross-cutting risks for water-dependent sectors, forcing countries to devise policies under high uncertainties [1]. Understanding the quality, availability and origin of water resources is key information for their sustainable use. The IAEA promotes the use of isotope hydrology, which uses environmental isotopes to track the movement of water through the hydrological cycle, to trace the original source of groundwater, and to examine mixing processes within different components of the hydrological cycle (precipitation, surface water, groundwater). Although there are many useful isotope tracers in hydrology, the two most common are stable isotopes of oxygen and hydrogen, as these elements are the dominant components of the water molecule. The relative partitioning of the different oxygen and hydrogen isotopes into precipitation is governed by the hydrological and climatic conditions at the time, particularly temperature. The result is a unique isotopic fingerprint that can be tracked through the hydrological cycle.

Other stable isotopes, such as those of nitrogen, can be used to identify pollution sources and evaluate water quality. In addition to stable isotopes, radioisotopes (unstable isotopes) such as tritium, carbon-14 and certain isotopes of the noble gases are used by hydrologists to estimate groundwater age, i.e., the amount of time water has been present in the aquifer system and isolated from the atmosphere. Both stable isotopes and radioisotopes can be used to understand the processes that affect the availability and movement of water through the hydrological cycle and how these processes are affected by climate change.

Shrinking Wetlands and the Impact on Groundwater Recharge

Replenishment of the groundwater system is crucial for sustainable utilization of water resources. Wetlands are often maintained during the dry season by discharge from groundwater systems, while during the wet season, wetlands help to purify water and replenish the groundwater system. Worldwide, wetlands are under pressure from conversion to

Groundwater collection from hand pumps in the Sahel, Ghana. (Photo: Ghana Atomic Energy Commission)

agricultural land, water abstraction and diversion, and climate change, with substantial reductions in the surface area of wetlands in many regions. The reduction of wetlands creates serious problems for groundwater quantity and quality, while at the same time large quantities of carbon stored in wetlands each year may be released into the atmosphere. Isotopes enable evaluation of the hydrological and ecological connection between groundwater and wetlands and allow the quantification of water balances. Understanding interactions in the water cycle and providing accurate water balances helps water managers to determine the ecological reserve: the minimum amount of water needed to sustain the natural environment. Maintenance

Ascertaining the quality and quantity of water resources in the Central African Republic

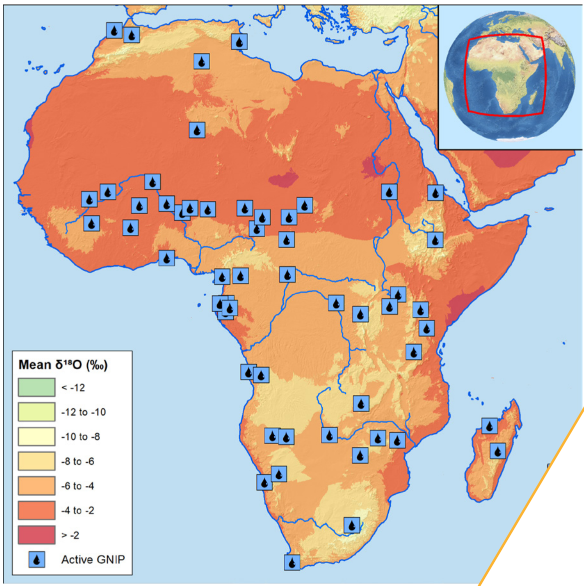
The first ever isotope hydrology maps of the Central African Republic were produced in the context of water resources assessment and management, and subsequently shared with various national stakeholders. The Atlas of Isotope Hydrology for the Central African Republic compiles all isotope results generated in the framework of IAEA-supported activities and projects in isotope hydrology carried out in the country over the last decade. Isotopic data on precipitation, surface water and ground water were used to produce several thematic maps providing insight into the quality, availability and origin of water resources. These maps provide key information for future decision-making on the sustainable use of water resources, and how monitoring programmes are required to adopt policies on water management matters in response to climate change. The Atlas was presented to the Ministry of Water Resources for consideration in the ongoing process to develop a new legal framework for water resource management.

The isotope hydrology project team during a field sampling exercise. (Photo: IAEA)

of the ecological reserve under changing climate conditions is critical to sustaining wetlands and the important biological functions they perform in supporting water quality and storing carbon.

Changes in Precipitation Patterns

Climate modelling predicts that precipitation will likely decrease over northern Africa and the southwestern parts of southern Africa by the end of the 21st century. In contrast, in some regions of high or complex topography such as the Ethiopian Highlands, downscaled projections indicate likely increases in rainfall and extreme rainfall by the end of the 21st century. These changes in precipitation patterns make management of surface and groundwater systems challenging. Stable water isotopes can be used to determine the origin of air masses and the seasonality of precipitation and to allow the tracing of groundwater recharge sources. Stable water isotopes can also be used to understand how groundwater recharge sources have varied over time in response to climate change.



(Source: IAEA)

The importance of monitoring – The Global Network of Isotopes in Precipitation

In collaboration with the World Meteorological Organization (WMO) and IAEA Member States, the IAEA coordinates a global monitoring programme – GNIP. Started in 1960 as a monitoring network for atmospheric tritium fallout, GNIP has evolved over the last six decades to become the world's most spatially comprehensive dataset of oxygen and hydrogen isotopes in precipitation. This unique global isotope database is a critical tool, used in many disciplines ranging from isotope hydrology and ecology to animal migration and forensics. It is also at the forefront of the IAEA's climate observation efforts and is widely used to validate models reproducing atmospheric processes [5, 6, 7]. Currently, there are over 350 active GNIP sites of which around 60 are situated in Africa. The IAEA continually works with Member States across Africa to expand and improve the network coverage.

In Djibouti, modelling of the origin of air masses leading to precipitation events is being used to develop a conceptual model of the groundwater dependency on specific climate variations, and to evaluate the impact of these variations on the sustainability of water resources, considering different recharge scenarios.

To assist Member States in managing their water resources, the IAEA has run the Global Network of Isotopes in Precipitation (GNIP) programme for over 60 years. The GNIP programme helps countries to understand how their precipitation is changing and what this means for the sustainability of water supply. Despite being one of the poorest countries in Africa, the Central African Republic has long-term isotope data collected through the GNIP programme. This data was used to develop an interactive map of the groundwater recharge zones and contamination risk areas to support the advancement of national water management. This type of water resource mapping helps countries build resilience to climate change and allows them to develop appropriate adaptation management strategies to supply water to the agricultural sector, for example.

