論文の内容の要旨

農学国際専攻

平成 23 年度博士課程　入学

氏　　　名　張　国友

指導教員名　小林　和彦

論文題名　Effects of elevated CO_2 concentration on grain yield and quality of rice (*Oryza sativa* L.)

（高 CO_2 濃度がイネの収量と品質に及ぼす影響）

Atmospheric concentration of carbon dioxide ([CO_2]) is projected to exceed 500 μmol mol^{-1} by 2050 (IPCC, 2007), when the world population will reach 9 billion or higher demanding a substantial increase in food production. Rice (*Oryza sativa* L.) is the most important food crop in the world, providing energy and nutrients for more than a half of the world's population. Despite the greater demand for rice production by the growing population, the grain yield increase had started to slow down the beginning of this century.

The elevated [CO_2] will stimulate grain yield of rice. The yield stimulations by elevated [CO_2] vary depending on field managements and rice cultivars. In order to maximize the beneficial effect of elevated [CO_2] on grain yield, we need to understand the mechanisms better, to develop suitable field management practices, and to select and breed better adapted cultivars. Despite the beneficial effects, elevated [CO_2] could deteriorate the grain quality, which is becoming more important as rice serves as a palatable food component more than just as the source of food energy. Therefore, in order to help the farmers to take advantages of elevated [CO_2] and provide the larger population in the future with sufficient amount and quality of rice, it's urgent to understand the mechanisms that elevated [CO_2] changes grain yield and quality of rice (**Chapter 1**).

Developing efficient field management practices which will fit the future environment may be one of the strategies to take the advantages of elevated [CO_2]. As the growth of rice depends on various environmental factors such as: water availability, air temperature and soil fertility, which may have interacting effects with elevated [CO_2] on rice. Understanding the interactions and the underlying mechanisms can help us to develop suitable management practices so that we can maximize the benefit from rising [CO_2]. Nitrogen fertilizer is one of the most important factors, affecting the grain yield and quality of rice, while studies on the interactions between nitrogen fertilization and elevated [CO_2] on rice have been limited. Therefore, I studied the interactive effects of elevated [CO_2] and nitrogen fertilization levels on the grain yield and quality of a japonica rice cultivar Koshihikari in a free-air CO_2 enrichment in Tsukuba Mirai city, Japan (**Chapter 2**).

Like previous studies, we found that nitrogen fertilizers regulated the effects of elevated [CO_2] on grain yield of rice. Rice gained larger yield stimulation by elevated [CO_2] under ample nitrogen condition than low nitrogen condition. Elevated [CO_2] increased the nitrogen fertilizer efficiency on grain yield stimulation. Elevated [CO_2] degraded the grain quality of rice in terms of increasing the occurrence of various types of chalky kernels, nitrogen fertilizer application failed to counteract the negative effects.

Chalkiness of rice grain is caused by loosely packed starch granules in the endosperm, which is closely related with the grain growth processes. And both grain yield and quality are tightly linked with the grain growth processes, which may be also affected by the elevated [CO_2] and nitrogen fertilizer application. The grain growth is not uniform among grains located at different positions within a panicle, inducing very large differences in grain weight and quality at maturity. Therefore, the responses of grain growth to elevated [CO_2] were compared between superior and inferior spikelets of a rice cultivar Koshihikari grown under different nitrogen fertilizer levels in the free-air CO_2 enrichment in Tsukuba Mirai **(Chapter 3)**.

The effects of elevated [CO_2] was only significant at ample nitrogen fertilizer level, in which the grain growth in inferior spikelets was significantly stimulated by elevated [CO_2], whereas the grain growth in superior spikelets was unaffected. At maturity, the grain weight of inferior spikelets was significantly increased by elevated [CO_2] while that of superior spikelets was unchanged. Elevated [CO_2] reduced the grain nitrogen of the superior spikelets, but did not increase the individual grain mass. Moreover, whereas the grain mass of inferior spikelets was significantly increased by elevated [CO_2], their grain nitrogen was not reduced. The results showed that when the source supply was increased by elevated [CO_2], especially under ample nitrogen fertilizer conditions, the grain filling of inferior spikelets was improved but not in superior spikelets which have a larger sink capacity than inferior spikelets.

