Rice Research: Open Access

Washio, J Rice Res 2013, 2:1
http://dx.doi.org/10.4172/jrr.1000e103

Editorial Open Access

The Prediction of Climate Change and Rice Production in Japan

Kenji Washio*

Faculty of Environmental Earth Science, Hokkaido University, Sapporo, Japan

Staple food is defined to be reasonable, routinely available, and energy-rich foods that are essential for the daily life of humankind. The species of staple foods regionally vary from region to region in the world. Most of the staple foods are derived from the cereal plants including wheat, barley, maize, rice, and so on. Food and Agriculture Organization of the United Nations reported that productions of paddy rice have been increasing each year and accounted for 722,559,584 metric tons (MT) at 2011. This value is comparable to those of wheat (701,395,334 MT) and maize (885,289,935 MT). Then, these plants are recognized as the three major crops that are required for human nutrition and caloric intake. There are many varieties of rice being grown worldwide, especially in Asia. Asian rice is classified into two major types, namely Japonica and Indica rice [1]. Japonica rice is generally grown at temperate climates. Indica rice is cultivated in tropical and subtropical regions. The properties of rice grain significantly differ among the cultivars. For example, the grain of Japonica rice is short to middle size, round, and rigid. When cooked by boiling or steaming, Japanese rice becomes moist and stick together due to higher contents of amylopectin, highly branched polysaccharide of glucose. Although Indica, Aromatic, and Japonica rice accounts for 75%, 12-13%, and more than 10% of global rice trade, respectively, the rice produced in Japan is mostly Japonica type.

Cultivated rice is usually grown as an annual plant. The methods of rice cultivation are differing among the living cultures and localities. Japonica rice belongs to semi aquatic rice, then, the general procedure practiced in Japan is the paddy field. At the juvenile stage, the seedlings of rice are transplanted to the flooding fields to ensure the secure growth of young plants by protecting from water-loss, pest, and vermin. During the vegetative growth period, irrigation is maintained by the coordinated water supply with canals or hand watering. The fields are allowed to drain before harvesting. Since the paddy fields have to be flooded by rain or rivers throughout the growth periods, high rainfall should be required for rice cultivation. Climate in Japan has four clear distinct seasons (spring, summer, autumn, and winter), and rainy season begins at early May. Also, August to October is the typhoon season in Japan. These circumstances provide good weather conditions for rice production. On the other hand, Japan is a country surrounded by big oceans and consists of four major islands (Hokkaido, Honshu, Shikoku, and Kyusyu), associated with many small islands. There are few flat plains and the agriculture in Japan is characterized by the shortage of farmlands. Paddy fields of rice are widely planted at the countryside, the alluvial plains, and the terraced slopes near the mountains. In recent years, rice production in Japan has gradually declined due to the shift to the Western style of food culture, and to the increasing population of elderly farmers. The Japanese government has showed intention to decrease the planted area of rice since the 1970s (Ministry of Agriculture, Forestry and Fisheries in Japan), however more recently, the necessity of rice has been reevaluated in consideration of coming open trade such as the Trans-Pacific Partnership (TPP).

There is no doubt that global warming is one of the great issues facing the Earth. Since the early 20th century, the average surface temperature of the Earth has unusually increased by about 0.8°C coupled with the rapid warming of 0.6°C over the past three decades [2]. The scientists show the opinion that global warming should be reasoned by the increasing concentration of greenhouse gases produced by human activities such as use of fossil fuels, unsustainable agriculture, and land development. The Intergovernmental Panel on Climate Change (IPCC) is a scientific intergovernmental body that is organized by the request of participating governments (http://www.ipcc.ch/index.htm). The IPCC itself does not conduct scientific research. The mission of the IPCC is to provide comprehensive assessments of global climate change, future predictions, and possible measures about the risks of climate change caused by human activity. The 5th assessment report (AR5) showing the current state of climate change is underway. The summary for policymakers (SPM) of the Working Group I (the physical science basis) for AR5 was approved and accepted by the IPCC on 27 September 2013, and the final version was published on 11 November 2013. The report is very long and it seems to be difficult to understand the whole contents at a glance. The outline of SPM is that warming of the climate system is definitive, represented by the warmed atmosphere and ocean, the diminished amounts of snow and ice, the rising of sea level, and the increasing concentration of greenhouse gases. The carbon dioxide (CO_2) concentrations have increased by 40% since pre-industrial times by burning of fossil fuels and land-use change. It is extreme likely that human activities influence on the climate system from the middle of 20th century, because the increasing concentration of greenhouse gases showed the correlation with the positive radiative forcing and the observed warming of climate system. Several scenarios have been predicted with reference to the different rates of future CO_2 emission. It is warned that the average surface temperature of the Earth rise exceed 1.5°C during the 21st century relative to pre-industrial levels, and global warming will affect broad ranges of the climate system, including global water cycle, ocean circulation, and carbon cycle processes.