Evaluating Groundwater Age and Sustainability

Groundwater sustainability is intrinsically linked to the age and volume of a groundwater system. Fossil groundwater systems are not in direct contact with the atmosphere and are hence regarded as not being actively recharged. The lack of active recharge in fossil systems raises questions about the sustainability of such systems. Being able to differentiate between young and fossil groundwater systems and how these are evolving in response to climate change requires knowledge of the groundwater age. Tritium, carbon-14, and isotopes of dissolved noble gases (including helium-3, helium-4, krypton-81, argon-39), and other long-lived radioisotopes, such as chlorine-36, are powerful dating tools used in isotope hydrology studies, and enable groundwater dating from about one year up to one million years. Recent technical advances that facilitate precise analysis of trace amounts of these isotopes in groundwater have opened up these dating tools to Member States through the specialized noble gas facility developed and maintained by the IAEA.

Tracking of groundwater ages along flow paths allows countries to evaluate the impact of variable precipitation patterns linked to climate change

Water sampling at a polluted pond in Port-Louis. (Photo: Ioannis Matiato/IAEA)

on groundwater resources, and to assess the sustainability of current abstraction practices. Mauritius is using isotope hydrology tools to obtain information on the age of groundwater, which is helping the country to understand the movement and distribution of groundwater within complex aquifer systems. The use of complementary stable isotopes in conjunction with more traditional hydrological and hydrogeological methods has also allowed the country to study the impact of hydrological change on water quality and how this is evolving as anthropogenic water use patterns adapt to climate change. Similarly, Namibia, which gets over 50% of its water supply from groundwater, is using radioisotopes to determine how old its groundwater is in different parts of the country and, therefore, how sustainable its current groundwater use will be if recharge patterns change due to climate change.

Salinization of Aquifers

Coastal aquifers are very vulnerable to climate change. Across Africa, more than 10% of the population of many countries is located in low lying coastal areas, with some countries hosting up to 40% of their population in low lying coastal zones that will be affected by rising sea levels [8]. People living in these zones also need freshwater to drink. High rates of groundwater extraction in these zones lead to saltwater intrusion in aquifers, compounding the pressures from saltwater intrusion due to rising sea levels. Isotope hydrology tools are used to evaluate the movement of groundwater in these zones to better understand the mechanisms of groundwater salinization and declining water quality. For example, in many coastal locations in Gabon, drinking water is contaminated by salt water. Isotopes are used to determine unpolluted sites, the characteristics of the groundwater recharge and discharge zones, and the interaction of groundwater with surface water to better understand how climate change is affecting water quality. Similarly, in Morocco and Togo, isotope hydrology is used to assess the scale of seawater intrusion and sources of groundwater pollution. In particular, information on pollution sources and vectors derived from nitrate isotopes, facilitates improved management of coastal waters.

Groundwater Vulnerability to Climate Change

Any future development of groundwater resources to address the direct and indirect impacts of climate change, population growth, industrialization and the expansion of irrigated agriculture will require much more knowledge of groundwater resources and aquifer recharge potentials than currently exists in Africa. Observational data on groundwater resources in Africa are extremely limited and significant effort needs to be expended to assess groundwater recharge potential across the continent. Multiple competing factors in the African context mean that successful adaptation will depend upon developing resilience in the face of uncertainty. Isotope hydrology tools are providing the means to build this resilience in multiple countries. From Tunisia to Namibia, isotope hydrology tools are used to support management of different aquifer systems that often provide the only

Improving aquifer management in climate change-affected Namibia

Namibia is the driest African country south of the Sahara Desert. Sandwiched between the Namib and Kalahari deserts with only five permanent rivers, Namibia has limited freshwater resources and is prone to droughts. Groundwater supports water security in much of the country, but climate change is having a severe impact on the availability and quality of groundwater across Namibia, a situation occurring in many African countries. With a drought emergency declared in 2019 and increasingly extreme weather conditions, annual rainfall may not be sufficient to replenish groundwater resources in Namibia, according to experts. The growing influx of people living in and moving to the capital Windhoek and to coastal cities is adding to Namibia’s struggle to maintain water supplies. The IAEA is assisting Namibia to apply isotope hydrology tools to monitor groundwater resources and to assess the impact of climate change and variability on water from major aquifers in the south-western part of the country.

(Photo: Ivars Krutainis)

Borehole used for irrigation in southern Tunisia. (Photo: Rim Trabelsi/ Laboratoire de Radio-Analyses et Environnement, Ecole Nationale d'Ingénieurs de Sfax)

Understanding the impact of climate change and anthropogenic pressure on water resources in Sfax, Tunisia

Namibia is the driest African country south of the Sahara Desert. Sandwiched between the Namib and Kalahari deserts with only five permanent rivers, Namibia has limited freshwater resources and is prone to droughts. Groundwater supports water security in much of the country, but climate change is having a severe impact on the availability and quality of groundwater across Namibia, a situation occurring in many African countries. With a drought emergency declared in 2019 and increasingly extreme weather conditions, annual rainfall may not be sufficient to replenish groundwater resources in Namibia, according to experts. The growing influx of people living in and moving to the capital Windhoek and to coastal cities is adding to Namibia's struggle to maintain water supplies. The IAEA is assisting Namibia to apply isotope hydrology tools to monitor groundwater resources and to assess the impact of climate change and variability on water from major aquifers in the south-western part of the country.

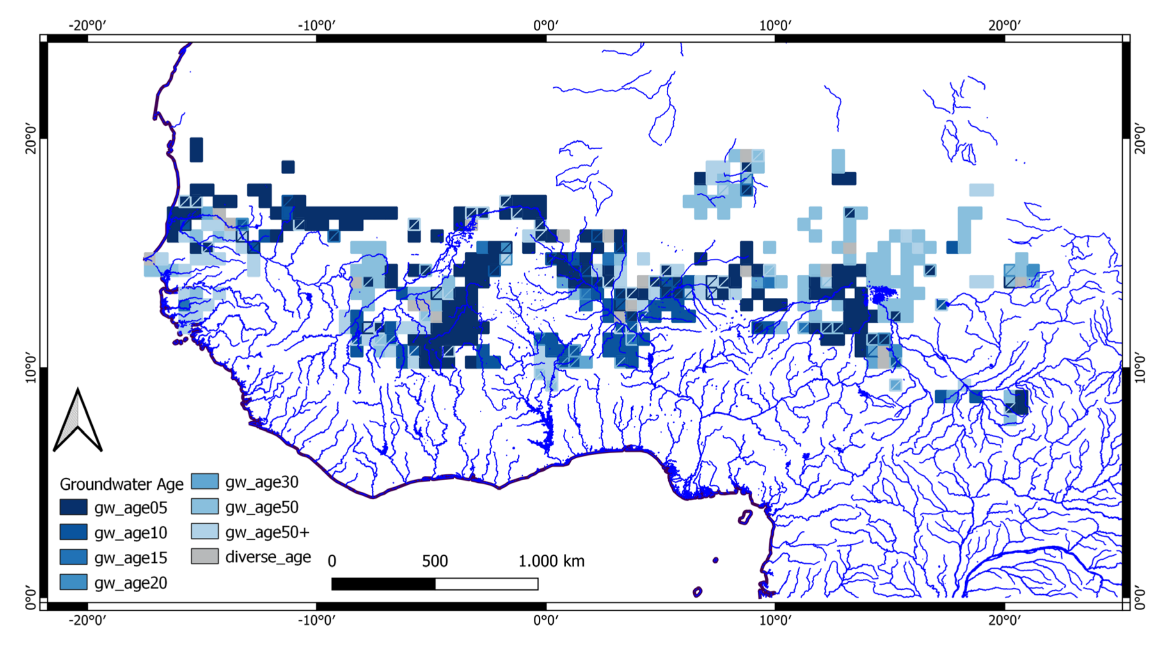
water available for drinking purposes. Developing national capacity in isotope applications allows local scientists in charge of water management as well as graduate students to take advantage of stable water isotopes to determine the origin of groundwater and to study natural water circulation and groundwater movements – information that is essential to determine the sustainability of the groundwater system.