Differential responses of carbon and nitrogen allocation to superior and inferior grains in response to elevated [CO_2] may be a part of the mechanisms that accounts for the grain protein reduction. The grain nitrogen reduction should be able to explain the increase of grain chalkiness. The increase of grain chalkiness should also be explained by alterations of source-sink interactions as shown in the disturbed grain growths.

These changes in rice grain growth, however, could vary greatly among cultivars that differ in panicle structures and sink capacity. The grain yield responses to elevated [CO_2] differ among rice cultivars, and a large sink capacity may be the trait that confers a greater yield advantage under elevated [CO_2]. The increased sink capacity can be achieved through changes in panicle structures for either greater grain size or a larger number of grains. The both traits had been found to be effective for achieving higher productivity in cultivars Akita 63, a large-grained japonica cultivar, and Takanari, an indica cultivar bearing numerous spikelets within a panicle. Both Akita 63 and Takanari had indeed shown greater yield enhancements under elevated [CO_2] than other cultivars. In order to better understand the grain growth response to elevated [CO_2] and resultant changes in the grain yield and quality, three rice cultivars: Koshihikari, Akita 63 and Takanari were subjected to the free-air CO_2 enrichment in the field (**Chapter 4**).

If elevated [CO_2] preferentially supports grain mass and nitrogen accumulation in inferior spikelet as shown in Koshihikari (**Chapter 3**), reduction in grain protein could be more pronounced in superior spikelet than in inferior spikelet. A cultivar having proportionately more inferior spikelets than Koshihikari with a larger number of secondary rachis branches, as seen in Takanari, could show larger increment of grain yield under elevated [CO_2], since the inferior spikelet exhibit the greater grain growth and less nitrogen reduction than the superior spikelets. To the contrary, the increment of grain yield in Akita 63 may be smaller and the grain nitrogen reduction in superior spikelet of Akita 63 may be not as great as that in Koshihikari, because Akita 63 bears fewer secondary spikelets. Thus, we hypothesised that elevated [CO_2] would increase the grain yield and degrade the grain quality of rice most in Takanari followed by Koshihikari and Akita 63 (**Chapter 4**). The results of the study conformed to the expected order of the cultivars in their changes of grain growth in inferior spikelet and grain nitrogen in superior spikelet, and the stimulation of the grain growth of inferior spikelet was indeed largest in Takanari. Nevertheless, the grain nitrogen degradation under elevated [CO_2] was less in Takanari than Koshihikari and Akita 63. Takanari being a high yielding cultivar with high nitrogen use efficiency showed the largest grain yield enhancement and smallest grain quality degradation pointing to a strategy of breeding for varieties better adapted to elevated [CO_2] in the future.

The above findings in the elevated [CO_2] effects on grain yield and quality of rice can be synthesized as follows (**Chapter 5**). Firstly, nitrogen applications will increase the yield stimulation by elevated [CO_2] but additional application of nitrogen fertilizer would not gain proportional yield enhancement. Secondly, nitrogen application cannot counteract the negative effects of elevated [CO_2] on grain quality of rice. This is probably caused by the low efficiency of conventional? nitrogen application in meeting the plant nitrogen demand under elevated [CO_2]. The plant nitrogen conditions may have to be improved by a greater nitrogen application after panicle initiation. Thirdly, the grain yield stimulation by elevated [CO_2] is mainly accomplished by the increment in spikelet number with the individual grain weight on the average across the entire spikelets being often unaffected. Nevertheless, the grain growth of inferior spikelets is enhanced by elevated [CO_2] with no change in that of superior grains, which may contribute to a greater yield enhancement. Fourthly, the enhanced grain growth of inferior spikelets is supported by allocating less nitrogen to superior grains, which caused the grain quality degradation in elevated [CO_2]. These insights may be used to design field management practices and rice cultivars that can take better advantages of elevated [CO_2] in the future. Ensuring the plant nitrogen conditions by extra nitrogen fertilizer application especially after panicle initiation may help rice to increase sink capacity to make use of the advantages of elevated [CO_2]. Rice grain yield will be increased more with the grain quality being maintained with cultivars that have more inferior spikelets accompanied by a greater capacity of sustaining nitrogen supply to the growing grains.