Climate change is also projected to have significant impacts on crop production. Now, many kinds of crops are grown at various conditions in the world so that the effect of climate on agriculture should be related with local climates rather than global climate patterns. The previous 4th assessment report of IPCC (2007) predicted (with medium to low confidence) that the moderate warming of atmosphere (1-3°C) can benefit to crop yields in mid- to high-latitude regions by the increase of CO_2 concentration and rainfall changes, while similar increases (1-2°C) have negative effects on major crop productions in low-latitude regions. When further warming occurs over a range of 1

***Corresponding author:** Kenji Washio, Faculty of Environmental Earth Science, Hokkaido University, Sapporo, Japan, Tel: +81-11-706-2281; Fax: +81-11-706-2281; E-mail: washi@ees.hokudai.ac.jp

Received November 29, 2013; **Accepted** November 30, 2013; **Published** December 02, 2013

Citation: Washio K (2013) The Prediction of Climate Change and Rice Production in Japan. J Rice Res 2: e103. doi: 10.4172/jrr.1000e103

to 3°C, crop yields should be declined in all regions [2]. Climate change will have different impacts on each plant. Photosynthesis is the central mechanism of plants to produce organic molecule (glucose) from light energy, CO_2, and water. It is known that plants have evolved to acquire better photosynthesis machineries in the different habitats [3]. Plants are classified into two major groups, namely C_3 and C_4 plants, based on the type of photosynthesis. C_3 plants make a three carbon compound (3-phosphoglycerate) as the first product of CO_2 fixation by the catalysis of Rubisco. About 85% of plants belong to C_3 plant, including wheat, barley, rice, oats, soybeans, and most trees. The disadvantage of C_3 photosynthesis is photorespiration that is the opposite reaction of photosynthesis. When the CO_2 concentration in the chloroplast drops below 50 ppm, Rubisco begins to fix O_2 instead of CO_2 and the growth of plants is consequently diminished by consumption of the sugars produced by photosynthesis. The researchers suggested that the potential output of C_3 photosynthesis might be reduced up to 25% through photorespiration [4].

This problem is overcome by C_4 plants. C_4 plants have acquired carbon storage mechanisms in order to increase the intracellular concentration of CO_2 [3]. In C_4 plants, CO_2 is initially converted into a four carbon compound (malic acid) or other molecules by the catalysis of PEP carboxylase that only works with CO_2, and the metabolite of CO_2 is subsequently transferred into the specialized cells where CO_2 is again released and refixed by Rubisco. This procedure greatly reduces photorespiration due to the distinct compartment of CO_2 uptake and fixation in plants. In addition, C_4 plants can close their stomata and prevent the evaporation of water under the conditions in which C_3 plants must open such as high temperature, drought, low CO_2, and limited nitrogen. Taken together, C_4 plants are thought to have advantages in warm and dry climates, while C_3 plants perform better in moist conditions with high CO_2. Despite the relative merits of C_4 photosynthesis in crop production, less than 1% of plants are characterized as C_4 plants, including maize, sugar cane, and sorghum. Global climate tends to become warmer, coupled with the increasing of CO_2 concentration. This trend appears to have the benefit to C_3 photosynthesis that is stimulated by the elevation of CO_2. But farmlands are occasionally suffered from heat waves and droughts that give rise to the advantages of C_4 plants. Rice belongs to C_3 plant, but several genes encoded for the key enzymes involved in C_4 photosynthesis such as PEP carboxylase and pyruvate phosphate dikinase (PPDK) are found in the rice genome [5]. This implies the potential abilities to conduct C_4 photosynthesis in rice plants. If C_4 photosynthesis is successfully transferred into rice, the increasing of yield would be expected in hot and dry environments with less fertilizer. The scientific program in aiming to integrate the C_4 photosynthesis system into rice has been starting at the International Rice Research Institute from 2012.