Intensive Evaporation and Water Balance Budgets

One of the most important water management concepts is that of a water balance budget. Water balance refers to the accounting of inflow and outflows from a system. This helps water managers understand how much water is available for use, taking into account precipitation patterns, environmental needs and natural losses such as through evaporation. Climate change is leading to intensification of evaporation and to changing patterns of evapotranspiration, and this in turn is leading to changes in water balance budgets in many parts of Africa. Isotopes are important in tracing the water cycle, and they can also be used for effective monitoring of the impact of evaporation on water balance budgets. In Algeria, isotope hydrology is being used to calculate with high accuracy the water balance for the available resources and to provide answers to the issues and concerns of managers and decision-makers from the point of view of geographical location, climate and socio-economic sectors. Similarly, actions are being undertaken in both Lesotho and the United Republic of Tanzania to develop capacities to sustainably manage water resources using isotope hydrology, and to better understand how the inputs and outputs of the hydrological and hydrogeological system can be balanced.

Water vulnerability across the Sahel

The Sahel is a region extending from Senegal to Sudan, covering the transition from the Sahara Desert to the tropical savannas. This transitional climate zone is characterized by recurrent surface water droughts that result in severe water shortages. The impacts of climate change are already evident but natural and anthropogenic factors converge to potentially cause major humanitarian catastrophes in a region where water resilience is limited. The IAEA is assisting thirteen countries (Algeria, Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Ghana, Mali, Mauritania, Niger, Nigeria, Senegal, and Togo) to characterize shared water resources in five river basins using isotope hydrology tools. Using the isotope data generated, advanced modelling and mapping tools have been used to generate unique isotopic maps that can be used by aid agencies and local governments to assist with the management and prevention of environmental and social crises by securing safe sources of water.



Groundwater age distribution in shallow aquifers across the Sahel, derived from tritium. (Source: IAEA).

2.3. Dryland Agrifood Systems

Drylands are arid, semi-arid, and dry sub-humid zones, with low rainfall, high temperatures and a lack of water, constraining crop, animal and forest production. More than half of the African continent consists of drylands. These drylands account for three quarters of the area used for agriculture, and are home to half of the continent's population, including a disproportionate share of the poor. Climate change, which is expected to increase the frequency and severity of extreme weather events, will exacerbate the challenges facing drylands. Inhabitants of drylands are vulnerable to shocks, especially those resulting from droughts and other extreme weather events. Africa faces severe food security challenges associated with dryland agriculture, including the urgent need to boost agricultural production and enhance crop productivity, and to address insect pests, livestock productivity and health, and food safety issues. Faced with these challenges, Africa remains largely food insecure, which directly affects 70% of its population. Better crop production and protection practices, including improved crop varieties, better animal production and health practises, better insect pest control, and better soil, water, and nutrient management, including for increased soil fertility are needed, while at the same time ensuring the preservation of the natural environment.

Protecting Soils and Preventing Land Degradation

Land degradation and desertification are among the world's greatest environmental challenges. Africa is the most affected region, due to the impacts of climate change and human-related activities. Among land degradation processes, the most significant are desertification and soil erosion. It is estimated that 65% of the African continent's farmland is affected by land degradation-induced losses of topsoil and nutrients. In addition, sediments and nutrient export derived from erosion contributes to eutrophication and water pollution of surface and groundwater for drinking and irrigation of crops.

65%

OF THE AFRICAN CONTINENT'S FARMLAND IS AFFECTED BY LAND DEGRADATION-INDUCED LOSSES OF TOPSOIL AND NUTRIENTS

With sustainable soil management Africa can achieve agricultural growth, ensure food security, and adapt to a changing climate. The IAEA, in partnership with the FAO, has been assisting its Member States to use isotopic techniques to combat soil erosion. Fallout radionuclides can be used to provide reliable and foundational information on soil erosion rates over different time spans and to assess sediment sources in watersheds that result from erosion, thus facilitating better, more targeted soil conservation practices. In Tunisia, traditional farming practices such as the construction of terraces and erosion ridges have helped reduced soil erosion rates by 40 to 60%. To further reduce erosion rates, modern soil conservation measures such as no tillage and mulching are be combined with terracing and ridges.

Agricultural Water

A major problem at the heart of food insecurity in Africa is water scarcity. This affects the productivity of land and has a significant effect on the food security of low-income smallholder farmers. The combination of harsh climatic conditions and

Soil sampling for caesium-137 determination. (Photo: Mansour Oueslati and Gdiri Amira/National Center for Nuclear Sciences and Technologies of Tunisia)

Effectiveness of traditional soil conservation methods in Tunisia validated with fallout radionuclides

Soil conservation is important for maintaining food security in semi-arid countries with scarce vegetation that provides only poor protection of soil against erosion. Rains are rare in many parts of Tunisia, and often cause erosion. Radionuclide tracers such as caesium-137 are used to assess the soil erosion rate and validate the efficiency of soil conservation measures in many parts of Africa. A study in a 335-hectare Sbaihia Experimental Watershed in Tunisia used caesium-137 to test soil conservation ridges, a traditional measure used in Tunisia for soil protection. The results showed that the 80 cm ridges situated about 40 m from one another reduced soil erosion by 41% (from 37 to 22 t/ha/y). The study also showed that soil conservation efficiency can be further improved by reducing the distances between ridges, with a separation of 20 m found to be effective. of environmental and social crises by securing safe sources of water.

widespread poverty contribute to low levels of resilience in African drylands. Integrated soil and water conservation technologies can improve agricultural water management in rainfed systems in the drylands and improve farmers' resilience. Currently irrigated areas account for less than 10% of the farmed area (5.2 million hectares) in Africa, however, this sector is growing. Agriculture accounts for approximately 70% of all freshwater use globally, yet in many places the efficiency of irrigation water use is very low. With climate change and increasing demand for water, it is necessary to improve agricultural water use efficiency. Water-saving technological packages ('more crop per drop'), using carbon-13, oxygen-18, deuterium and nitrogen-15, allow to track water movement and pathways in agricultural landscapes with different cropping systems and farming practices, at the same time determining sources of pollution.

