Climate Change-induced High Temperature Stress on Global Crop Production

Kyoungmi Lee* · Hyun-Suk Kang** · ChunHo Cho***

Abstract: Exposure to high temperatures during the reproductive period of crops decreases their productivity. The Intergovernmental Panel on Climate Change’s (IPCC) fifth Assessment Report predicts that the frequency of high temperatures will continue to increase in the future, resulting in significant impacts on the world’s food supply. This study evaluate climate change-induced heat stress on four major agricultural crops (rice, maize, soybean, and wheat) at a global level, using the coupled atmosphere-ocean model of Hadley Centre Global Environmental Model version 2 (HadGEM2-AO) and FAO/IIASA Global Agro-Ecological Zone (GAEZ) model data. The maximum temperature rise (1.8-3.5°C) during the thermal-sensitive period (TSP) from the baseline (1961-1990) to the future (2070-2090) is expected to be larger under a Representative Concentration Pathway (RCP) 8.5 climate scenario than under a RCP2.6 climate scenario, with substantial heat stress-related damage to productivity. In particular, heat stress is expected to cause severe damage to crop production regions located between 30 and 50°N in the Northern Hemisphere. According to the RCP8.5 scenario, approximately 20% of the total cultivation area for all crops will experience unprecedented, extreme heat stress in the future. Adverse effects on the productivity of rice and soybean are expected to be particularly severe in North America. In Korea, grain demands are heavily dependent on imports, with the share of imports from the U.S. at a particularly high level today. Hence, it is necessary to conduct continuous prediction on food security level following the climate change, as well as to develop adaptation strategy and proper agricultural policy.

Key Words: climate change, high temperature, heat stress, agricultural crop

요약: 작물의 생산성은 생식기간 중 고온에 노출되면 감소한다. IPCC 5차 평가보고서는 고온의 빈도가 미래에 계속 증가할 것이며, 이는 세계 식량 공급에 영향을 미칠 것으로 전망하였다. 이 연구에서는 기상청의 Had GEM2-AO(함사·대양·대양 기후모델과 FAO/IIASA의 GAEZ(전지구·식물건·생물기후) 작물모델) 자료를 이용하여 전 지구 규모에서 4개의 주요 작물(쌀, 옥수수, 콩, 밀)에 대하여 기후변화로 인한 작물의 고온 스트레스를 평가하였다. 과거기간 (1961~1990년)에 비해 미래(2070~2090년)에 생식기간 동안 최고기온은 약 1.8~3.5°C 상승할 것으로 전망되며, RCP2.6 시나리오에 비해 RCP8.5 시나리오에 따른 기온 상승이 더 클 것으로 전망된다. 특히 옥수수

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1. Introduction

Over the past 132 years (1880-2012), the global average temperature has risen by 0.85°C (from 0.65 to 1.06°C), and the frequency of high temperatures has continued to increase due to climate change (Hansen et al., 2012; IPCC, 2013). As with changes in the mean temperature, the trends in extremes are primarily attributable to greenhouse gas emissions, these trends are expected to continue in the coming decades (IPCC, 2013).

The tendency toward a rise in temperature is substantially larger in cultivated land areas (IPCC, 2007).

Temperature variability is an important determinant of crop productivity. The effects of temperature on crop production can be divided into two mechanisms (Challinor et al., 2005). The average temperature determines the growth duration of plants, with an optimal average temperature generally increasing the growth duration. High temperatures generally affect fruit or grain formation, with the impact particularly large near the flowering time. Crops are particularly sensitive to extremely high temperatures during the reproductive period. Only a few hours of exposure to a high temperature can sharply decrease crop production and sometimes result in a poor harvest (Porter and Semenov, 2005). The Intergovernmental Panel on Climate Change’s (IPCC) fifth Assessment Report pinpointed heat stress as one of the major threats to global food supplies (IPCC, 2014). In 2010, more than 20% of agricultural area in Russia was unprecedentedly affected by extremely high temperatures, resulting in 50% hike in wheat prices on the international market (FAO, 2010; NOAA, 2011).

