(Photo: FAO)

Fertilizer and an atomic balancing act to increase productivity and protect the environment

By Nathalie Mikhailova

When it comes to fertilizer, balance is critical: with the right amount at the right time, crops can flourish to help feed the world's growing population, but too much can cripple plants, pollute soil and water, and perpetuate global warming. So how do you strike the right balance? One way is with the help of isotopic techniques to optimize fertilizer use and tackle its impact as an agro-contaminant and source of greenhouse gas emissions.

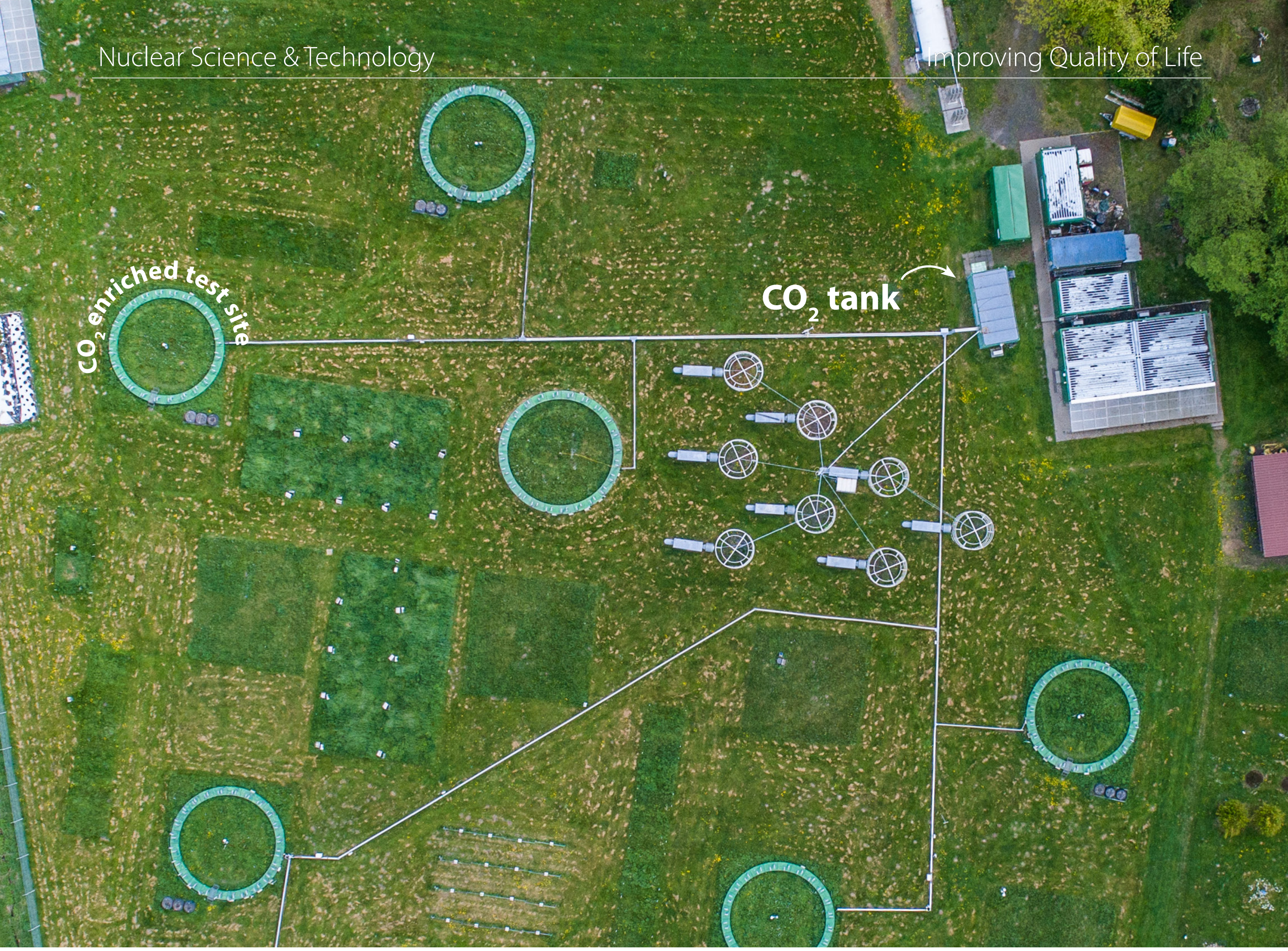
Helping farmers while cutting greenhouse gas emissions

"There are more mouths to feed worldwide than ever before, but the answer is not more fertilizer — the overuse of fertilizer is a big part of why the agriculture sector has gradually become one of the major sources of greenhouse gases over the last 70 years," said Christoph Müller, a soil and plant expert at the Institute of Plant Ecology, Justus Liebig University Giessen in Germany and at the School of Biology and Environmental Science at University College Dublin.
In 2014, the agriculture sector, including forestry and other land use, accounted for 24% of global greenhouse gas emissions, according to the Food and Agriculture Organization of the United Nations (FAO).