In recent years, small-scale irrigation systems have helped address the constraints of water scarcity in Africa. The IAEA, in partnership with the FAO, is working with many scientists in Africa to use small-scale drip irrigation systems to determine the most effective use of water and fertilizer in agriculture, and to enhance irrigation water management. The IAEA provides support to establish capacity in the use of isotopic techniques to measure the available water in the soil, and to determine the right amount of water needed at the right time to enhance the production of high-value crops. Knowledge is then transferred to assist smallholder farmers, mostly women, in improving the use of water and nutrients

Farming on poor soil with little rainfall in Kenya's drought-prone areas: Isotopes used to develop new strategies

Despite poor soil fertility and water scarcity, thousands of farmers in Kenya have increased their crop yields by 17 to 20% and saved 20% of their fertilizer costs thanks to climate-smart agricultural techniques. The techniques, introduced with the support of the IAEA in partnership with the FAO, helped improve soil fertility for farmers and supported better management of the crop water requirements. Scientists from the Kenya Agricultural and Livestock Research Organization (KALRO) used nuclear and isotopic techniques to monitor changes in soil water and nutrients. These techniques were used in the Kajiado-Central and Tharaka sub counties to assess nitrogen use efficiency and to calculate nutrient and water requirements using the stable isotope nitrogen-15 and soil moisture sensors. The techniques helped to provide quantitative data on the efficiency of nutrient use by crops, which enabled experts to improve water and fertilizer application strategies.

(Photo: KALRO)

How nuclear technology helps female farmers in Sudan move out of poverty

In eastern Sudan, in the Kassala region, hundreds of subsistence farmers have to face rainfall variability, water scarcity and the inaccessibility of water sources to maintain adequate livelihoods. The IAEA, in partnership with the FAO, helped scientists in Sudan to use the soil moisture neutron probe technique to measure moisture levels in the soil at Kassala Research Farm to quantify the amount of water needed by the crops and to use the nitrogen-15 isotopic technique to optimize nitrogen fertilizer applications. These techniques help to determine how much water and fertilizer to deliver through the watering system known as drip irrigation. Now, through small-scale farms and home gardens optimized using nuclear technology, the women, their families and entire villages benefit from growing and selling vegetables such as onions, eggplants, okra and leafy greens.

Nuclear science helps Sudanese women turn dry lands into vegetable fields. (Photo: Nicole Jawerth/IAEA)

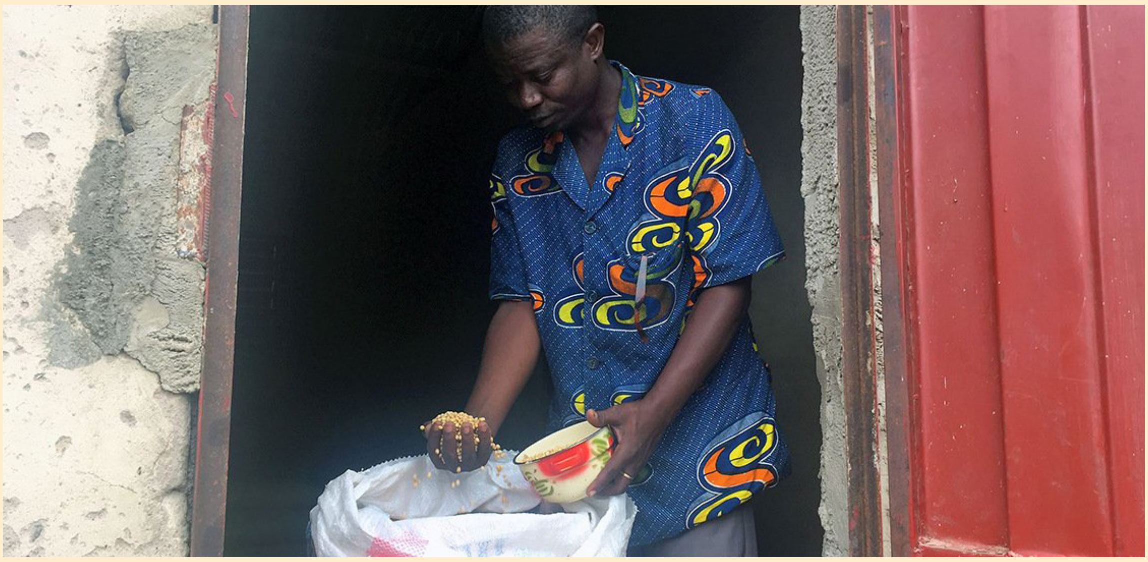
of high-value crops, improving the socio-economic situation of local communities.

Nutrient Management

More than 40% of African soils, amounting to 1121 million hectares of agricultural land, are deficient in essential plant nutrients including nitrogen, phosphorus, potassium, sulphur, micronutrients and soil organic carbon, due to years of crop nutrient mining and inefficient use of chemical and organic fertilizers. According to the FAO, the average fertilizer application rate in Sub-Saharan Africa is around 16 kg per hectare for all major nutrients, which is far below the continent-wide recommendation of about 100 kg per hectare, thus leading to poor soil quality and health. Phosphate fertilizer use in Sub-Saharan Africa is extremely low compared to non-arid areas in other continents of the world. In general, nitrogen and phosphorus use efficiency of these chemical fertilizers on-farm are reported to be less than 50% and 20 %, respectively; however, the fertilizer use efficiency of these two major plant nutrients is likely to be much lower in low fertile soils and harsh environmental conditions, such as in Africa. The IAEA assisted in conducting on-farm studies in Burundi, Central African Republic and Rwanda, involving hundreds of farmers. The results showed that applying nitrogen, phosphorus and potassium at appropriate ratios increased cassava production four-fold compared to conventional farming practices. Similar results were obtained in Mauritania, where rice production was significantly increased by the strategic

Isotopic technique helps Benin farmers triple yields and improve livelihoods

Legumes such as soybeans and peanuts can capture nitrogen from the atmosphere, and deposit it in the soil. This increases soil fertility and enhances the maize crop that farmers plant the following season. The intercropping of maize and legumes results in an increase in the yields of both crops. Farmers inoculate their legume seeds with natural biofertilizers that induces nitrogen fixation in the legumes, meaning no or little commercial fertilizer is required, saving farmers additional expense. There are 100 000 soy farmers in Benin, and about 20 000 farmers use the new technique. Yields in farmers' fields have increased from an average of 600 to 1700 (kilogram per hectare) to 57 000 to 220 000 production (tonnes) and the export value has risen from US $6.6 to US $109 million from 2009 to 2019. This has resulted in soybean becoming an export rather than an orphan crop (one that is not traded internationally).