It is unpredictable what kinds of impact will happen to crop production by global climate change, but several lines of evidence indicate that the elevation of CO_2 concentration has the benefit to increase crop yields at moderate high temperatures. Since C_3 photosynthesis has a great response to the atmospheric CO_2 than do C_4 plants, the elevation of CO_2 level is predicted to stimulate the yields of C_3 plants. The researchers examined that the yields of C_3 plants were enhanced by ca. 15% with the increase of 200 ppm CO_2 [6]. In contrast, worse high temperatures counteracted the positive effects caused by elevated CO_2. This phenomenon is explained by the water availability, the carbon loss through photorespiration, and the depletion of several nutrients including nitrogen. When severe warming occurs, farmlands might have to be supplemented with more fertilizers to help the growth of crops. It is also known that rice paddy fields are a major source of atmospheric methane that exhibits prevalent greenhouse effect by ca. 72 times stronger than the same mass of CO_2 [7]. We have to pay careful attentions to control methane emission by microbial ecology in the future practice.

The responses of plant to the elevated CO_2 concentration have been analyzed by the several ways, but the data obtained within the laboratory conditions are never accurate reflections of the natural events. For this reason, Free-Air Carbon dioxide Enrichment (FACE) have been developed that allows to understand the combined effects influenced by the elevated CO_2 concentration in the environments [8]. FACE facility usually consists of a ring field in which atmospheric conditions can be readily controlled. The results of FACE test indicated that the yields of crops were slightly increased by elevated CO_2, but the extents of induction were lower than those expected from the laboratory tests using the growth chambers, perhaps due to the existence of counter-balance involved by other environmental factors such as atmospheric changes in nature [9]. There are two large FACE for rice paddy field operated in Japan at Shizukuishi (Iwate, northern Japan) and Tsukuba (Ibaraki, near Tokyo). The annual mean temperature of Tsukuba is more than 4°C warmer than that at Shizukuishi. The comparative analyzes performed at the two different sites provided convincing evidence that the same set of rice cultivars exhibited better performance at Tsukuba but lesser at Shizukuishi with the similar CO_2 conditions [10]. It should be noted that eight cultivars planted at Tsukuba had diverse sensitivities to CO_2, showing a wide range of yield induction ranging from 3 to 36%. These observations suggest that the interplays between climate changes and plant responses under the field conditions create substantial complexity for crop production.

Japan's climate is changing. The report for regional climate change and prospects in Japan based on IPCC AR4 has projected that the mean surface temperature of Japan has warmed by ca. 1.15°C over the past century, and expected to rise by 2.1 to 4.0°C within the end of next 100 years [11]. These values are slightly higher than those calculated for global warming of the Earth (0.8°C/100 years). The report also illustrated that the notable changes of precipitation trends should not be occurred during the 20th century, while the patterns of rainfall became more variable and unpredictable. There has been an increase in the frequency of extreme weathers such as storms, droughts, floods as well as an increase of typhoon intensities. In addition, the recent climate trends in Japan are represented by the drastic increase of hot days exceeding 30°C in summer. These climate changes will greatly affect Japan in many aspects, and make difficult to plan the agricultural practice. Japonica rice is usually cooked as intact white rice, and Japanese prefer soft and glutinous texture of rice. Then, the quality of rice grain is very important for marketing in Japan. In the summer of 2010, Japan have experienced the extremely hottest summer on record. The yields of rice have not been severely influenced while the qualities of grain were negatively impacted [10]. Filling of rice grains deteriorated, and many white immature grains have been harvested. It is warned that the reproductive phase of rice is highly sensitive to high temperature, and hotter conditions lead to increasing sterility. In this context, farmers are required to adapt the agricultural techniques to avoid the risks caused by climate change. Genetically modified (GM) crops are the useful breeding technique to rapidly introduce a new trait to the plant, but rice is cultivated as the major staple food for nearly half of the world's population. The risk of GM crops for the human health and the natural ecosystem is still under debate [12]. The genetic evidence has indicated that Japonica and Indica rice have evolved from a single