Global warming has a direct effect on agricultural productivity and food security (Ainsworth and Ort, 2010; Lobell et al., 2011). According to previous studies, tropical regions are particularly vulnerable to the negative impacts of an increase in the average temperature (IPCC, 2014; Fischer et al., 2005). On the other hand, the negative impacts of higher seasonal temperatures are less pronounced in temperate regions where global warming may increase the length of the growing period and render land suitable for cropping where low temperatures used to limit agriculture (Olesen and Bindi, 2002). Recent studies have investigated not only the impacts of changes in the average temperature but also those of extremely high temperatures or heat stress on crop productivity (Vara Prasad et al., 2000; Challinor et al., 2005; Shah et al., 2011; Deryng et al., 2014). Most of these studies have focused on the national or local level. Understanding the damages that heat stress causes to crops at the global scale and the geographical distribution of such damage is insufficient. As global supply and demand determine the distribution or market price of food, the impact of climate change on crops needs to be considered at the global scale.
We conducted a spatially explicit assessment of the effect of heat stress on four major crops at the global scale to examine the risk posed by climate change-induced heat stress to agricultural crops. This study utilized HadGEM2-AO Representative Concentration Pathway (RCP) 2.6 and RCP8.5 climate-change scenario data to assess the risk of such heat stress on each crop in the future (2070-2090) compared to that of the baseline (1961-1990).

2. Data and methods

The climate projection in this study is based on the coupled atmosphere-ocean model of Hadley Centre Global Environmental Model version 2 (HadGEM2-AO). HadGEM2-AO simulates observation patterns reasonably well, although it shows a cold bias over land in the Northern Hemisphere (Baek et al., 2013). HadGEM2-AO has a spatial resolution of 1.875 degrees of longitude by 1.25 degrees of latitude. Data from two (RCP2.6 and RCP8.5) of four (RCP2.6, 4.5, 6.0, and 8.5) greenhouse gas emission scenarios were used. The RCP2.6 scenario assumes complete recovery of Earth from anthropogenic-related activities. The RCP8.5 scenario assumes that greenhouse gas emissions remain at their current levels (i.e., they do not decrease). The period for the baseline climate is 1961-1990, and the period for the future climate is 2070-2090.

To assess the heat stress on crops, four types of crops were selected: rice (Oryza sativa), maize (Zea mays), wheat (Triticum aestivum), and soybean (Glycine max). These are very important crops with respect to the global food supply, accounting for more than 40% of human calorie intake and 45% of global cultivated cropland (FAOSTAT, 2009). FAO/IIASA Global Agro-Ecological Zones (GAEZ) model data were used for cropping calendar data, such as the start and length of the crop growth cycle (Fischer et al., 2002). To ensure the assessment of heat stress focused specifically on areas suitable for agriculture, grid cells were only considered when at least 5% of the land in a grid cell was indicated as cultivated in 2000. For wheat, maize, and soybean, only rain-fed conditions were considered. For wetland rice, data on irrigated crops were used because rice is mostly cultivated worldwide under irrigated conditions.

Diverse crops tend to show a similar response to heat stress. For example, heat stress decreases the number of flowers, damages pollen tube development, limits pollen release, decreases pollen survival, and reduces flower pollination (Matsui et al., 2000; Suzuki et al., 2001; Vara Prasad et al., 2006). The threshold temperature above which heat-stress responses occur differs among species and cultivars. As the temperature rises above these critical thresholds, the relative intensity of yield-damage increases until total yield loss is reached.