Soybean farmer Leonard Djegui from central Benin has tripled his income following the introduction of intercropping and the optimization of fertilizer levels. (Photo: Miklos Gaspar/IAEA)

application of nitrogen, phosphorus and potassium fertilizer. In Benin, the use of biofertilizer (Rhizobium inoculant) and isotopic techniques led to a four-fold increase in soybean production between 2009 and 2019, raising smallholder incomes and the availability of healthy soya-based foods, leading to significant increases in soil fertility as well as in export earnings at a value of US $19 million, annually. In addition, the incorporation of soybeans in maize-based cropping systems resulted in more than 50% savings in nitrogen fertilizers without a decrease in maize yield.

Crop Improvement: Plant Breeding and Genetics

Improved genetic capacity is a key prerequisite for stable and enhanced crop production and global food security. The productivity of crops is challenged globally by the various facets of climate change, such as reduced precipitation, warming temperatures, flooding, soil salinization, intensifying diseases and an increase in pests. Agriculture in arid, semi-arid and sub-humid regions is dominated by subsistence farming, in which climate-resilient crops naturally adapted for growth and production under dry conditions predominate. These crops provide food, feed and fodder in the crop–livestock systems in many of the dryland regions as well as staple foods for their population. Traditionally considered ‘orphan crops’, without value for international trade, such crops are now increasingly considered as ‘climate-smart’, ‘smart-food’ and ‘future’ crops and are sought out for their climate resilience and/or nutritional value, especially under the looming threat of climate change in dryland ecosystems. The inherent resilience and hardiness of crops such as cowpea, groundnut, sorghum and other millets in Sub-Saharan Africa allows them to grow under increasingly harsh environments, although at lower than optimal production potential. Many other underutilized crops are also grown in these regions and remain an important source of nutrition for the population. In addition, crops such as maize, while not fully adapted to such harsh environments are also grown. Such crops face challenges in productivity due to both abiotic stresses such as drought and heat, and biotic stresses such as diseases and pests. Genetic improvement of crops grown in dryland ecosystems is important to enable productivity at levels close to their production potential, and such genetic improvement is best achieved by breeding based on induced genetic variation.

An IAEA Fellow training at the Plant Breeding and Genetics Laboratory, IAEA Seibersdorf, Austria. (Photo: Dean Calma/IAEA)

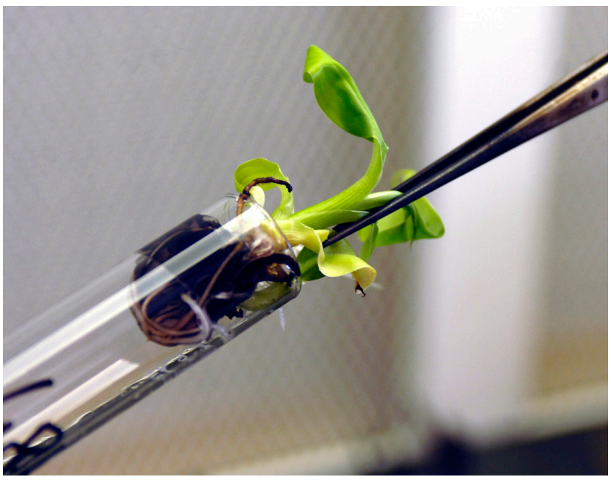
Genetic improvement of productivity in cowpea

Cowpea is the most important grain legume crop in Sub-Saharan Africa and is mostly grown in hot drought-prone areas due to its resilience. It is a pulse crop important for its protein-rich grain, and hence of important nutritional value to the population in this region. On-farm yields of cowpea

A joint FAO/IAEA project to increase soil fertility provides locals with training on the use of nuclear-derived techniques to measure nitrogen quantities in soil with the aim of optimizing the use of nitrogen fertilizer. Here, Ephrem Kosh-Komba, professor and researcher at the University of Sciences in Bangui, prepares equipment at the laboratory in Bangui. (Photo: Laura Gil Martinez/IAEA) in Sub-Saharan Africa reach only 10 to 30% of their biological yield potential, primarily due to drought, and attacks by insects and diseases.

In Namibia, after nine years of research and field experiments, five mutant cowpea varieties resulting from gamma ray induced genetic diversity and mutation breeding were recommended for national release in 2020, making them the first Namibian-bred varieties to be officially released in the country. The released cowpea varieties were selected for earliness and high yield. Multiplication of the seed of released varieties started thereafter and it is reported that 2000 kg of improved seed have been multiplied for distribution to local farmers during the 2021 cropping season under the supervision of the Ministry of Agriculture, Water and Land Reform in Namibia. In Zimbabwe, the first mutant variety of cowpea was released and commercialized in 2018 based on its performance under drought. The variety, CBC5, is drought tolerant, has grains that are 10% larger than those of its parent CBC1 and performs 20% better in terms of grain yield potential compared with most farmer-preferred varieties in Zimbabwe.

Induced genetic diversity based on gamma ray mutagenesis is also being used for resistance to the most serious cowpea pest, the pod borer Maruca vitrata. The Joint FAO/IAEA Centre is testing induced genetic variation for insect pest resistance as an alternative to other techniques. Seven African countries are participating in this project, with a focus on the cowpea pod borer. Early success has already been demonstrated by one participating research group in India.



IAEA Plant Breeding Unit, Seibersdorf, Austria. (Photo: Dean Calma/IAEA)

Using nuclear technology, scientists are developing new nutrient-rich crops that accumulate higher contents of iron and other micronutrients. By using radiation, scientists can significantly enhance the genetic diversity necessary to develop novel and improved varieties. (Photo: Laura Gil/IAEA)

Genetic improvement of groundnut productivity

With an annual cultivated area of two million hectares under groundnut, Sudan ranks fourth and is among the leading exporting countries of this crop. The rainfed sector in western Sudan accounts for about 80% of the total groundnut area, producing 70 to 80% of the total production. A new improved variety of groundnut, Tafra-1, developed through mutation breeding, with drought tolerance, high pod yield and early maturity was released in Sudan in 2018 after being ranked as best among the tested lines by all participatory research committees at the village level, locality level and state levels. The ranking was based on the agronomic superiority of the mutant which produced 1024 kg per hectare compared to 926 kg per hectare produced by the recently released check cultivar, Gubeish.

