주제-04

Strategies for Improving Crop Productivity under a Changing Climate: A Case Study in Japan

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In Japan, food supply per capita per day has been stable around 2600kcal after 1961 to now, in contrast with a rapid increase in Korea (from 2100 to 3300kcal) and China (from 1500 to 3000kcal) (Fig.1). Although the percentage of rice accounts for food supply has getting decrease in the past few decades it is still a fundamental food for Japanese.

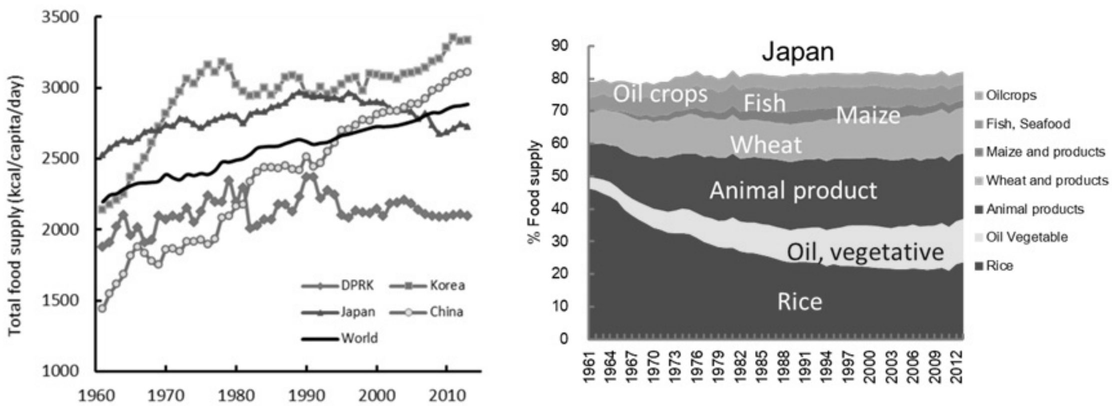

Fig. 1. Food supply per person (kcal/capita/day) and the contributions in Japan.
(FAOstat)

Japan consists of four major islands, Hokkaido, Honshu, Shikoku and Kyushu, latitude from 45°N31' to 20°N25', altitude from 0 to 3776 m (Fig.2). Climate largely differ among locations in temperatures, precipitation, day-length, solar radiation. Here, I present four topics for seeing strategies for improving crop productivity under a changing climate, especially for rice of staple food.

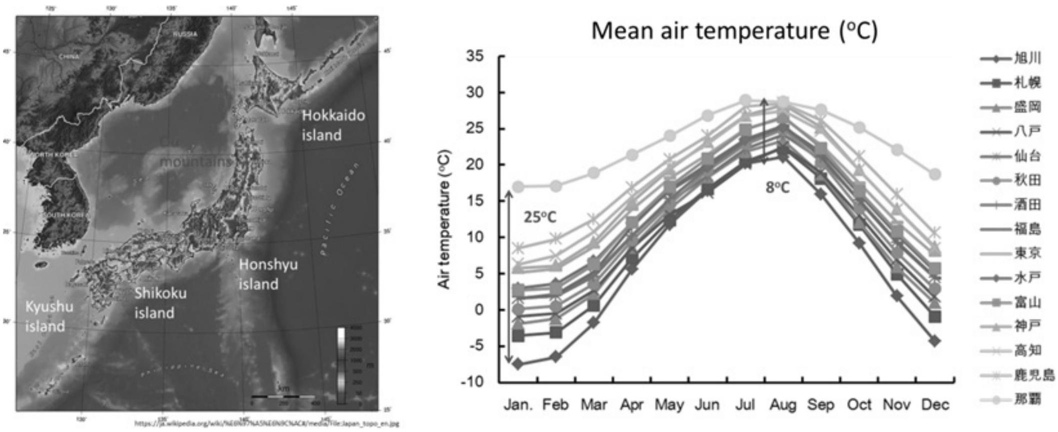

Fig.2. Map of Japan and diverse variation of air temperature.

Topic 1: Can global warming solve cold damage in rice?

Accurate prediction of rice yield under the future climate is a critical factor for future food security. I evaluated the impact of global warming on rice yield fluctuation especially in cool climates using (1) air temperature trend for the past 70 years and

(2) rice yield trend. Annual averaged air temperature has been rising at a rate of 0.2°C per 10 years, but the magnitude differed with season and locations (Fig. 3). The increase in air temperature in summer tended to be slight especially in the northern part of Japan. This is the main factor why we have been suffered from cold damage even under global warming.

