Adaptation to climate change and increasing CO₂ in rice

Improving yield response in rice under increasing atmospheric carbon dioxide (CO₂) concentrations will help this crop adapt to the changing climate. Dr Toshihiro Hasegawa, a plant physiologist at Tohoku Agricultural Research Center in Japan, studies the effects of climate change on rice yield and quality. The FACE (free-air CO₂ enrichment) platform provides experimental facilities under open-field conditions for modelling how future paddy ecosystems could respond to conditions caused by climate change. The need for better-adapted varieties of rice and improved management of nitrogen inputs and methane emissions in rice cultivation are also considered.

Rice (Oryza sativa L.) feeds about half the world’s population and the demand for it and other staple crops continues to increase. However, the rate of yield increase in these crops has been slowing and even plateauing in recent decades. Efforts to improve yield projections are needed in the face of rapidly changing and often adverse climate conditions.

Atmospheric CO₂ concentrations (CO₂) are rising at an unprecedented rate and, along with other greenhouse gases, this is causing environmental changes such as global heating that negatively affect the productivity of important crops, including rice. In addition, the nutritional value and appearance of edible crop parts are proving to be vulnerable to degradation under elevated CO₂.

However, increasing CO₂ also has the potential to have a direct positive effect on crop photosynthesis and thereby on grain yield – a phenomenon known as CO₂ fertilisation. A physiological understanding of how rice responds to elevated CO₂ and how this might vary genetically and with factors such as temperature, water and nitrogen inputs is essential.

**PHOTOSYNTHETIC PERFORMANCE AND YIELD IN RELATION TO NITROGEN APPLICATION**

How well a plant grows depends on it acquiring raw materials (carbon fixation and mineral uptake), allocating materials to plant organs and coping with a variety of changing environmental stresses. Photosynthetic CO₂ fixation is the most important process for plant biomass production. In addition, mineral nutrition, although contributing less to biomass, is essential for plant growth.

The historical increases seen in crop yields have depended on large inputs of nitrogen (N) fertiliser. In rice, achieving high yields requires an increase in grain number and a high proportion of ripened grains, both of which have been helped by N application. In contrast, single grain weight in rice has been found to be genetically constant irrespective of N application and growth environments.

A plant can be functionally divided into what is known as ‘source’ and ‘sink’, where source refers to the parts where CO₂ fixation (photosynthesis) occurs and sink to the sites where assimilates are stored or used. To substantially enhance yield in rice, its source capacity must be improved genetically.

Improving source capacity might also help reduce the added N required for a high yield.

Nitrogen is known to be a key element mediating plant responses to elevated CO₂ and is often a limiting factor in enhancing photosynthesis, biomass production and yield. Meanwhile, reducing the need for fertiliser amendments is important since applied N can have harmful environmental effects owing to emission of nitrous oxide (N₂O) and contamination of groundwater.

**STUDYING [CO₂] RESPONSIVENESS OF RICE CULTIVARS IN THE FIELD**

A technology known as Free-air CO₂ enrichment (FACE) is a reliable way of comparing CO₂ responsiveness for different rice cultivars in open fields. It was originally developed in the USA in the late 1980s and then modified for rice paddies in Japan in the late 1990s. Hasegawa and colleagues used FACE to demonstrate, for example, that yield enhancement ranged widely from 3% to 36% among eight cultivars when exposed to CO₂.

Other FACE experiments found that yield enhancement under elevated CO₂ decreased when N application levels. In contrast, single grain weight in rice has been found to be genetically constant irrespective of N application and growth environments.

In addition, elevated CO₂ is known to reduce grain appearance and quality in rice, and this is exacerbated by increases in temperature. The severity of grain quality degradation under elevated CO₂ was found to be both cultivar dependent and N dependent; however, the combined effects of N and CO₂ needed further investigation.

Hasegawa and colleagues studied two cultivars with contrasting yield potential and grain appearance. Takanari, a high-yielding indica cultivar was identified as a candidate for high productivity under elevated CO₂. For comparison, they chose a japonica cultivar Koshihikari, the main rice cultivar grown in Japan for over 50 years.

Takanari has several favourable traits under elevated CO₂, including greater photosynthetic capacity, biomass and grain yield and better grain appearance, with little increase in water use when compared to Koshihikari. To make full use of the superior traits of Takanari, the researchers wanted to determine how N levels and temperature influence the yield response of this cultivar under atmospheric CO₂.

They then set up a second FACE site at Tsukuba about 430 km south of Shizuksui. The two sites differ in temperature conditions: the average growing-season air temperature being much warmer at Tsukuba than at Shizuksui. FACE experiments were conducted for many growing seasons and three different N levels to ensure that the desired varietal traits could be repeated under different conditions.

Free-air CO₂ enrichment (FACE) is a reliable way of comparing CO₂ responsiveness for different rice cultivars in open fields.
These results indicate that Takanari may occur in Takanari even without N fertiliser applications, under elevated [CO2].

In two growing seasons, they found that CH4 emissions increased by ~60% due to the combined effects of elevated [CO2] and warming. It appears that higher rates of photosynthesis led to greater release of organic compounds from rice plant roots into the surrounding environment, which then acted as substrates for methane production. Further assessment of the extent of this harmful effect is needed.

VARIATION AMONG RICE MODELS IN YIELD RESPONSE TO CO2

Two types of experimental facilities have been exploited to determine the effects of elevated [CO2] on rice traits: small-scale growth enclosures or chambers and (more realistic) large-scale field environments using FACE. The experimentally observed CO2 enhancement effects on yield and plant traits differ between FACE and enclosed chambers, suggesting uncertainty in the observations.

Hasegawa’s studies using data from Japan, China and USA confirmed variation in yield prediction in response to elevated [CO2] among rice crop models that was greater than the experimental variation observed. Testing multiple models against multiple sources of experimental results in different locations remains desirable and improvements in the rice models are still needed.

Since the land available for rice planting is likely to decrease in the future, the drive to increase rice productivity by all available means continues to be urgent. In addition, ongoing efforts to determine the traits that can confer better adaptability to elevated [CO2] will be crucial for genetic improvement of rice productivity under challenging climate conditions.

References