Genetic improvement of sorghum

Sorghum is an important staple crop for Africa. In South Africa, mutant varieties of sorghum with suppressed storage kafirin proteins in the endosperm were obtained through gamma irradiation. Kafirins in sorghum are associated with poor nutritional quality. They are deficient in major essential amino acids; they restrict digestion of the proteins when sorghum is cooked, and they also interfere with the availability of other nutrients in

Mutation breeding versus genetically modified organisms

Mutations are spontaneous random changes in the genome of organisms that naturally occur during their lifetime. While mutations induced by traditional mutagenesis techniques are no different from spontaneous naturally occurring mutations, the process of mutagenesis helps to speed up naturally occurring genetic variability, which is an important requirement for crop improvement and adaptation to its changing environment. The mutation induction process (mutagenesis) used in plant mutation breeding has established a long safety record, as plant mutation breeding has been used since the 1930s as a means of enhancing crop improvement, contributing to global food security, and increasing genetic diversity. Mutation breeding uses external agents such as radiation to induce natural changes in the genome, in a manner akin to spontaneous evolution but at a faster pace. These techniques do not involve the introduction of genetic material into an organism. In contrast, genetically modified organisms are developed using known molecular information to introduce genes into an organism or edit genes within an organism with specific DNA integration sequences and techniques.

Drought-tolerant crops contribute to food security in Namibia

Farmers in Namibia now have access to new crop varieties of cowpea and sorghum that are more tolerant to drought and pests, thanks to nuclear technology provided with the support of the IAEA and the FAO. Traditional seed varieties no longer meet the needs of close to 700 000 agricultural households in northern Namibia, where drought and poor soil inhibit crop productivity. Farmers have reported yield losses and the resulting decrease in productivity is contributing to food insecurity, malnutrition and even famine. The enhanced cowpea varieties produce higher yields during a shorter growing period. The new sorghum varieties also have higher yields, as well as increased resistance to the ergot fungus, to which the traditional varieties are susceptible. Ergot fungus affects yields, and possibly causes poisoning if consumed by humans or animals. Farmer-participatory selection of cowpea and sorghum varieties during the breeding process is facilitating early adoption.

Farmers selecting their preferred varieties of cowpea, on the basis of factors such as growth duration, during a field trial. (Photo: Fatma Sarsu/IAEA) diet. Suppression of the kafirins resulted in sorghum with high content of essential amino acids such as lysine, methionine and tryptophan and digestible protein and starch. In addition to these important crops of Sub-Saharan Africa, mutation breeding is also being applied to crops such as rice, maize, wheat and tuber crops for better yield performance under climate change phenomena, including the increasing incidence of diseases and insect pests.

Management of Insect Pests

Invasive insect species can interfere with ecosystem services or disrupt whole ecosystems and cause the decline of native species that are now listed as endangered or threatened. The impacts of invasive species are second only to habitat destruction as a cause of global biodiversity loss. In addition, the lack of natural enemies and limited management knowledge of the invasive insect pest allows them to overwhelm the invaded areas rapidly and to cause significant damage to agricultural production, including of crops and livestock. The significant costs of invasive pest control and lost output is a cross-boundary issue requiring effective regional and international coordination.

The rapidly increasing rates of international transport and trade and population migration, as well as the movement of livestock and agricultural commodities between geographical regions, have significantly increased the probabilities of introducing invasive pest species into new regions. Climate change projections to 2050 predict a net average increase of 18% in the occurrence of arthropod invaders. This expansion applies not only to plant pests, but also to vector-borne diseases, affecting not only the spatial-temporal distributions and population dynamics of the vectors, but also speeding up their life cycles (including those of parasites), their modes of transmission, and opportunities for development in new hosts.

The Insect Pest Control Laboratory, Seibersdorf, Austria. (Photo: Dean Calma/IAEA)

Campaigns to eradicate invasive insect pests often lack the tools to effectively remove all individuals of a target population and rely on indiscriminate and large-scale application of insecticide sprays, as well as the drastic removal of infested animals and plants or even the destruction of whole herds, crops and orchards.

Citrus is the second most important agricultural export commodity in South Africa, with most of the production destined for exports. The industry employs 10% of the country's agricultural labour force. Some parts of the country are a natural habitat for the false codling moth, whose larvae feed in the fruit, destroying the pulp and threatening the livelihoods of farmers and farm workers. Since the introduction of SIT in 2008, the moth population has gradually diminished, because the sterilized insects produce no offspring. (Photo: Miklos Gaspar/IAEA)

Morocco sets up pest surveillance network in preparation for the suppression of the Mediterranean fruit fly

The cultivation and export of citrus plays a significant role in Morocco's economy: the sector employs more than 13 000 farmers and farm workers and produces exports worth US $300 million per year. The continued growth and success of this industry has been threatened by the presence of a pest species: the Mediterranean fruit fly. The IAEA, in cooperation with the FAO, has helped Morocco achieve its first victory in the ongoing campaign to suppress the Mediterranean fruit fly. Moroccan counterparts have received the training and equipment necessary to detect and respond in a timely manner to any incursion by other fruit fly pests, which is a prerequisite for sustained suppression using the SIT. Without a surveillance system in place to keep out other pests, successful use of SIT would lead to another pest taking their place in devastating citrus orchards.

Invasive fruit fly species including the Oriental fruit fly (Bactrocera dorsalis, Hendel), are threatening Morocco's economy. (Photo: Ana Rodriguez)

Sterile Insect Technique

Jointly with the FAO, the IAEA assists its Member States in developing and adopting nuclear-based technologies such as SIT for optimizing agricultural insect pest management practices that support the intensification of crop production and the preservation of natural resources.

The SIT is an environment-friendly insect pest control method involving the mass rearing and radiation-induced sterilization of a specific target pest. It follows the systematic area-wide release of the sterile male insects by air over defined areas, where they mate with wild females resulting in no offspring and a declining pest population. The SIT does not involve transgenic (genetic engineering) processes.

Integrated with other control methods, the SIT has been successful in controlling a number of high-profile insect pests, including fruit flies, tsetse flies, screwworm, moths and mosquitoes. In several countries where the technology has been applied, retrospective economic assessment studies have shown a very high return on investment. Benefits of using the technology include: a significant reduction in crop and livestock production losses; protection of the horticultural and livestock industries through prevention of pest introductions; providing conditions for commodity exports to high value markets without quarantine restrictions; protecting and creating jobs; significant reduction in production and human health costs; and environmental protection through reduced use of insecticides.

Use of the sterile insect technique against tsetse flies

The IAEA, in partnership with the FAO, provided technical support to the Government of Senegal in its efforts to create a tsetse-free zone in the highly productive agricultural region of Niayes in western Senegal, using an area-wide integrated pest management approach with a SIT component.

The tsetse fly populations in the entire project area are suppressed by more than 97%, resulting in a very low prevalence of the disease trypanosomosis that the flies transmit. This resulted in a significant increase in milk yields, and a ten-fold increase in the use of imported, more productive, exotic cattle with a positive overall return on investment.