The heat-stress intensity index (fHS) of each crop was calculated according to the method developed by Teixeira et al. (2013). The index was based on the framework developed by Challinor et al. (2005). This method assumes the following: First, crops are sensitive to heat

<table>
<thead>
<tr>
<th>Crop species</th>
<th>Tmin (°C)</th>
<th>Tlim (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize (Zea mays)</td>
<td>35</td>
<td>45</td>
</tr>
<tr>
<td>Wetland rice (Oryza sativa)</td>
<td>35</td>
<td>45</td>
</tr>
<tr>
<td>Soybean (Glycine max)</td>
<td>35</td>
<td>40</td>
</tr>
<tr>
<td>Wheat (Triticum aestivum)</td>
<td>27</td>
<td>40</td>
</tr>
</tbody>
</table>
stress only during the reproductive period, which is called the thermal-sensitive period (TSP). Second, yield-damage occurs when maximum temperatures (Tmax) exceed a critical temperature threshold (Tcrit), and the maximum impact occurs when the Tmax exceeds the limit temperature threshold (Tlim). Table 1 shows the temperature threshold of each crop (Gourdji et al., 2013; Teixeira et al., 2013). Although the TSP is likely to differ among different species or cultivars of crops, the reproductive period in this study was assumed to last 30 days for all crops. The TSP was centered around 5 days prior to a critical crop-specific event (i.e. heading for wheat and rice, pod-setting for soybean, and silking for maize). This date was presumed to occur a fixed proportion of the season back from the harvest date, with the proportions varying by crop. These proportions were 0.45 for wheat, 0.55 for maize, 0.50 for soybean, and 0.3 for rice (Gourdji et al., 2013).

To calculate the fHS (Challinor et al., 2005), the daily heat-stress intensity (fHSd) was first obtained (Equation 1). The value of fHSd is a surrogate for the intensity of yield-damage due to heat stress and is assumed to linearly increase from 0.0 at Tcrit to 1.0 at Tlim.

\[
f_{\text{HS}} = \begin{cases} 
0.0 & \text{for } T_{\text{max}} < T_{\text{crit}} \\
\frac{T_{\text{max}} - T_{\text{crit}}}{T_{\text{lim}} - T_{\text{crit}}} & \text{for } T_{\text{crit}} \leq T_{\text{max}} < T_{\text{lim}} \\
1.0 & \text{for } T_{\text{max}} \geq T_{\text{lim}} 
\end{cases}
\]

(1)

To calculate the fHS for the entire TSP, the daily values of fHSd were accumulated and averaged throughout the TSP (Equation 2).

\[
f_{\text{HS}} = \frac{\sum_{j=1}^{\text{TSP}} f_{\text{HSd}}}{\text{TSP}}
\]

(2)

Hence, the value of fHS reflects both the frequency and the intensity of heat stress events experienced during the sensitive period of crop growth.

3. Results

Looking at the geographical distribution of the average maximum temperature during the TSP of each crop for the baseline climate (1961-1990) and the RCP2.6 and RCP8.5 climate-change scenarios (2070-2090), the temperature rise was greater under the RCP8.5 scenario than under the RCP2.6 scenario (Fig. 1 and Fig. 2). For rice, the RCP2.6 scenario predicted that the global average maximum temperature during the TSP would increase to 31.2°C, which was approximately 1°C higher than the baseline (30.4°C). In contrast, the RCP8.5 scenario predicted that it would rise by more than 3°C, up to 33.9°C (Fig. 1, left). For the baseline, rice in Northern India, Iran, and Southern Pakistan is already subject to a high temperature of over 35°C. Under the RCP8.5 scenario for rice, regions located between 30°N and 50°N (North America, in particular) will experience the largest temperature rise.

For maize, the global average maximum temperature during the TSP for the baseline climate was 27.7°C. Based on the RCP2.6 and RCP8.5 scenarios, it will increase to 28.4°C and 30.6°C, respectively (Fig. 1, right). The strong warming from the baseline under the RCP8.5 scenario for maize is forecasted for the Sahel region, Eastern China, Western Europe, and Western North America.

For soybean, the global average maximum temperature during the TSP for the baseline was 27.9°C, which was similar to that of maize (Fig. 2, left). The RCP2.6 and RCP8.5 scenarios predicted that it would increase to 28.7°C and 31.4°C, respectively, with the latter scenario forecasting a greater temperature rise. According to the RCP8.5 scenario, temperatures for soybean will increase substantially from the baseline, particularly in Central North America, Europe, and Central Asia.

