WATER AND RESOURCE MANAGEMENT COPING WITH CLIMATE CHANGE IN RICE CULTURE

Motohiko Kondo
National Agriculture and Food Research Organization (NARO), National Institute of Crop Science (NICS), Rice Research Division
2-1-18, Kannondai, Tsukuba, Ibaraki, 305-8518, Japan

ABSTRACT
Crop management under changing climate is required to satisfy not only increasing productivity but also mitigation of greenhouse gases (GHGs) emission, stabilizing yield and quality of crops exposed to fluctuant climatic conditions with sustainable water and resource use. Elevated temperature, increased water demand, and larger fluctuation of radiation and rainfall must be considered in developing effective water and resource management in rice in coping with climate change. This paper presents following strategies proposed for irrigated rice in Japan, (1) to minimize high temperature damage on grain quality by water and nutrient management; (2) to mitigate GHGs emission with improved water and fertilizer management; 3) to increase water use efficiency by improved water and crop management. High temperature during ripening stages seriously affects grain quality with increased chalky and fissured grain Improvements of water and N management are important component in countermeasure to stabilize grain quality. CH4 and N2O emission can be reduced with improved water management and N fertilizer management. To improve water use efficiency, adjusting cropping patterns is proposed. Integrated crop management techniques adapted to climate change will be discussed.

Key words: rice, global warming, grain quality, water management, water use efficiency

INTRODUCTION
With the trend of global warming, coping with rising temperature and fluctuating climatic conditions is becoming a new challenge for developing agronomic management and genotypes adaptive to climate change. It has been known that high temperature has negative effect on yield and grain quality in rice by inducing decline of grain setting, reduced grain weight, increased respiration, and also through aggravating biotic stress such as insect damages. In recent years, threat by high temperature to rice yield and grain quality is emerging even in sub-tropical and temperate areas. Yield reduction by sterility has been reported and deterioration of grain appearance quality by high summer temperature is now critical issue in Japan, Korea, and Taiwan. It is also important to notice that high temperature indirectly suppresses rice production by increasing water demand.

IPCC reports strongly imply that the tendency of increasing temperature on the globe in the last decades is caused by anthropodic emission of greenhouse gases (GHGs). In the summer of 2007, 40.9°C was recorded in central Japan which has broken the previous highest temperature record in 1933. The temperature increase by around 2 °C during May to September is predicted by 2030s according to a scenario of the global climate change in Japan. In preparing for anticipated farther temperature increase and more fluctuant radiation, understanding the response of rice to high temperature and developing countermeasures in water and resource management are crucial challenges in rice research. This paper deals with current knowledge on physiological response of rice to high temperature and developing countermeasures in water and resource management to cope with elevated temperature. We also focus on the improvement in water and N management to mitigate GHGs. The future research priorities will be discussed.
Major damages caused by high temperature in yield and grain quality of rice

Total biomass production is relatively stable under high temperature as compared with grain yield which is largely affected by high temperature-sensitive processes from reproductive stages to grain filling. Effect of high temperature on biomass production is determined by interactions of various factors which include accelerated phonological development, single leaf photosynthesis, canopy development, respiration, root activity in nutrient and water uptake, and others. Although photosynthesis system per se is relatively tolerant against short-term exposure to high temperature, it can be suppressed by high temperature due to lower stomatal conductance with increased transpiration demand and reduced root activity to take up water. Grain yield is reduced by high temperature through decreased number of spikelet, sterility, and reduced single grain weight. Spikelet number per unit biomass at heading stage tend to be lower under high temperature, which is partly attributed to lowered number of spikelet per panicle caused by larger degradation of spikelet associated with excessive growth, reduced N uptake and larger ratio of unproductive tiller also leads to reduced spikelet number.

The most serious threat by high temperature to reduce grain yield is floret sterility. High temperature during anthesis time above 35°C in a day is most detrimental to spikelet fertility. High temperature induces sterility by reducing the number of pollen grain shed on stigma which is partly attributed to less swelling of pollen grain in the cavity. Avoiding high panicle temperature at flowering time in a day is effective to reduce the damage of sterility.

