Chapter 5
Climate Change Forecasting and Modeling for the Year of 2050

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Abstract Climate change as a result of global warming is a concern all over the world. Scientists have tried to understand the place in the future scenario of climate change by developing different forecasting systems to investigate these concerns. There are many forecasting systems have been developed to plan and minimize the negative consequences of climate change in various fields in our lives. Agriculture is a production platform and severely affected by parameters result from climate change such as drought, flooding, heat and cold stresses. Climate Forecast and agriculture is an interdisciplinary research program based on advances in various fields. It is predicted that the temperature, which is expected to increase by 2 °C by 2050, will cause close to 50 million people to experience hunger risk due to agricultural effects. This concern in agriculture has demonstrated the need for maximum use of agricultural resources and areas. Many models have been developed for these purposes, which are a simplified description of a system through a computer adapted representation that allows us to conduct virtual experiments. In this chapter, there is brief discussion of climate change for the year of 2050 through the world and information about forecasting and modelling systems on agriculture.

Keywords Climate change · Modelling · Forecasting system · Agriculture

5.1 Overview

Climate change is defined as alteration on climate due to anthropogenic (human-induced) activities that directly or indirectly alter the composition of the atmosphere, in addition to the natural variability of the climate observed in a comparable period. Human activities, such as fossil fuel use, deforestation, wrong land use, agricultural activities and industrial processes, cause climate change by changing the composition of the atmosphere. Consumption of fossil fuels, together with other

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human activities, has been caused increasing the atmospheric concentrations by creating a greenhouse effects by gases. In global temperature estimations on agriculture, it is predicted that the temperature, which is expected to increase by 2 °C by 2050, will cause close to 50 million people to experience hunger risk due to agricultural effects (Watkiss 2005; Fahad and Bano 2012; Fahad et al. 2013, 2014a, b, 2015a, b, 2016a, b, c, d, 2017, 2018, 2019a, b). Agriculture is one of the most valuable field among economic sectors due to the nature of the impacts of climate change. Production process include the direct use of weather inputs (temperature, solar radiation and rainfall). Climate change alter the weather and thus has a direct, biophysical effect on agricultural productivity. How can science help to get over all complexities arising from environmental situations? On one sense, continuous explosion in the amount of published information and data gives opportunities from every field of science. Due to the major effects of climate change such as drought, heat, flooding and freezing, there have been essential needs on agricultural forecast systems. Additionally, scientific examination of an agricultural ecosystem requires a system model and interactions of components that take into account agricultural production, natural resources, environmental and human factors. The model, once operated by the simulation mechanism, contains a set of instructions, rules, equality or constraints based on input and output behavior. Therefore, models are required to understand and estimate overall agroecosystem performance for specific purposes (Wallach et al. 2018). In conclusion, climate change by the year of 2050 will cause severe effects on every branch of our lives, however, we have huge data about forecast and modelling systems that enable us to predict the adverse conditions and their possible solutions by the help of simulations. Thus, understanding and improvement in forecast and modelling systems will enable us the precious way to save our future generations.

5.2 Climate Change and Its Effects

Climate change is defined as alteration on climate due to anthropogenic (human-induced) activities that directly or indirectly alter the composition of the atmosphere, in addition to the natural variability of the climate observed in a comparable period according to the United Nations Framework Convention on Climate Change (UNFCCC) (BMİDÇS 1992).

Human activities, such as fossil fuel use, deforestation, wrong land use, agricultural activities and industrial processes, cause climate change by changing the composition of the atmosphere. Consumption of fossil fuels, together with other human activities, has been caused increasing the atmospheric concentrations by creating a greenhouse effects by gases that are naturally present in the composition of the atmosphere and make the world a livable place. As the greenhouse gases in the atmosphere are permeable to the incoming solar radiation, but are much less permeable to the long-wave (infrared) ground radiation emitted, this natural process which makes the world warm up more than expected and regulates the heat balance is called "Greenhouse Effect" (Türkeş 2001) (Fig. 5.1).