For wheat, the global average maximum temperature during the TSP was relatively low compared to that of
the other crops (Fig. 2, right). The average maximum temperature for the baseline was 21.9°C. Based on the RCP2.6 scenario, the average maximum temperature will decline to 21.7°C, which is lower than that of the baseline. In contrast, the RCP8.5 predicted that the average maximum temperature would increase to 23.7°C. The RCP2.6 scenario for wheat forecasted that some regions in Europe would experience higher temperatures than those of the baseline, whereas it predicted that the average maximum temperature in North America and Eastern China would decrease. The RCP8.5 scenario also predicted that regions located between 40°N and 60°N would experience strong warming.

Figure 3 and Figure 4 show the geographical dis-
tribution of the intensity of the heat stress on the four agricultural crops according to the RCP2.6 and RCP8.5 scenarios compared to that of the baseline. Overall, the RCP8.5 scenario predicted a drastic increase in the heat stress on all crops in the future, particularly, in North America, South Asia (e.g., India), Northeastern China, and Central Asia, including the Russian Federation and Kazakhstan.

For the baseline, rice already experienced high heat stress, particularly in Northern India and North America (Fig. 3, left). Based on the RCP2.6 scenario, heat stress on rice will be high in Eastern China and North America, whereas it will be lower or similar in other regions in the future. However, the RCP8.5 scenario predicted that heat stress would increase in many parts of Europe, as well as in Kazakhstan, North America, and Eastern China. In the Korean peninsula, for the baseline, the intensity of heat stress on rice is very low, and it is expected...
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For the baseline climate, maize is subject to low heat-stress intensity in most regions (Fig. 3, right). The RCP2.6 scenario predicts that maize in Central North America will be subject to high heat stress in the future compared to that of the baseline. However, the RCP8.5 scenario forecasts that the intensity of the heat stress on maize will increase in most regions. In particular, heat stress will be high in some parts of Northern India, the Sahel region, North America, Western China, and Southeastern Asia. Maize in the Korean peninsula is predicted to be lower than that of other regions.

Figure 3. The heat-stress intensity in areas suitable for the production of wetland rice (left) and rain-fed maize (right) for the baseline climate (1961-1990) and RCP2.6 and RCP8.5 climate-change scenarios (2070-2090). The intensity of the heat stress was categorized as very low (0<fHS<0.05), low (0.05≤fHS<0.15), medium (0.15≤fHS<0.30), and high (fHS≥0.30).
subject to a very low level of heat stress under the baseline climate. For maize, the stress intensity is expected to increase by one level under the RCP8.5 scenario, but the damage due to heat stress will not be severe.

According to the baseline data, soybean is subject to relatively low heat stress (Fig. 4, left). Under the RCP2.6 scenario, the heat stress on soybean in the future will be higher only in inland North America. In the rest of the regions, the heat stress is expected to be similar or lower than the current baseline level. However, the RCP8.5 scenario predicts that the intensity of heat stress on soybean will be high in India, Eastern China, and North America. In Europe and Central Asia, although the level of heat stress on soybean is very low for the baseline, the RCP8.5 scenario predicts that it will significantly increase in the future. In the Korean peninsula, heat stress on soybean is very low under the baseline and the RCP2.6 scenario. However, it is expected to increase by one level under the RCP8.5 scenario.

According to the baseline data, wheat is exposed to
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relatively high heat stress in Central Asia and Eastern China (Fig. 4, right). According to the RCP2.6 scenario, heat stress on wheat will be either very low or absent in most regions in the future. In contrast, the RCP8.5 scenario forecasts that it will be relatively high in some parts of Eastern Europe, Eastern China, Russia, and North America. In the Korean peninsula, the intensity of the heat stress on wheat is “low” under the baseline climate. However, the RCP8.5 predicts that it will increase by one level in the Northern region of the country in the future.

Figure 5 shows the relative changes in the intensity of the heat stress on the different crops under the RCP8.5 scenario compared to those under the baseline climate. Among the regions that are suitable for growing each crop, those with a heat stress index of 0 (i.e., the regions where heat stress is not observed) are not included in the

Table 2. The percentage of areas without heat-stress events within the thermal sensitive period (TSP) for the baseline climate (1961-1990) and the RCP8.5 climate-change scenario (2070-2090) in areas suitable for the production of rain-fed wheat, maize, and soybean and wetland rice.