Statistics from the Ministry of Agriculture, Fisheries, and Forestry (MAFF), Japan, indicated that grain appearance quality grade tends to decline in the last decades, particularly in western part of Japan. This trend is associated with increasing temperature during ripening stages. The deterioration of grain quality is due to chalky opaque grain, fissured grain, and small grain size with deep ditch on a grain surface.

Physiological and environmental aspects in grain chalkiness

Chalky opaque grain include various types such as white back, milky white, white belly, and white-based grain having different opaque endosperm portion. Milky white grain degrades the appearance grade most seriously. Chalkiness is a result of disorder in formation of amyloplast and starch granule. The causes of chalkiness and small grain are hypothesized to be source limitation or disorder of sink ability or both.

Under high temperatures, ripening process is accelerated which results in shorter ripening period. It is likely that substrate supply to endosperm becomes limiting in starch formation under accelerated ripening processes. High temperature increases carbon loss due to respiration in spikelet and enhances senescence of tissues for transportation and transfer of substrate. Carbon source of sucrose in endosperm depends more on reserved non-structural carbohydrate (NSC) in stem and leaf sheath rather than newly assimilated carbon under high temperature. High temperature affects starch synthesis activity in grain. It has been reported that activities of some key enzymes involved in starch synthesis from ADP-glucose and conversion of sucrose to ADP-glucose are lowered under high temperature. In addition, high temperature stimulates the activity of α-amylase that decomposes starch. Involvement of interactive response of source supply, starch synthesis and decomposition to temperature should be further studied.

Panicle temperature is more influencing than the leaf temperature in determining occurrence of chalky grain. There are differences in environmental factors and physiological mechanisms among the formations of different types of chalky grains. Milky white grain is caused by interactive effect of high temperature and low radiation. Also, increasing spikelet number and heavy lodging magnify the occurrence of milky-white grain. On the other hand, white-base and white-back grain are mainly responsive to increasing temperature. In addition, white-base and white-back grain are enhanced with low N conditions. Application rate of N has been decreasing since 1980s in Japan because of consumer’s preference for low protein content in the grain. Increased protein content leads to the less stickiness of the grain mainly due to prolamine. Average N rate is currently 60-80 kg ha⁻¹ in most area. This low N application rate, in turn, induces the increased sensitivity to high temperature.

Water and nutrient management for improving grain quality

Agronomic techniques to reduce high temperature damage to cause chalky and fissured grain have
two strategies. First, to reduce canopy temperature. Second, to enhance plant tolerance. The most sensitive period to high temperature is the first 20 days after heading for chalky grains. Field trials demonstrated that cool water irrigation at this period is effective to reduce the occurrence of fissured grain. Lowering canopy temperature, especially panicle temperature is crucially important for avoiding deterioration of grain quality. High soil temperature may suppress aboveground growth by forming smaller and shallower root system to limit nutrient uptake and possibly, by other process related to root-signaling. Keeping the soil temperature at optimum ranges would indirectly contribute to maintaining grain quality. It is reported that negative effect of high temperature to reduce grain size is larger at night time than in day time. The extent of differential effects between day and night temperatures on the grain quality remains unclear and needs for further study.

Water stress increases chalky grains and fissured grains. Timing of drainage for preparing harvest is becoming earlier to increase soil hardness to assure the use of heavy harvesting machine. This early drainage before harvest, however, induces water stress that magnifies deterioration of grain quality. Ensuring sufficient water supply till the time of completion of grain filling is recommended to reduce chalky and fissured grain.

For enhancing plant tolerance to high temperature during ripening, crop management before heading is important. Deep water management during vegetative stages stabilizes the grain quality under high temperature. This effect can be at least partly attributed to suppress excessive tillering. Maintaining strong tillers lead to enhancing accumulation of NSC in stem and leaf sheath before heading which helps grain filling, especially when the solar radiation is low. Also, leaf N can be maintained with less excessive tillers with deep water management. High leaf N contributes to enhance photosynthesis to source.

