The role of nuclear techniques in climate-smart agriculture

By Christoph Müller

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Our current challenge in agriculture is to increase production to feed a growing human population, while keeping environmental costs to a minimum. Climate-smart agriculture (CSA) refers to those agricultural systems that are highly productive and have low environmental footprints. These systems' management options enhance the transfer of atmospheric carbon, or carbon dioxide, to the soil for long-term storage, limiting the emission of greenhouse gases (GHGs) to the atmosphere.

The tricky part, however, is that these systems' productivity is not solely dependent on absolute carbon content. It also depends on the ratio of carbon to all other essential nutrients that plants need for growth. Therefore, the key to sustainable CSA systems is to ensure appropriate management of nutrients — in particular, nitrogen.

Through the groundbreaking 19th-century discoveries of Justus Liebig and others, it became known that plants take up nitrogen predominantly in mineral form. This discovery led to the development of chemical fertilizer strategies and, ultimately, to the "green revolution" — a set of technology transfer methodologies that led to increased agricultural production worldwide and helped to feed an ever-increasing population, especially in developing countries in the 1960s.

But this progress came with a side-effect. Plants started to take up more nitrogen, and so did the microbes. It is the uptake by these microbes that is chiefly responsible for the 25% increase in atmospheric nitrous oxide (N_2O) levels. Nitrous oxide not only has climate warming potential, but it is also an effective ozone-depleting gas with an atmospheric lifetime of over 100 years.

The challenge in CSA systems is to decouple synthetic fertilizer application from population growth: to feed people without adding more nitrogen. One way to do so is to supply nitrogen to the plants by converting unavailable nitrogen stored in soil organic matter into available nitrogen, for example, ammonium, nitrate or plant-available organic substrates. The effectiveness of this nitrogen use in agricultural systems can be evaluated with something called nitrogen use efficiency: the ratio between nitrogen input and nitrogen harvested in the plant.

CSA systems strengthen the capacity of the soil to store nutrients and water through management options that increase soil organic matter content, making soil resilient to climate change. This increase in soil fertility will, in the long term, increase the capacity of the soil to supply nitrogen internally. By taking into account soil-borne nitrogen supply, less fertilizer can be applied and nitrogen use efficiency enhanced.

Where nuclear comes in

The effect of agricultural practices on carbon storage and internal nitrogen supply dynamics can only be assessed and quantified with nuclear and isotopic techniques using nitrogen-15 and other isotopes. With nitrogen-15, it is possible to quantify the supply of nitrogen originating from various inputs, including fertilizer and soils. The technique also allows scientists to identify

The role of the IAEA in climate-smart agriculture

The IAEA, in cooperation with the Food and Agriculture Organization of the United Nations (FAO), helps Member States apply nuclear and related techniques to sustainably increase agricultural productivity, adapt and build resilience of agricultural and food security systems to climate change, and reduce greenhouse gas emissions in agriculture, taking into account national and local specificities and priorities.

which legume crops best capture atmospheric nitrogen through biological nitrogen fixation, improving soil fertility and enhancing soil quality and health.

It is important to evaluate CSA techniques that aim to reduce emissions of greenhouse gases such as N_2O. With the help of nitrogen-15 or oxygen-18 labelling techniques, it is possible to identify and quantify the exact source of N_2O production. This enables researchers and land users to opt for proper mitigation strategies to reduce its emission. One other way of reducing N_2O emissions is to enhance the conversion of N_2O to environmentally benign N_2 through management options that optimize the carbon supply or increase the pH of the soil. One way or the other, it is essential to measure both the N_2O and N_2 emissions. To quantify N_2 emissions from soil, the only method available is based on the nitrogen-15 labelling of nitrate.

Nuclear techniques play an essential role in evaluating the management options used in CSA. Basic scientific methods related to the use of nuclear techniques enable scientists to quantify the effects that management options have on the dynamics of nitrogen in plant-soil-atmosphere systems. We often find that nuclear techniques are the only option for evaluating CSA practices, in terms of both the effect on carbon storage in soil and the processes that are responsible for the release of climate-relevant gases.

Nuclear techniques play an essential role in evaluating options used in climate-smart agriculture. Here, Christoph Müller is leading a group of experts from IAEA Member States in the analysis of the nitrogen content of the soil in a field study.

(Photo: IAEA)