<table>
<thead>
<tr>
<th>Crop species</th>
<th>Baseline (1961-1990)</th>
<th>Future (2070-2090)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wetland rice</td>
<td>34.1</td>
<td>19.0</td>
</tr>
<tr>
<td>Maize</td>
<td>45.0</td>
<td>23.7</td>
</tr>
<tr>
<td>Soybean</td>
<td>46.8</td>
<td>25.5</td>
</tr>
<tr>
<td>Wheat</td>
<td>20.7</td>
<td>17.3</td>
</tr>
</tbody>
</table>

Figure 5. Relative change in the heat-stress intensity from the baseline climate (1961-1990) to the future climate-change scenarios (RCP8.5, 2070-2090) for the different crops. The solid horizontal line inside the boxes indicates the median value for the analysis period, the box-boundaries are the 25th and 75th percentiles, and the whiskers denote the 5th and 95th percentiles.
For all four crops, the proportion of regions where heat stress does not occur during the reproductive period out of the total cultivation area is expected to decrease with increasing heat stress intensity. For maize and soybean, regions without high-temperature stress occupy approximately half the total cultivation area, but the proportion is expected to decrease to below 30% in the future. On the other hand, the proportion of heat stress-free regions for wheat will not decrease much, from 20.7% for the baseline to 17.3% in the future. As the increase in the intensity of the heat stress is predicted to be large for rice and soybean compared to maize and wheat, rice and soybean production will fall substantially. Approximately 20% of the future cultivation areas of all four corps will experience unprecedented extreme heat stress, with the intensity of the heat stress particularly affecting rice and soybean.

Figure 6 shows the distribution of the heat stress intensity index for the four crops in five aggregated global regions under the baseline and the RCP8.5 scenario. The intensity of the heat stress on agricultural crops is expected to increase in most of the regions. For rice, the heat-stress intensity is strongest in East Asia and South Asia under the baseline climate. Under the RCP8.5, high-temperature induced damage to rice is predicted to be strongest in North America. Although heat stress on rice is low in Central Asia, Russia, South America, and Africa in the baseline, the heat-stress intensity of these regions is expected to increase to a level similar to that in East Asia and South Asia.

Heat stress on maize is expected to increase from the baseline level in the future, but the increment will not be as large as the heat stress on other crops. Under the RCP8.5 scenario, the intensity of heat stress on maize is expected to be relatively high in Africa, East Asia, and South Asia compared to that in other regions. The intensity of heat stress on soybean, which is higher in North America than in other regions under the baseline climate, is expected to be strongest in North America under the RCP8.5 scenario and to have a large impact on soybean production in the region.

For the baseline, wheat is subject to higher heat stress in East Asia and South Asia than in the other regions. The RCP8.5 scenario predicts that Africa will be exposed to very strong heat stress, with the possibility that the region could become unsuitable for wheat growing. In East and South Asia and South America, the intensity of heat stress on wheat in the future will not be different from that of the current level, unlike other regions and other crops.

4. Discussion

Heat stress can be expected to pose a risk to crop production if greenhouse gas emissions continue to follow the current trend. Mid-latitude regions in the Northern Hemisphere will be most vulnerable to heat stress-related production risks. The IPCC (2007) has predicted that temperature rises and variability will be larger in temperate zones and that these will increase the risk that heat stress poses to crops. The aforementioned implies that agricultural production in countries in temperate and subtropical zones will suffer substantial climate change-induced losses, which is consistent with the results of previous studies (Fischer et al., 2005; Teixeira et al., 2013).