In N management, maintaining appropriate plant N status during ripening is important to reduce white-back and white-base grains. Early top dressing at panicle initiation stages has effect to increase spikelet number, but may induces the occurrence of milky-white grain. Early top dressing generally induces lodging by elongating lower internodes. Late topdressing, on the other hand, at and after meiosis are effective to increase N content in leaves during ripening, but it generally leads to higher protein content. Ideal N management should satisfy the conditions simultaneously to minimize chalky grain, maximize yield, and maintain good eating quality. Controlled release N is useful tools to satisfy these requirements.

**Water use efficiency**

Maximizing water use efficiency (WUE) by improvement of crop and water is another critical issue in coping with climate change. Irrigations for rice paddy occupy approximately 70% of all water consumption in Japan. Elevated temperature must have significant impact on water balance in rice culture through the increase of evapotranspiration and change in rice growth patterns. Water deficit is predicted in warm western region in Japan. Assuming the temperature increase by 2°C in Kyusyu area in future, water-crop model predicts that the area suffering from negative water balance in mid summer (August) expands substantially. Shifting cropping season can be effective to reduce water consumption and increase WUE. Delaying transplanting date would reduce the area suffering from water shortage. Early transplanting generally increases water demand due to increased evaporation from water surface in early stages. Determining optimum water balance under climate change needs consideration not only on climatic condition, but also on crop phenology, variety, and socio-economic conditions. Genotypic variation in WUE is known in rice with the tendency of high WUE for japonica as compared with indica. Adaptive cropping system to maximize WUE is established by combining the improvement of crop and water management.

**GHGs emission in relation to water and N management**

The other important requirement for agronomic technique under climate change is to minimize GHGs emissions without sacrifice on crop production. Soil water regime, organic matter and N management are critical factors influencing the emission of CH₄ and N₂O. Paddy soil is usually flooded during the crop season. But the soil can occasionally be under unsaturated conditions such as at the time of mid-season drainage, drainage after the harvest, or after seeding in direct seeding practice. The alternate wetting and drying (AWD) irrigation technique is also attracting attention as one of the promising water-saving techniques. Our knowledge on the effect of these fluctuations in soil water regimes on CH₄ and N₂O has been substantially advanced in the last decades. One of
the difficulties in water management is trade-off relationship between emissions in CH$_4$ and N$_2$O. CH$_4$ emission is generally reduced with temporal aeration while it can enhance N$_2$O emission. Temporal aeration is effective management option to mitigate the CH$_4$ emission especially when rice residue is applied to the fields. However, this reduction of CH$_4$ emission does not effectively lead to reducing global warming potential (GWP) since there is a risk here that N$_2$O emissions offsets reduction of CH$_4$ especially when high N fertilizer is applied. Timing and placement of N must be optimized to minimize N$_2$O emission derived from applied N. Keeping standing water for a week after N fertilizer top dressing can be effective to reduce N$_2$O emissions. As to compare the placement of N, NO in unsaturated conditions could be reduced by deep placement as compared with incorporation. N$_2$O emission could also be reduced by the deep placement at the time of aeration. It is likely that the level and the depth of NH$_4^+$ at the time of drainage determine the magnitude of nitrification and N$_2$O emission during the aeration and after re-flooding. Deep N placement of controlled-release N would be useful to reduce the exposure of NH$_4^+$ to oxidation and consequently the N$_2$O emission during and after the aeration practice.

CONCLUSION

In the history of rice research in temperate areas such as Japan, the efforts to alleviate low temperature damages have made successes to stabilize rice yield in cool regions, which have advanced our scientific knowledge on genetic and physiological factors improving cold tolerance and agronomic techniques. Coping to increasing temperature with greater water scarcity can provide another opportunity to advance our knowledge on ecosystem of paddy land and physiological potentials of rice. Increasing yield per unit land is basically effective to improve water and resource use efficiency. Physiological response of rice to elevated temperature and CO$_2$ and their interaction needs further understanding. Global warming scenario predicts greater fluctuation in climatic conditions. Development of robust and flexible rice cultivation system against fluctuant climatic conditions is desired with multidisciplinary cooperation between crop production science and environment science.