Adaptation to climate change and increasing CO_2 in rice

Improving yield response in rice under increasing atmospheric carbon dioxide (CO_2) 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 CO_2 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 CO_2 concentrations ([CO_2]) 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 [CO_2].

However, increasing [CO_2] also has the potential to have a direct positive effect on crop photosynthesis and thereby on grain yield – a phenomenon known as CO_2 fertilisation. A physiological understanding of how rice responds to elevated [CO_2] and how this might vary genetically and with factors such as temperature, water and nitrogen inputs is essential.

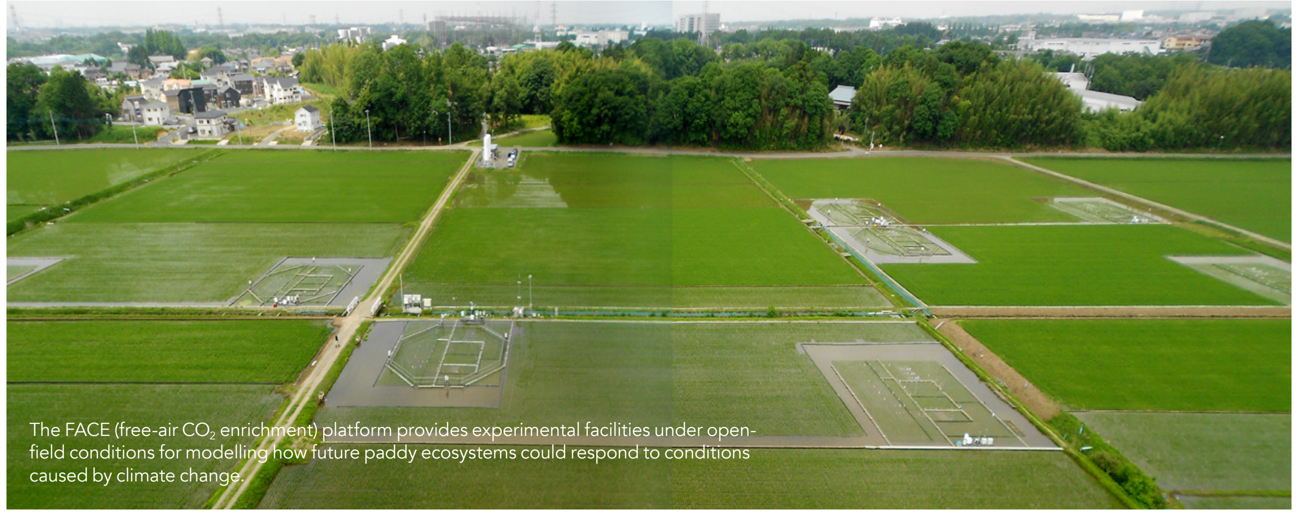
PHOTOSYNTHETIC PERFORMANCE AND YIELD IN RELATION TO NITROGEN APPLICATION

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 CO_2 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 CO_2 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 [CO_2] 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 (N_2O) and contamination of groundwater.



The FACE (free-air CO_2 enrichment) platform provides experimental facilities under open-field conditions for modelling how future paddy ecosystems could respond to conditions caused by climate change.

STUDYING [CO_2] RESPONSIVENESS OF RICE CULTIVARS IN THE FIELD

A technology known as Free-air CO_2 enrichment (FACE) has proven to be a reliable way of comparing [CO_2] 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 [CO_2].

Other FACE experiments found that yield enhancement under elevated [CO_2] decreased when N application was low (<80 kg/ha). To design future N management regimes for contrasting rice cultivars, Hasegawa and colleagues set out to compare field-level responses to elevated [CO_2] under different N application levels.

In addition, elevated [CO_2] is known to reduce grain appearance quality in rice, and this is exacerbated by increases in temperature. The severity of grain quality degradation under elevated [CO_2] was found to be both cultivar dependent and N dependent; however, the combined effects of N and [CO_2] needed further investigation.