"We need to protect the environment while helping farmers, but to do that, we first need a detailed understanding of how fertilizers interact with soil and crops, and at what point they release greenhouse gases," said Müller. "Nuclear techniques can help us get those details and find sustainable ways to grow more food while minimizing the environmental impact."

As plants and soil convert fertilizer into useful nutrients, some of the by-products are greenhouse gases: carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). With the right amount of fertilizer, plants thrive and minimal greenhouse gases are released.

> "Nuclear techniques can help us . . . find sustainable ways to grow more food while minimizing the environmental impact."
>
> *—Christoph Müller, soil and plant expert, Institute of Plant Ecology, Justus Liebig University Giessen, Germany*



The Free-Air CO_2 Enrichment (FACE) experiment pumps CO_2 enriched air into several test sites through rings of pipes to simulate atmospheric CO_2 conditions over typical grassland expected by the middle of this century.

(Photo: C. Müller/Justus Liebig University Giessen)

However, when there is too much fertilizer for plants to process and a surplus is left in the soil, it causes an exponential increase in emissions.

Müller and scientists from nine countries along with experts from the IAEA, in partnership with the FAO, are tracking isotopes to understand the link between fertilizer, crops, soil and greenhouse gas emissions (see The Science box). These techniques are also being used as part of a Free-Air CO_2 Enrichment (FACE) experiment, which is helping scientists to study how crop quality and fertilizer needs can be affected by the higher levels of CO_2 in the atmosphere associated with climate change. The findings of their isotopic studies will be used to develop guidelines to help reduce fertilizer use in agriculture, without compromising crop quality and yield.

Their research results have already revealed ways to optimize fertilizer use on an area of over 100 hectares with pasture and rice, maize and wheat crops: greenhouse gas emissions were reduced by 50% and crop yields increased by 10%.

"We have also seen in our FACE experiment that plants are growing more, but their quality is changing," said Müller. FACE is a large-scale climate change facility under natural conditions. The test site in Giessen, Germany is one of the longest running studies of this kind simulating the atmospheric CO_2 conditions over typical grassland expected by the middle of this century.

Plants grown in these high CO_2 conditions become tougher and their protein content drops. As cows graze on these plants, their stomachs have to work harder and they have to eat more to extract enough nutrients to produce milk. This not only jeopardizes milk production but also causes the cows to emit more methane — a greenhouse gas 34 times more potent than CO_2.

Finding fertilizer in drinking water and beyond

Alongside contributing to greenhouse gas emissions, excess fertilizer is often washed away into rivers and streams by rain or melting snow, ending up in the ocean and drinking water supplies.

"Agro-contaminants can make water undrinkable and harm aquatic ecosystems and biodiversity," said Lee Heng, Head of the Soil and Water Management and Crop Nutrition Section at the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture. "The nutrients in fertilizer, for example, encourage algae growth, which lowers oxygen levels in water and harms fish and aquatic life."

Fertilizers are one of several agricultural chemicals that contaminate the environment. Others include pesticides, salt from irrigation, sediments and drug residues from livestock. The use of these substances is rising as food producers seek ways to increase food production while combating the effects of climate change, said Heng.

Scientists from 15 countries are working with experts from the Joint FAO/IAEA Division to track multiple stable isotopes to analyse agro-contaminants, their origins, and movement (see The Science box).These techniques will form a toolkit for identifying agro-contaminant sources and developing innovative sustainable practices to counteract their overuse and impact on the environment.

For over 20 years, scientists have used single isotopes to identify agro-contaminants, but using one isotope at a time does not provide enough information to distinguish between different contaminants and their distinctive isotopic signatures.

"Analysing multiple isotopes allows for a more complete picture of the relative contribution of each chemical from each source, so scientists can know which approach to take to deal with contaminants in fields and across landscapes," Heng said.

Algae grow in the Danube Delta by feeding on nutrients in fertilizer contaminating the water.

(Photo: Joint FAO/IAEA Division)

THE SCIENCE

Stable isotope techniques

Isotopes are atoms of the same element with the same number of protons, but a different number of neutrons, resulting in a different atomic weight. For example, nitrogen-15 has the same chemical behaviour as nitrogen-14, but has one more neutron, making it heavier. Scientists can use this to understand and trace how isotopes transform, as well as their flow paths and exchanges with plants, soil and water bodies.

Scientists use nitrogen-15 and carbon-13 to trace the movement and origin of nitrous oxide, methane and carbon dioxide emissions in agriculture. By using fertilizers labelled with nitrogen-15 isotopes, scientists can track the isotopes and determine how effectively fertilizer is taken up by the crops and how much is leftover. Carbon-13 is tracked to determine the movement and origin of carbon dioxide and methane.

Multiple isotope analysis

Scientists use stable isotopes of carbon, hydrogen, nitrogen, oxygen, and sulphur to track agro-contaminants, including their origin and movement from soil to water bodies. These isotopes are used because fertilizers and pesticides contain nitrogen, sulphur and carbon, which are dissolved and transported by water, which contains oxygen and hydrogen isotopes. The isotopes are simultaneously measured to distinguish between the water and pollution cycles and to better understand where contaminants are coming from and where they are going.