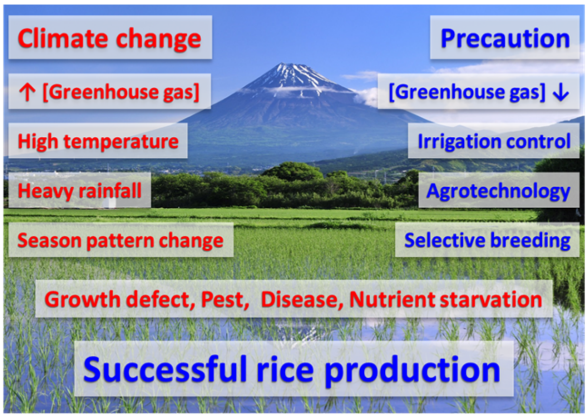

Figure 1: The impacts of climate change on rice paddy field and the measures for rice production. The projected impact caused by climate change and the possible measure for successful rice production is indicated by the red- and blue-coloured letters, respectively.

domestication in China 8,200-13,500 years ago [1]. It is said that there are more than 40,000 varieties of cultivated rice in the world, and some of which capable of crossbreeding. Many samples of cultivated and wild rice are stocked at the International Rice Genebank, and shared by the world researchers. The screening of rice gene functions responsible for the adaptive role for environmental changes such as heat tolerance of grain quality [13] and improved root system for drought resistance [14] has been ongoing in Japan. These studies will contribute to the rice breeding in aiming to counteract the impacts caused by climate change in the future (Figure 1).

References

1. Molina J, Sikora M, Garud N, Flowers JM, Rubinstein S, et al. (2011) Molecular evidence for a single evolutionary origin of domesticated rice. Proc Natl Acad Sci USA 108: 8351-8356.
2. Core writing team, Pachauri RK and Reisinger A (2007) Contribution of working groups I, II and III to the fourth assessment report of the Intergovernmental Panel on Climate Change IPCC, Switzerland, pp104.
3. Sage RF, Pearcy RW (2000) The physiological ecology of C4 photosynthesis. Photosynthesis. Advances in Photosynthesis and Respiration 9: 497-532.
4. Leegood RC (2007) A welcome diversion from photorespiration. Nature Biotechnol 25: 539-540.
5. Susanne VC, Quick WP, Furbank RT (2012) The development of C_4 rice: Current progress and future challenges. Science 336: 1671-1672.
6. Long SP, Ainsworth EA, Leakey ADB, Nösberger J, Ort DR (2006) Food for thought: Lower-than-expected crop yield stimulation with rising CO_2 concentrations. Science 312: 1918-1921.
7. Conrad R, Erkel C, Liesack W (2006) Rice Cluster I methanogens, an important group of Archaea producing greenhouse gas in soil. Curr Opin Biotechnol 17: 262-267.
8. Taub D (2010) Effects of rising atmospheric concentrations of carbon dioxide on plants. Nature Education Knowledge 3: 21.
9. Leakey AD, Ainsworth EA, Bernacchi CJ, Rogers A, Long SP, et al. (2009) Elevated CO_2 effects on plant carbon, nitrogen, and water relations: Six important lessons from FACE. J Exp Bot 60: 2859-2876.
10. Hasegawa T, Sakai H, Tokida T, Nakamura H, Zhu C, et al. (2013) Rice cultivar responses to elevated CO_2 at two free-air CO_2 enrichment (FACE) sites in Japan. Functional Plant Biol 40: 148-159.
11. Climate change and its impacts in Japan: Synthesis report on observations, projections, and impact assessments of climate change. (2009) Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan Meteorological Agency (JMA), Ministry of the Environment (MOE).
12. Li ZK, Zhang F (2013) Rice breeding in the post-genomics era: from concept to practice. Curr Opin Plant Biol 16: 261-269.
13. Uga Y, Sugimoto K, Ogawa S, Rane J, Ishitani M, et al. (2013) Control of root system architecture by DEEPER ROOTING 1 increases rice yield under drought conditions. Nat Genet 45: 1097-1102.
14. Kobayashi A, Sonoda J, Sugimoto K, Kondo M, Iwasawa N, et al. (2013) Detection and verification of QTLs associated with heat-induced quality decline of rice (*Oryza sativa* L.) using recombinant inbred lines and near-isogenic lines. Breed Sci 63: 339-346.

Citation: Washio K (2013) The Prediction of Climate Change and Rice Production in Japan. J Rice Res 2: e103. doi: 10.4172/jrr.1000e103