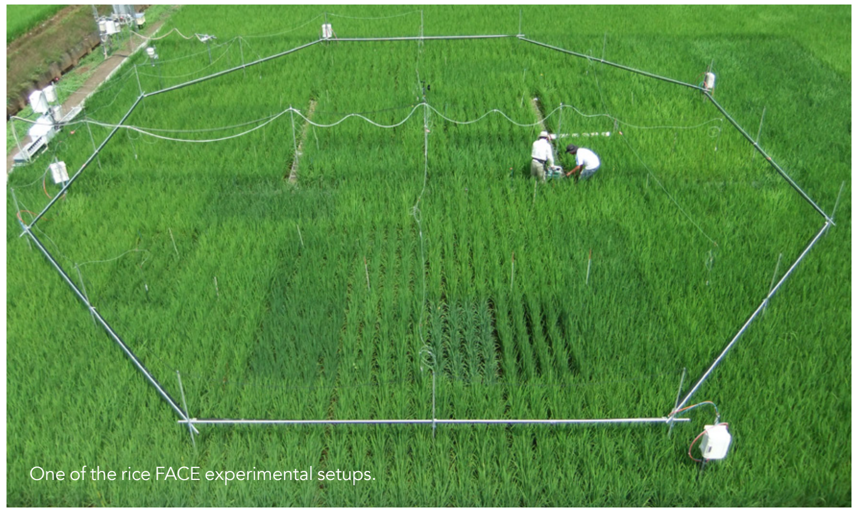
Hasegawa and colleagues studied two cultivars with contrasting yield potential and grain appearance. Takanari, a high-yielding indica cultivar was identified as a candidate for high productivity under elevated [CO_2]. For comparison, they chose a japonica cultivar Koshihikari, the main rice cultivar grown in Japan for over 50 years.

Free-air CO_2 enrichment (FACE) is a reliable way of comparing [CO_2] responsiveness for different rice cultivars in open fields.

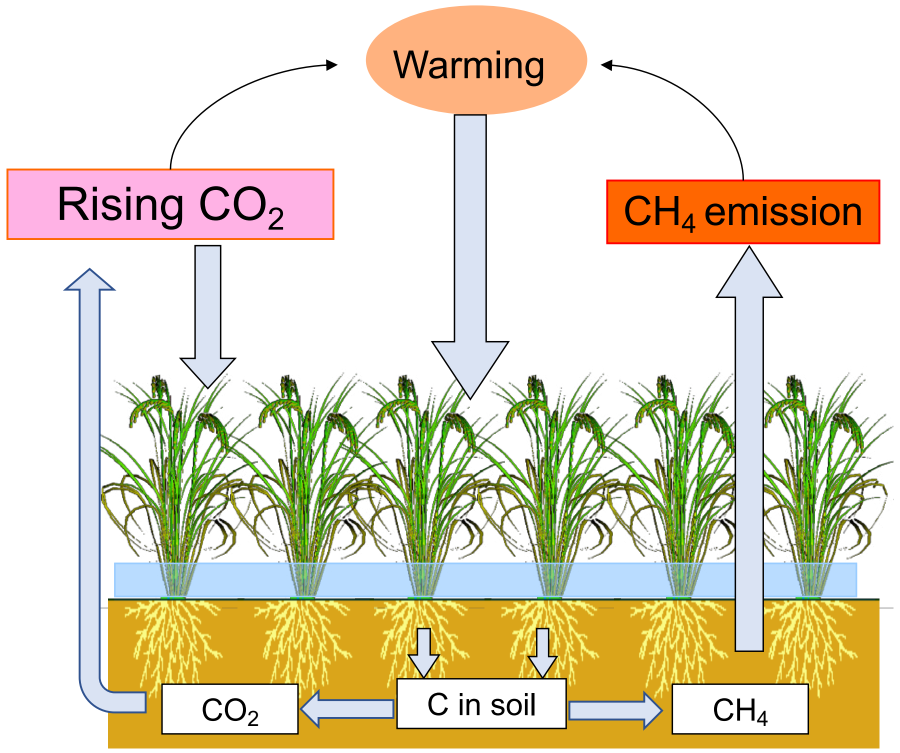
Takanari has several favourable traits under elevated [CO_2], including greater photosynthetic capacity, biomass and grain yield and better grain appearance, with little increase in water use when compared to Koshihikari. To make full use of the superior traits of Takanari, the researchers wanted to determine how N levels and temperature influence the yield response of this cultivar under atmospheric [CO_2].

They had conducted a series of rice FACE experiments in Shizukuishi in northern Japan, to find out how temperate rice crops grown in cold climates responded to high [CO_2]. The results showed variation in grain yield enhancement due to elevated [CO_2] among genotypes, N regimes and years tested under cool climates.