In global temperature estimations on agriculture (Fig. 5.1), developing countries will be adversely affected by the increasing temperature rise. However, the European Union countries and the USA will be positively affected by the temperature rise up to 2 ° C. However, it is estimated that the average temperature increases exceeding 2 °C will have negative consequences for the European Union countries. In addition, a temperature increase of 2.5 °C by 2080 will cause hunger risk on close to 50 million people (Watkiss 2005). Due to rising temperatures, areas where certain crops are grown will change northward and higher. This will adversely affect developing countries in the tropics. African and Central American countries in the tropics, who earn most of their income from exports of agricultural products, will be adversely affected by global warming. For example, rice production in the Philippines is expected to be adversely affected by the increasing temperature rise. In a case where the temperature rise is 1 °C, 10% reduction in rice production is expected. Countries in the northern latitudes, such as Canada and Russia, will have

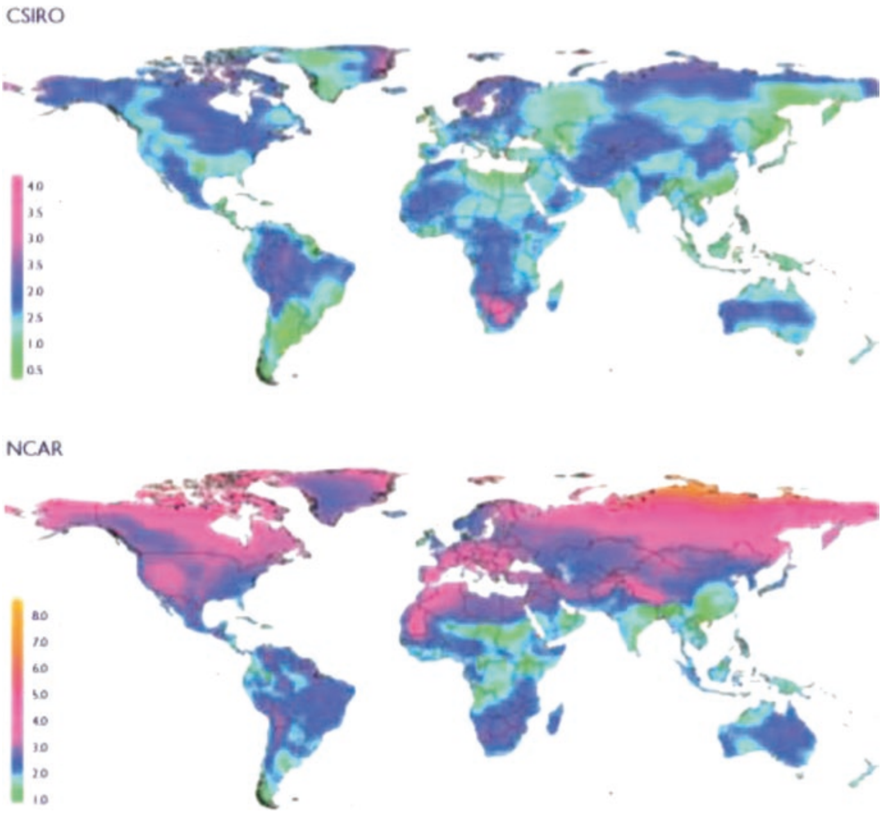

Fig. 5.1 Shows the change in average maximum temperature between 2000 and 2050 for the CSIRO and NCAR scenarios (IFPRI 2009)

expanding agricultural areas due to global warming. However, even if the climate in these countries offers favorable conditions, there are some doubts that soil conditions may be suitable for intensive agriculture (UNEP 2006). Changes in the rainfall will have an impact on agriculture. In this respect, the southern latitudes, which are mostly developing countries, will be at a disadvantage compared to the northern latitudes. Increased carbon dioxide concentration in the atmosphere is expected to contribute positively to the growth of certain agricultural products. Plants classified as C3-class, including rice and wheat (plants with high carbon dioxide concentration and low temperature, low ability to use light intensity, temperate zone plants), will be positively affected by the increased amount of carbon dioxide. In addition, C4-class plants such as corn, sugar cane (plants with low carbon dioxide concentration, high temperature and lower water requirements, seasonal drought-resistant organic compounds that initially contain 4 carbon atoms, high ability to use light intensity), increased carbon dioxide amount will be negatively affected. These products are grown mainly in African and Latin American countries.

Assuming no CO2 fertilizer effect in developing countries, there is a decrease in agricultural products compared to 2000 in 2050. In these countries, the highest crop losses are expected to be in rice and wheat grown by irrigation systems. On the other hand, it is seen that developed countries are less affected by these effects of climate change on average compared to developing countries and even climate change has a positive effect on the quantity of some agricultural products in developed countries (IFPRI 2009).

While making these projections depending on climate change scenarios, the situations of Central and Far East Asian countries including China were taken into consideration and countries with tropical temperate climate were evaluated. Accordingly, South East Asian countries such as Indonesia, Philippines, Singapore, Vietnam, Cambodia and Thailand are expected to experience severe losses of agricultural products due to climate change, and decrease in the productivity and product quality of all product groups in these countries is expected (IFPRI 2009).