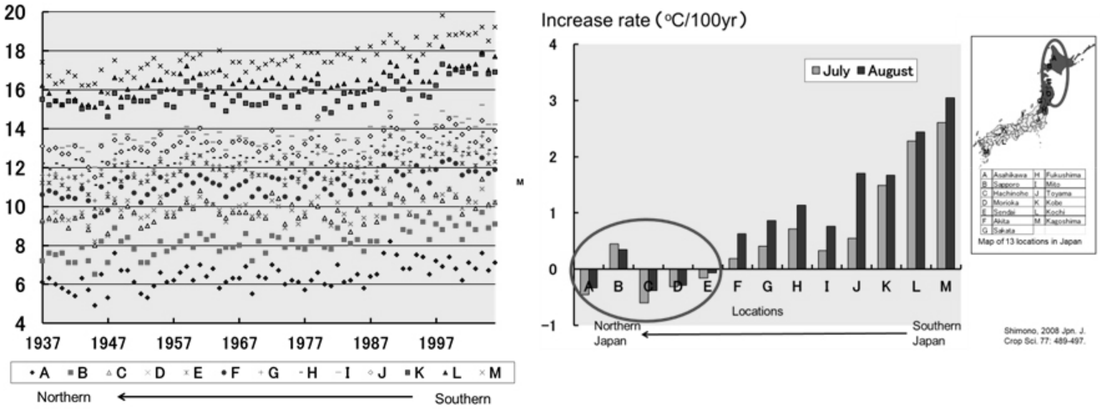

Fig. 3. Not uniformly increase of temperature among seasons and locations in Japan.
(Shimono, 2008, Jpn. J. Crop Sci.)

<u>Topic 2: How can we adapt the cropping schedule to on-going global warming in cool climates?</u>

Adaptation of cropping schedules in response to climate change is essential for increasing rice productivity. I analyzed yield, cropping schedule and cultivar characteristics records from 1958 to 2007 in a case study of four prefectures in northern Japan, where low temperatures can severely limit rice growth (Fig.4). The transplanting date became 0.07 to 0.91 days y^{-1} earlier before 1983, but did not appear to change thereafter. The growing period duration from transplanting to harvesting increased over time, especially during the first 25 years. The length of the potential growing period, defined as the period from the earliest potential date for transplanting and the latest potential date for harvesting, increased over time in all four prefectures. The gap between the actual growing period and the potential growing period increased after 1983. The safe reproductive period, which is defined as the duration within which rice can escape cold damage during its reproductive stage, did not appear to change over time. Based on these results, we discuss future cropping schedules capable of increasing rice productivity under a changing climate in the future.

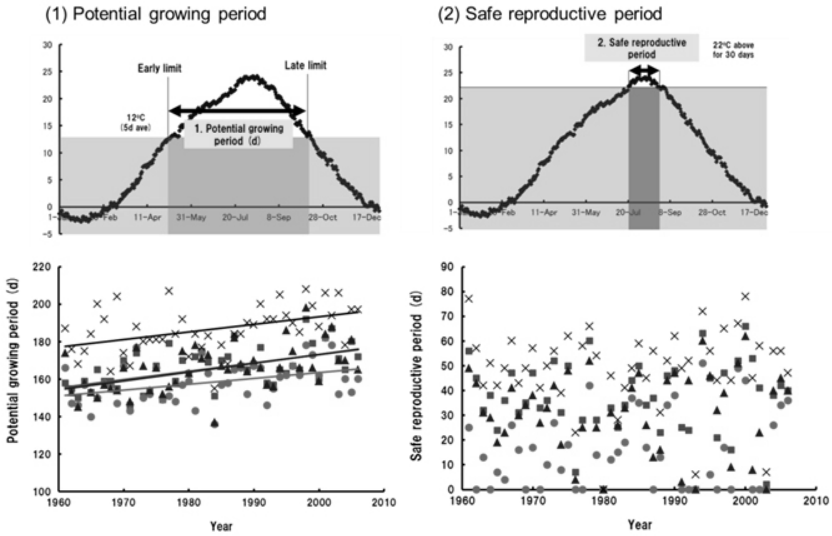

Fig. 4. Potential growing period has been extending, but not for safe reproductive period.
(Shimono et al., 2010, Field Crops Res.)

Topic 3: Improvement of cold tolerance: Genetic or epigenetic ways?

In rice, chilling-induced male sterility increased when plants experienced low water temperature before panicle initiation (Fig. 5). The number of mature pollen grains after chilling at the booting stage was only approximately 45% of total pollen grains in low-T_w plants, whereas it was approximately 71% in normal-T_w plants (T_w not controlled; approximately 23 °C under air temperature of 26 °C/21 °C, day/night). Microarray and quantitative PCR analyses showed that many stress-responsive genes (including *OsFKBP65* and genes encoding a large heat shock protein OsHSP90.1, heat shock factors, and many small heat shock proteins) were strongly up-regulated by chilling in normal-T_w spikelets, but were not or rather down-regulated by chilling in low T_w spikelets. *OsAPX2* and genes encoding some other antioxidative enzymes were also significantly down-regulated by low T_w in the chilled spikelets. In low-T_w plants, lipid peroxidation products (malondialdehyde equivalents) were significantly increased in the spikelets after chilling, and ascorbate peroxidase activity in the chilled spikelets was significantly lower than that in normal-T_w plants. Our data suggest that an *OsFKBP65*-related chilling response, which protects proteins from oxidative damage, is indispensable for chilling tolerance but is lost in low-T_w spikelets.