The IAEA, in cooperation with the FAO, helped Senegal to suppress pest populations by applying the SIT. The disease that tsetse flies transmit can kill livestock or make them sick. (Photo: USUNVIE)

Use of the sterile insect technique against fruit flies

A new fruit fly mass rearing facility in Mauritius went into service in August 2019, with the capacity to produce 15 million flies per week. The target is to release the sterile flies in fruit and vegetable production areas to suppress fruit and vegetable infestations in selected areas. The facility is helping Mauritius to apply SIT to control pests that attack fruit and vegetable crops such as mango, peach and cucumbers. The IAEA, in partnership with the FAO, has also been supporting Morocco to use SIT to control the Mediterranean fruit fly in citrus production areas in Agadir. Here, the government has completed the construction of a Mediterranean fruit fly mass rearing facility capable of producing 130 million sterile males per week. A fly emergence and release facility in Agadir has also been established with the aim of applying area-wide SIT over the entire citrus production area in the Souss-Massa Valley.

Use of the sterile insect technique against false coddling moth

The IAEA, in partnership with the FAO, has provided technical support to a false codling moth project in South Africa. The insects are produced locally in a mass rearing facility and released in the citrus production areas. The release period is from September to June over a period of ten months, with 40 million moths per week released throughout 16 500 hectares. Excellent results have been obtained in the suppression of the false codling moth population by up to 93%, resulting in a 38% reduction in post-harvest losses in the areas under the SIT.

Animal Production and Health

Climate change and variability has compounding impacts on animal production and health in developing countries. Climate change affects the emergence and re-emergence of transboundary animal and zoonotic diseases, and the availability of livestock feed of adequate quantity and quality. On the other hand, livestock production contributes to loss of biodiversity and to the climate change problem.

A nuclear technique has helped Senegal suppress the tsetse fly in the Niayes region by 99%, enabling local farmers to significantly increase milk and meat production. (Photo: USUNVIE)

A course offered by the Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture trained veterinarians and wildlife experts from seven African countries. In their labs, scientists look for any of the hundreds of viruses that bats can transmit to animals and humans, Ebola included. (Photo: Laura Gil/IAEA)

Climate change affects pathogens, vectors and hosts, increasing their geographic range, incidence, and the spread of infectious diseases. Climatic conditions determine the movement and behaviour of migratory birds, increasing opportunities for the transmission and spread of viruses such as those that cause avian flu. Altered rainfall patterns associated with floods increase the abundance and distribution of vectors for diseases such as Rift Valley Fever. Higher temperatures and humidity generally increase the rate of development of pathogens, whereas climate stress (heat, inadequate food and water) lowers the immunity of animals, making them more vulnerable to diseases. Decision-makers need to be able to identify likely disease outbreaks as a consequence of climate change early, in order to put in place adequate disease prevention and control measures. The IAEA, through the VETLAB network of laboratories in 46 African countries, is strengthening capacities to utilize nuclear and

Hunting for viruses in Sierra Leone with the help of nuclear technology

While bats play a vital part in ecosystems, they also carry threats to people: every year, around ten new viruses are discovered in bats. Among these are viruses like Ebola, which can be transmitted through close contact with infected bats' blood, secretions, organs or other fluids. After suffering from a devastating Ebola outbreak in 2014, veterinary scientists in Sierra Leone are now training their peers from around Africa to catch, sample and diagnose — using nuclear-derived techniques — potentially virus-transmitting bats. With IAEA support, personnel are trained to capture and identify bats. The animals are measured and probed for blood, faecal and oral samples, to be analysed for any of the hundreds of viruses that bats can transmit to animals and humans, Ebola included. To do this, Sierra Leone is using nuclear-derived techniques and equipment donated by the IAEA TC Programme.

Veterinary scientists catching a bat in the jungles of Sierra Leone. (Photo: Laura Gil/IAEA)

nuclear-derived immunological and molecular diagnostic tools and techniques for the surveillance and early diagnosis of diseases that are most likely to emerge or re-emerge in response to climate change, to enable adequate disease prevention and control measures in Member States. Capacities have been enhanced in more than 40 countries to control foot-and-mouth disease, avian influenza-H5NX/H7N9, Rift Valley fever, Ebola, lumpy skin disease, trypanosomosis and capripoxviruses. Support has been provided to 130 countries to detect COVID-19.

Vets from Cameroon's National Veterinary Laboratory are testing animals' blood for peste des petits ruminants using nuclear-related techniques. (Photo: IAEA)

Climate change affects the availability of livestock feed resources of adequate quantity and quality. Inadequate animal nutrition leads to low productivity, resulting in the rearing of a larger number of animals for the same amount of production, and consequently leads to more livestock GHG emissions, further aggravating climate change. Improving feed efficiency has the potential to reduce GHG emissions. Compound-specific stable isotopes of various elements are used in decision support for livestock nutrition. Within animal populations, there are those that are adapted to the harsh production environments, enabling them to thrive and perform better than their contemporaries. Radiation hybrid mapping enables production of genome maps for characterisation and selection for breeding of such individuals. Addressing these challenges and opportunities enables sustainable livestock production practices that ensure food security while reducing the carbon footprint of animal products. The Animal Production and Health Section of the Joint FAO/IAEA Centre is helping IAEA Member States to identify and utilize locally available feed resources for animal nutrition, supporting feeding strategies that may reduce GHG emissions from livestock production, and promoting the utilization of locally adapted animal breeds for sustainable livestock production.

Improving animal production using nuclear and related techniques in Burundi

Livestock productivity in Burundi is low due to the high prevalence of transboundary animal and zoonotic diseases, low genetic performance, and inadequate animal feeding. Improved laboratory diagnosis has helped the veterinary services of Burundi to develop and maintain safe, effective, and efficient animal health management systems. The IAEA, in partnership with the FAO, assisted Burundi to upgrade the capacity of the national veterinary laboratory, and several technicians were trained in laboratory diagnostics, laboratory management and epidemiology. During the first outbreak of Peste des petits ruminants (PPR) in Burundi in 2017, the laboratory was able to analyse more than 4000 samples in two weeks for post vaccination sero-monitoring.

Food Safety

Livestock farming is a major component of dryland agriculture. Serving as a global 'food basket', drylands are climate change hotspots, suffering not only from water scarcity but also a range of endemic and emerging pests and diseases. Crops in drylands are infested by over 1000 insect species that are believed to cause 50 to 100% of pre- and post-harvest food losses [9]. The use of agrochemicals to control these pests and associated diseases in both crops and animals has become inevitable, yet these chemicals leave residues that are of consumer and trade concern.

In drylands, livestock production suffers from feed scarcity and seasonality which is exacerbated by climate change. Feeds are prone to fungal growth and therefore to contamination with mycotoxins [10]. For instance, the fungus Aspergillus proliferates in hot, dry and humid conditions and can result in the contamination of ingredients used in animal feed with aflatoxins. The carcinogenic aflatoxin B1 in feed is excreted as aflatoxin M1, another carcinogen, in milk for human consumption.