On the other hand, the CO2 fertilizer effect slows down product reductions in some regions and increases the amount of products in some products compared to 2000. Nevertheless, there may be decreases in the production amount of corn grown with rain water and wheat grown with irrigation system/rain water. In Sub-Saharan Africa, the situation is more complex. As a matter of fact, there may be small ups and downs in the production of rain-growing corn; the most negative effect is observed in the amount of wheat grown by rain. Lastly, the effects of climate change in Latin America and the Caribbean cause some product increase in some products, but some decrease in the amount of product in some regions. Since the occupancy rate of the watersheds of the countries depends on the amount of precipitation, climate change is expected to have a direct impact on the watersheds and aquifers. As a matter of fact, in both climate scenarios (NCAR and CSIRO), they concluded that climate change will reduce the amount of precipitation falling on the earth. Changes in the amount of precipitation may increase the need for agricultural products to water due to the increasing temperatures and climate change. A small increase in the water consumption rate is expected to create great stresses on crops where irrigation is made (IFPRI 2009).

Agriculture both promotes the climate change and can be affected by climate change. The EU needs to decrease greenhouse gas emissions from agriculture and adapt the food production system to overcome effects of climate change. However, climate change is just one of many oppression on agriculture. Encounter with increasing global demand and rivalry for resources.

Agricultural production is heavily dependent on air, climate and water availability and is severely affected by weather and climate disasters. The occurrence of rain and natural disasters such like drought and flood can cause crop degradation, famine, food-insecurity, loss of property and lives and negative national economic growth. Therefore, the use of various traditional indicators in order to estimate seasonal climate behaviour is major key factor that enable agricultural communities to cope with climate variability.

Since we live in dynamic society where economic conditions and consequently price and relations among prices are constantly changing, our decisions and business decisions are largely based on forecasts. An forecast is an expression of what can be expected based on current situations and observations interpreted in light of previous experiences; and the basis for deciding what action to take to achieve the desired result. A scientific prediction is an estimate based on a discovered systematic order of normal experience.

It is likely that several avenues will improve the quality of forecasts of the agricultural impacts of climate change over the next five to ten years. First, dynamically combined crop models in climate models is going to promote a refined two-way interaction among agricultural and atmosphere land use. Secondly, remote-sensing and increase of spatial environmental databases supplies significant opportunities to increase the use and improve the quality and tenacity of climate based crop forecasts. Finally, climate-based crop estimates will benefit every branch of agricultural community based on weather within climate.

5.3 Agricultural Forecasting

Climate Forecast and Agriculture is an interdisciplinary research program based on advances in various fields, particularly in climate forecasting science, to reduce large-area climate forecasts for local applications and to improve alternative scenarios for the integration into operational crop models in order to minimize the effects of climate risks and maximize benefit for agricultural communities.

The major weather variables for crop estimation are precipitation, solar radiation and temperature, humidity and wind speed also play a role. Doblas-Reyes et al. (2006) reported that seasonal climate forecasts can provide insight into future climate development in seasonal timelines, as the slowly evolving variability in the oceans significantly affects changes in weather statistics. The climate forecasting community can now offer an end-to-end multi-scale (in space and over time) integrated forecasting system that provides skilled, useful estimates of variables with socio-economic interest.

How can science help to get over all complexities arising from environmental situations? On one sense, continuous explosion in the amount of published information and data gives opportunities from every field of science. On the other sense, the problem of handle all this information and supporting data becomes severe difficulties and causes information overload. The continuous knowledge explosion is promoting the important recognition of interconnectedness of what should have been applied earlier as independent process and components. These kind of interactions between components may get major effects on responses of system, thus overall system by studying components in isolation is not sufficient to make conclusions (Hieronymi 2013). These interactions go beyond the limits of traditional discipline. Although there is a strong emphasis on disciplinary science that causes a better understanding of the components and individual processes, system science is also increasingly emphasized.

Scientific examination of an agricultural ecosystem requires a system model and interactions of components that take into account agricultural production, natural resources, environmental and human factors. Therefore, models are required to understand and estimate overall agroecosystem performance for specific purposes. Data is needed to improve, estimate, and run models so that when a system is examined, inferences about the actual system can be simulated by model-based "experiments. If we need to list what these data are; crop yield, climate demands of the relevant crop and anticipation of possible risks, market characteristics and consumer requests of the related crop, etc. The development of integrated model-based prediction that will predict the future with all of these data at the same time is of paramount importance, and interest and demand have also increased in the near future.