The intensity of heat stress on agricultural crops is predicted to be increase substantially in major agricultural regions, including China, America, and India, in the future. Figure 7 provides data on the production of the four crops by the top 10 producers during the past 10 years (2003-2012). China is the top producer of rice, producing approximately 0.19 billion tons, followed by India, with approximately 0.14 billion tons. In India, rice is already subject to strong heat stress, as shown by the baseline climate. In China, although the current level of heat stress is not high, it is predicted to become a major
problem and affect rice production in the future. Other than these countries, rice production is high in Indonesia, Bangladesh, Vietnam, Taiwan, Myanmar, and the Philippines. Parts of South Asia are subject to high levels of heat stress today, and the intensity of this heat stress is expected to increase in most South Asian regions in the future.

The U.S. is the top producer of maize, producing approximately 0.3 billion tons, which is approximately twice the production in China, the second largest producer of maize. According to the RCP8.5 scenario, heat stress will exert a strong impact on maize in Western parts of the U.S. and Eastern China, with heat stress predicted to rise sharply, despite the current low level. The other top 10 producers of maize include Brazil, Mexico, Argentina, India, Indonesia, France, the Ukraine, and Canada. In these countries, the influence of heat stress on maize production is forecasted to be relatively mild in the future.

Soybean is mostly produced in South American regions, such as Brazil (approximately 0.06 billion tons) and Argentina (approximately 0.04 billion tons). In these
regions, the heat-stress intensity predicted to slightly increase from the current level according to the RCP8.5, with strong stress in some regions. However, the overall impact of heat stress on soybean production is not expected to be particularly important. In contrast, China (approximately 0.015 billion tons) and India (approximately 0.01 billion tons), which are the third and fourth largest producers of soybean, respectively, are expected to experience a decrease in production in the future due to higher heat stress.

China is the number one producer of wheat, with production of approximately 0.1 billion tons. Although the impact of heat stress on wheat in the future is expected to be relatively small worldwide compared to that of other crops, heat stress is predicted to be a problem for some other major wheat producers, such as China, the U.S., and Canada, with subsequent effects on wheat production. The intensity of heat stress is predicted to be low in the future in other major wheat-production countries, including India, France, Germany, Australia, Pakistan, and Turkey.

In Korea, which imports approximately 75% of its food crops, including maize, wheat, and soybean, but not rice, heat stress-induced effects on crop production will directly affect food security (Fig. 8 and Fig. 9). According to a report by the Korea Rural Economic Institute (Kim and Kim, 2013), the production base of crops, except for rice, has diminished in Korea, and the cultivation area of rice is continuously shrinking. It is unlikely that increased domestic agricultural production will enhance the self-sufficiency rate. Thus, current domestic agricultural supply and demand, which is vulnerable to world agricultural supplies, demand, and price fluctuations, will persist in the future (Kim and Kim, 2013). As shown in Fig. 8, the self-sufficiency rate of Korea in grain production was 23.1% in 2013, which is the lowest level since the records began. Korea must take steps to address this issue. These should include making continuous efforts to increase the food security level, while closely monitoring world agricultural supply and demand and price fluctuations.

Figure 9 shows the quantity and value of imported crops in Korea in 2012. Imports of maize accounted for 52.6% (47.4% in imported value) of the total number of imported crops, followed by wheat, which accounted for 36.3% (32.4% in imported value) (MAFRA and aT, 2013). Imports of soybean accounted for 7.4% of the total imported crops (13.5% in imported value). With regard to rice production in which Korea has a relatively high self-sufficiency rate, the share of total imported crops was 1.6%. As the share of the four crops (rice, maize, soybean, and wheat) of the total imported crops to Korea is as high as 98%, it is very important to predict their worldwide production in the future and to craft a suitable response to deal with production shortfalls.

Figure 10 shows the imported quantity of the four major crops from the main exporters to Korea. China (31.2%) and the U.S. (26.2%) accounted for more than half the rice imports in Korea. In the U.S., high heat-stress intensity is already apparent in some regions, and high temperatures are expected to affect crop production in most regions in the future. Heat stress is also expected to exert severe effects on rice production in China in the future. Although Korea has a relatively high self-sufficiency rate in rice, as noted above, the area of rice cultivation is continuously shrinking. Hence, it will be important to take note of the rice production trends of the largest rice producers and exporters in China and the U.S.