They then set up a second FACE site at Tsukuba about 430 km south of Shizukuishi. The two sites differ in temperature conditions: the average growing-season air temperature being much warmer at Tsukuba than at Shizukuishi. 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.



One of the rice FACE experimental setups.



The relationship between climate change, rising temperatures and rice production is complex.

The biomass of both cultivars increased under raised [CO_2] at all N levels. However, the harvest index (the ratio of grain yield to above-ground biomass) decreased under elevated [CO_2] in the N-limited treatment for Koshihikari but this was not so for Takanari. Even without N application, Takanari showed an average 18% yield enhancement over the three years of the study whereas no yield increase was observed for Koshihikari.

Rice cultivar Takanari is a useful genetic resource for improving N-use efficiency under elevated [CO_2].

In addition, grain appearance in Koshihikari was badly affected by elevated [CO_2], especially in N-limited and hot conditions. Again, this did not occur in Takanari even without N fertiliser. These results indicate that Takanari may well be a useful genetic resource for improving N-use efficiency, i.e., reducing N applications, under elevated [CO_2].

ELEVATED ATMOSPHERIC [CO_2] AFFECTS NUTRITIONAL VALUE IN RICE

A meta-analysis (a statistical analysis that combines the results of many scientific studies) using data from 143 comparisons of six different food crops grown at seven different FACE experimental locations in Japan (by Hasegawa's team) and in Australia and the United States found that elevated [CO_2] was also associated with significant decreases in zinc, iron and protein content.

The effects of elevated [CO_2] on zinc and iron content in fact showed great variation across different rice cultivars. This suggests that there is scope for breeding rice cultivars whose micronutrient levels are less vulnerable to increasing [CO_2]. Unfortunately, there are likely to be trade-offs in yield and other performance characteristics when breeding for increased nutritional value.

METHANE (CH_4) EMISSION IN RICE CULTIVATION

Although paddy fields act as a carbon cycling interface between atmosphere and land, they also produce the harmful greenhouse gas methane (CH_4). Hasegawa and colleagues have used FACE to study the effects of high [CO_2] and elevated soil temperature (heat stress) on CH_4 emissions under open-field conditions in Japan.

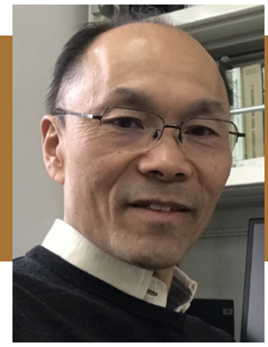
In two growing seasons, they found that CH_4 emissions increased by ~80% due to the combined effects of elevated [CO_2] and warming. It appears that higher rates of photosynthesis led to greater release of organic compounds from rice plant roots into the surrounding environment, which then acted as substrates for methane production. Further assessment of the extent of this harmful effect is needed.

VARIATION AMONG RICE MODELS IN YIELD RESPONSE TO CO_2

Two types of experimental facilities have been exploited to determine the effects of elevated [CO_2] on plant traits: small-scale growth enclosures or chambers and (more realistic) large-scale field environments using FACE. The experimentally observed CO_2 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 [CO_2] 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 [CO_2] will be crucial for genetic improvement of rice productivity under challenging climate conditions.



Behind the Research

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Research Objectives

Dr Hasegawa's work using the FACE platform aims to understand the effects that a global increase in CO_2 levels could have on rice yield and quality.

Detail

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Bio

Dr Hasegawa is a crop physiologist specialised in crop environmental response. His current research mainly focuses on rice yield and quality under global change, using the FACE experimental facilities and crop modelling. He is a Coordinating Lead Author of the IPCC 6th assessment report and is leader of the AgMIP (Agricultural Model Intercomparison and Improvement Project) rice team.

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Collaborators

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Personal Response

Your work is being extended through international collaborations. How important are these to your research?

" Global climate change is borderless. Its effects on crops appear as a result of multiple processes and differ among regions and cropping systems. International and multi-disciplinary research collaborations are indispensable in evaluating the impacts and developing technologies for adaptation to and mitigation of climate change. The FACE experimental platforms in different regions together with modelling research are the key drivers to enhance our study. "

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