Systems science, real world consisting of components defined by the expert "systems" to investigate. These components interact with each other and their environment in order to designate overall system behavior (Wallach et al. 2018). These interacting components are affected by an external environment that can affect the behavior of system components, but the environment itself cannot be exposed to changes that occur within the system boundary. Even though systems are small abstraction of the real world defined for specific targets, they are very useful in science and engineering in each branch of fields, consist of agriculture. An agricultural system or agricultural ecosystem is, as a general objective, a collection of components that produce crops and animal husbandry to produce food, fiber and energy from the world's natural resources. Such systems can also result in undesirable effects on the environment.

5.3.1 Forecasting Systems Developed in Last Decade

Due to the major effects of climate change such as drought, heat, flooding and freezing, there have been essential needs on agricultural forecast systems. In history, there are several model systems have been created for combat ability on climate change such as autoregressive integrated moving average (ARIMA), regression analysis, Markov chain, fuzzy logic (FL), different hybrid models, artificial neural network (ANN) and support vector regression (SVR) model systems (Han et al. 2010; Ozger et al. 2011; Belayneh et al. 2014; Masinde 2014; Stagge et al. 2015; Taormina et al. 2015; Belayneh et al. 2016; Sun et al. 2017; Ghorbani et al. 2018; Moazenzadeh et al. 2018).

Despite of the large variety data about forecasting models, researchers are still getting trouble to choose which model the best suited to their work. Therefore, the compilation of the model studies conducted in the last decade and briefly analysis of the pros and cons of the different models are definitely useful for the readers.

Regression analysis is simple and direct and has low computational cost, although it is not essential for long-lead forecasting by the reason of the assumption of linearity and need huge number of versions are required to produce accurate predictions. Stochastic models has ability to suit well to linear data, and it is systematic study for estimation, identification and diagnostic check for model development. However, low ability to model data with nonlinear characteristics and complicated computations are the main disadvantages for stochastic model. Probabilistic models is enable to combat with complex distributions but computationally expensive. The advantages of artificial neural network are the enable of detection all possible interactions among predictors and making multiple training algorithm, even though it is expensive and prone to over-fitting. Fuzzy logic has capability to model imprecise information and rule the arbitrary complexities, but the increasing fuzzy rules make the model expensive. Support vector machine can prevent over-fitting and has different kernels available for different datasets. However, support vector machines is numerically expensive in verification stage. Hybrid models have ability to compare pros of different models, although it requires large informative data to understand multiple models. Dynamic modelling gives real time results good for monitoring and forecasting purposes, but good connections is required among input and forecast system (Fung et al. 2019).

As a result, there are many criteria that affect the performance and accuracy of forecasting models. Appropriate inputs with appropriate time scales and appropriate timeframes are key factors for accurate estimations. The literature are also showing that the use of pre-treatment techniques give advantages to improve the accuracy of the models.

5.4 Modeling and Its History

Modeling is to create a structure that captures the interesting or noteworthy features and processes of the research topic. The model is simplified description of a system through a computer adapted representation that allows us to conduct virtual experiments on the behavior of a system. A system model is an abstract expression of its reality, with the exception of some details of its environment. The model, once operated by the simulation mechanism, contains a set of instructions, rules, equality or constraints based on input and output behavior. Many computer models have been developed for agricultural production systems. The models designed based on their specific purpose and in terms of the modeling and simulation approach on which they are based are quite different.

The history of agricultural system modeling is mainly based on the need of scientists from different branches to use models for different purposes. The first agricultural modeling was conducted by Earl Heady and his students on farm scale to assess the benefits of rural development on economic factors (Heady 1957). Following these early modeling studies in the 1950s, in 2012 Dent provided a book describing economic and biological contents and models of the agricultural system as an important resource. Shortly after agricultural economists began to model farm systems, a system called the International Biological Program (IBP) was created to help develop various ecological models that would also work in animal husbandry (Van Dyne and Anway 1976).

Later in the 1960s, physicists from Wageningen University made major contributions to the advancement of agricultural modeling within biological and physical principles. Another pioneer is W.G.Duncan, a chemical engineer who contributed to science with his publications on modeling of canopy photosynthesis. Even in the later years of his PhD, he began working on the first crop-specific simulation model especially for corn and maize. Integrated Pest Management has begun to arise with the study of diseases and pests on plantation in Malaysia (Duncan et al. 1967). The studies initiated especially by the pioneers in the modeling continued its development over the years. Wageningen University has taken great steps to reach the most widely used modeling techniques by educating many experts in agricultural modeling. In the 1990s, there has been an increase in modeling studies on the understanding of the effects of climate change on crops and economic aspects on a global scale. For this purpose, modeling studies have become widespread in order to understand the effects of greenhouse gas and carbon dynamics as well as economic modeling (IPPC 1990).