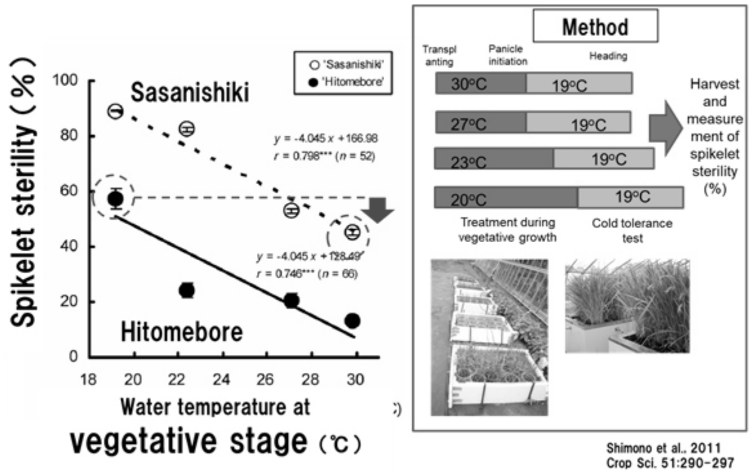

Fig. 5. Epigenetic control of cold tolerance in rice.
(Shimono et al. 2011; Suzuki et al.,2015, Plant Cell & Environ.)

Topic 4: Adaptation to future elevated CO_2

Phenotypic plasticity of plants in response to environmental changes is important for adapting to changing climate. Less attention has been paid to exploring the advantages of phenotypic plasticity in resource-rich environments to enhance the productivity of agricultural crops. Here, we examined genetic variation in phenotypic plasticity in *indica* rice across two diverse panels: (i) a Phenomics of Rice Adaptation and Yield (PRAY) population comprising 301 accessions and (ii) a Multi-parent-Advanced-Generation-Inter-Cross (MAGIC) *indica* population comprising 151 accessions. Altered planting density was used as a proxy for elevated atmospheric CO_2 response. Low planting density significantly increased panicle weight per plant compared with normal density, and the magnitude of the increase ranged from 1.10 to 2.78 times among accessions for the PRAY population and from 1.05 to 2.45 times for the MAGIC population. Genome-wide-association studies revealed three Environmental Responsiveness (ER) candidate alleles (qER1-3) that were associated with relative response of panicle weight to low density (Fig.6). Two of these alleles were tested in 13 genotypes to clarify their biomass responses during vegetative growth under elevated CO_2 in Japan. Our study provides evidence for polymorphisms that control rice phenotypic plasticity in environments with rich radiation and/or CO_2 conditions.

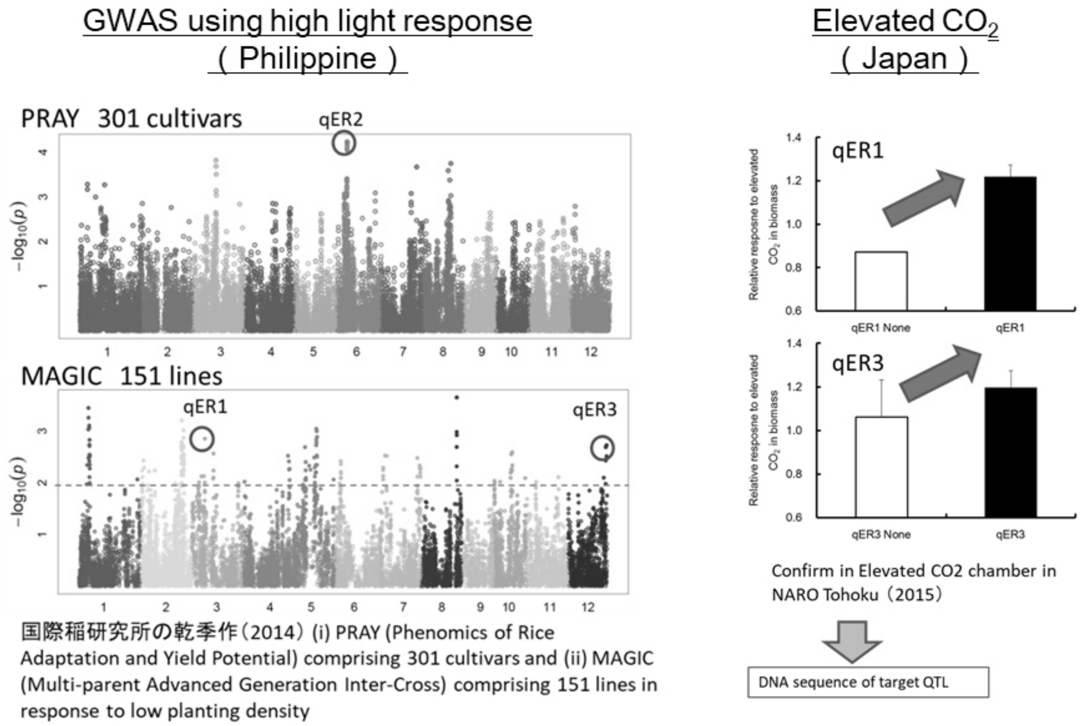

Fig. 6. Genome wide association mapping for elevated atmospheric CO_2 responsiveness in rice. (Kikuchi et al., 2017, Plant Cell & Environ.)

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