Certain poisonous plants may be the only source of feed for livestock in harsh environmental conditions. The toxins in these plants may also be excreted in milk for human consumption and are therefore another food safety concern in drylands.

Further, livestock in drylands largely drink from water points that may be exposed to a range of toxins including minerals whose concentrations are higher in drought. Such toxins are also of concern to consumers and need to be controlled. Consumer practices also contribute to food safety risks. During food shortages or as a cultural practice, inhabitants of drylands may consume wild foods that could have health implications [11] since information on their safety is limited.

While drylands may be a 'food basket' for many parts of the world, accessing global markets with their products can be challenging since these markets are highly regulated and subject to safety and quality control requirements not favorable to poor dryland producers [12].

The IAEA, in partnership with the FAO, is assisting more than 30 countries in Africa to establish food safety laboratories using a range of traditional and innovative nuclear and isotopic techniques. These techniques are used to test and control chemical hazards and promote market access. The techniques include stable isotope dilution assays, radio-immunoassays, radio-receptor binding assays and stable isotope ratio measurements, among others. Testing laboratories contribute to the generation of data on the scope of existing and emerging or unknown contaminants.

Packing house: Workers at a facility in South Africa sorting and packing healthy oranges, destined for export markets in the Northern America, Europe, Asia and Africa. (Photo: Miklos Gaspar/IAEA)

Enhanced food safety capabilities in Burkina Faso

The mission of Burkina Faso's National Public Health Laboratory (LNSP) is to ensure the safety and quality of domestic, imported and exported food. Mycotoxin contamination in cereals and livestock products is a challenge to food safety. Mycotoxins can create serious health risks in humans and animals and hinder trade in food commodities. Changing climatic conditions are increasing the growth of the fungal species that produce mycotoxins in food and animal feed. The IAEA and FAO have assisted LNSP in the set-up of a mycotoxin analytical laboratory, enabling the analysis of thousands of food samples annually by trained local experts. This has contributed to the protection of public health through the systematic control of domestic produce and products for export as well as imported food. The mycotoxin laboratory also serves as a platform for training students from universities in Burkina Faso and in the subregion.

03

SCALING UP

3. Scaling Up

A host of international and regional entities, as well as non-governmental organizations, are contributing to Africa's efforts to cope with the impacts of climate change. The IAEA's main regional partner is the AU with which it has Practical Arrangements. This agreement is aimed at "cooperating for the safe, secure and peaceful use of nuclear technologies for sustainable development in Africa, where the use of nuclear and nuclear-related techniques have a comparative advantage, or can supplement conventional technologies to meet the development objectives of the Member States of the African Union…". The thematic areas mentioned are human health and nutrition, food and agriculture, water and the environment, industrial applications of nuclear technology, energy planning and nuclear power infrastructure building, and radiation and nuclear safety and security.

One of the aspirations of the AU's 'Agenda 2063 – The Africa We Want', is "a prosperous Africa, based on inclusive growth and sustainable development". Some of the defined goals and priority areas are inextricably linked to climate change adaptation (see Table 1). Nuclear science and technology are playing an important role in each of these areas.

Goal	Priority areas
Modern agriculture for increased productivity and production	Agricultural productivity and production
Blue/ocean economy for accelerated economic growth	Marine resources and energy
Environmentally sustainable climate and resilient economies and communities	Biodiversity, conservation and sustainable natural resource management; Water security; Climate resilience and preparedness for natural disasters

Table 1: AU Agenda 2063 goals related to climate adaptation where nuclear science and technology is applicable.

The AU has initiated Africa's Climate Change and Resilient Development Strategy and Plan 2022–2032, which includes principles, priorities and action areas for enhanced climate cooperation, and long-term, climate-resilient development planning. The AU has also established the African Adaptation Initiative (AAI), a strategic plan to enhance action on adaptation, with the aim of addressing the adaptation financing gap and implementing measures to address disaster risk reduction and resilience needs in Africa. Over the next decade, the AAI will focus on assisting African countries to translate National Adaptation Plans into investment plans and will oversee the implementation of flagship programmes in the five African regions.

Supporting African countries on climate adaptation is at the heart of the efforts of an increasing number of bilateral and multilateral development partners aiming to mobilize resources, accelerate actions and support solutions through global, regional and national programmes. Within this context, the IAEA provides assistance to its Member States both in terms of raising awareness about the role those nuclear solutions can play alongside more conventional science and technology, as well as in building capacity to maximise and ensure the sustainability of results.

To do this, the IAEA avails itself of mechanisms such as Coordinated Research Projects, field projects in the framework of its TC Programme, in collaboration with the African Regional Cooperative Agreement for Research, Development and Training related to Nuclear Science and Technology (AFRA) network, and the establishment of partnerships with key stakeholders.

AFRA is an intergovernmental agreement established by African Member States, under the aegis of the IAEA, which aims to strengthen and enlarge the contribution of nuclear science and technology to the socio-economic development of the continent. Entered into force in 1990, AFRA provides a South-South cooperation framework that facilitate collaboration through programmes and projects focused on the specific shared needs of its State Parties.

Through the transfer of technology and the sharing of resources, knowledge and expertise among the participating countries, AFRA aims to create sustainable regional capabilities that, once developed, are expected to lead to further regional cooperation. Examples of AFRA activities related to climate adaptation include the 'Training Course on Best Soil, Nutrient and Water Management Practices for Cassava Using Isotopic and Related Techniques', which is designed to build capacity in the use of isotope and related conventional techniques for improving soil fertility management and enhancing climate change resilience under cassava production systems in Sub-Saharan Africa.

Practical Arrangements and Memoranda of Understanding are modalities utilized by the IAEA to establish collaborative frameworks targeting specific themes and geographic areas. For instance, the Practical Arrangements signed by the IAEA with the African Union Commission (AUC) establish a partnership that aims to enhance cooperation in the areas of food and agriculture, water and the environment, among other issues. The scope of the IAEA–AUC partnership includes the provision of assistance for the development of national and regional capacity to support activities of common interest, the development, application and validation of research methods to address technical gaps and bottlenecks, and support for the mainstreaming of science and technology for development.

Scaling up IAEA support in relation to climate change in Africa does not start from zero: still, while the scientific community is generally well aware of the potential of nuclear science and technology for climate adaptation, decision-makers, and the broader development and financing communities, are not always. As a consequence, the contribution of nuclear science and technology to climate adaptation solutions rarely features in the Nationally Determined Contributions, National Adaptation Plans or other national plans and programmes such as agrifood strategies and disaster risk reduction strategies.

The IAEA stands ready to continue supporting its Members States in Africa in identifying meaningful partnerships for mainstreaming nuclear science and technologies into national policies and programmes; for achieving the SDGs and for the implementing the Paris Agreement in all areas of vital importance for the continent, such as sustainable land use, climate-smart agriculture, food production systems, analysis of GHG emissions, water management, ocean and coastal protection.

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