Korea imports most of its maize from U.S. (34.9%), Brazil (24.3%), and Argentina (13.3%), with fewer amounts from Eastern European countries, such as the Ukraine, Serbia, Hungary, and Romania. In the U.S., maize production is currently subject to slight stress, and heat stress is expected to significantly increase in eastern parts of the U.S. in the future. The heat stress level in South American countries, such as Brazil and Argentina, is low at present, but it expected to rise in some parts of
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Figure 7. Production of the four different crops by the top 10 producers (Average 2003-2012).

Data: FAOSTAT

Figure 8. Changes in the self-sufficiency of Korean in crop and rice production.

Data: MAFRA, 2014
Figure 9. The quantity (left, tonnes) and value (right, 1,000$) of imported crops for 2012 in Korea.
Data: MAFRA and aT, 2013

Figure 10. The quantity (tonnes) of imported crops from the main exporters to Korea for 2012.
Data: MAFRA and aT, 2013
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Argentina in the future. Besides the aforementioned, crop production in other major Eastern European countries is expected to be exposed to relatively mild damage from high temperatures in the future.

Most soybean imports to Korea are from the U.S. (42.9%), Brazil (31.0%), Paraguay (13.5%), and China (10.8%). The U.S. is the top exporter of soybean to Korea, and strong heat stress has already been observed in the Central American region. Furthermore, high temperature-induced damage is expected to affect crop production in most regions of the U.S. in the future. In Brazil and Paraguay, the level of heat stress is very low at present, and the stress is predicted to remain at a low level in the future. In China, although the level of heat stress at present on soybean is low, heat stress is predicted to increase in many regions in the future.

Korea imports most of its wheat from the U.S. (43.2%) and from Australia (41.3%). In the U.S., heat stress on wheat is currently low in most regions, but this is expected to rise substantially in some parts of North America in the future. Australia has almost zero heat stress on wheat as of now, and wheat production is expected to continue under a stable environment in the future.

5. Conclusions

This study examined the risk of climate change-induced heat stress on agricultural crops at the global scale using HadGEM2-AO RCP2.6 and RCP8.5 scenario data. Although global model data are suitable for a large-scale analysis, it is not possible to interpret the high-resolution data at a local level due to the large uncertainty that exists in each grid at the cell level. This study did not consider a number of factors, including the microclimate, soil properties, socio-economic conditions, technologies, and infrastructure, all of which can be expected to affect heat stress at a local level. To detect local impacts of heat stress and identify adaptation strategies, the impact of heat stress on crops will need to be evaluated in a more high-resolution space in the future. In addition, this study uses a global climate change model and therefore excludes a key source of uncertainty in crop response to projected climate impacts. The need for research into uncertainties associated with different climate models is increasingly recognized (Deryng et al., 2015; Rosenzweig et al., 2014; Elliott et al., 2015; Müller et al., 2015).

This study confirmed that climate change affects tropical agriculture. If greenhouse gas emission continues to follow current trends, and efforts are not taken to mitigate climate change, the resulting high temperatures will affect agriculture in temperature and subtropical zones, with subsequent implications for the world food supply. This study points to a serious threat to food security in Korea, which depends on imports for most of its crop demands. To minimize the risks that heat stress poses to the world food supply, mitigation measures aimed at global climate change, as well as actively investing in local adaptation strategies, such as the development of new varieties that have a high tolerance to heat and changes in crop management, will be required.

References


Kim, T. H. and Kim, J. Y., 2013, Development of food security index, Korea Rural Economic Institute, 68. (In Korean with English abstract)


MAFRA and aT, 2013, Export and import trends for food, agriculture, forestry and fisheries, Ministry for Agriculture, Food and Rural Affairs (MAFRA) and Korea Agro-Fisheries & Food Trade Corp. (aT), 347. (in Korean)

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Vara Prasad, P. V., Boote, K. J., and Allen, J. L. H., 2006, Adverse high temperature effects on pollen viability, seed-set, seed yield and harvest index of grain sorghum [Sorghum bicolor (L.) Moench] are more severe at elevated carbon dioxide due to higher tissue temperatures. Agr. Forest Meteor., 139, 237-251.


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