From the late 1990s to 2010, many individuals and seed companies interested in modeling have made great efforts to adapt ecophysiological effects to plant breeding with the help of modeling (White and Hoogenboom 1996). Modeling studies from 2006 to the present have focused on climate forecasts in the future. In particular, modeling studies continued on the investigation of the interaction of carbon dioxide effect with temperature and other factors important for plant growth (Long et al. 2006). With the increasing importance given to the issue, after 2010, some private companies formed their own teams for modeling and some of them continued to work with public-private partnership.

5.4.1 Types and Brief Descriptions of Modelling Systems

There are several models have been created based on the characteristics of the systems to be examined and research objectives. Oteng Darko et al. (2013) have reported several model systems. Empirical model is a direct definition of the obtained or collected data expressed by regression equations. Regression equations can be used for one or more factors. The data is obtained, the equation is established and the desired result yield is easily calculated. For example, determining the relationship between fertilizer application and final yield. Other model system is mechanistic model which observed the results in the lowest level. An example would be to evaluate at the cell level. With the help of these models, it is provided to respond to the short process by imitation of the physical, biological or chemical process of interest. Such systems are generally divided into parts according to their operations. Thus, modeling starts experimentally and evaluations are continued by adding variables. Based on static and dynamic models, time is not accepted as a variable, whereas in the dynamic model, time is used as an important and indispensable variable while the last data to be obtained in the static model is formed over time. Simulation models is such model systems which are designed to mimic a system that actually exists naturally; they are easily adaptable to changes in weather and soil conditions. It is necessary to have a lot of inputs in this model type to obtain more clear and easy information. In this way, management methods can be obtained inexpensively, especially on the subject of interest. Additional to that report, Brockington (1979) has reported a model, deterministic model, is a kind of model commonly used in the evaluation of quantities such as yield without any variance. However, such data is also often observed in variance, this heterogeneity is something that is biologically inherent to agricultural systems. In spite of these intrinsic changes, although the deterministic model is still quite usable, the accuracy of the model decreases if the changes increase.

One of the other key subject is the mechanism of simulation and modeling. While, modeling is a kind of exhibition of a model that consist of construction and working similar to real system, which provide analyze predict the changes to system, system simulation is a study of a model in terms of space or time that provide analyze the performance of an available or a offered system. Cros et al. (2003) have reported several simulation systems. Spreadsheet simulation refers to the use of a spreadsheet as a platform for representing simulation models and performing simulation experiments. Spreadsheet simulation is often used for agricultural production system applications where logical relationships between studies variables are established (ration analysis) and can be defined by simple static models that are mathematically represented. Secondly, continuous system approach expresses continuous state variables and time with systems of differential equations. In other words, the rate of change of state variables is defined by derivative functions. Additionally, discrete time systems assume a graded mode of operation. The dynamics of the system are represented by differential equations or transfer functions, which generally explain how to update state variables based on the state in the previous time step or inputs (influencing factors). The simulation mechanism is based on one-step iterative algorithms. They jump from one simulation step to another and calculate the status after the current status and inputs. All model variables are scanned at each step. In the discrete-event system approach, the transition functions specify local changes, similar to the modeling used for discrete-time systems in modeling the dynamic behavior of the system. In addition, this approach is based on identifying events that cause transitions when they occur. The most important difference with discrete time systems is the event processing mechanism. This mechanism allows you to jump from one point to another when the time comes (when the event occurs). It only scans the time points and variables related to the current event. If the event does not occur during the operating time, the status change will not occur. The simulation clock depends on the event. The discrete event simulation runs by reading the list of events sorted by their scheduled times. Events are taken from this list and processed in sequence, and relational operations that produce state transitions are executed. According to the results of the transaction, new events can be planned and put on the list or the old ones can be deactivated or discarded. Events can be caused by environmental conditions that are not under the control of the system itself.

LINGRA is a crop growth model enhanced by the former DLO-Winand Staring Centre (SC-DLO) together with the former Research Institute for Agrobiology and Soil Fertility (AB-DLO), both placed in Wageningen and now piece of ALTERRA, The Netherlands.

The GRASSLAND GROWTH MODEL – LINGRA (LINTUL Grassland) was developed to foresee accretion and progress of perennial rye grass across the member states of the EC at the level of potential production and water restricted production. The model is on the basis of the LINTUL (Light Interception and Utilisation simulator) conceptions as offered by Spitters (Bouman et al. 1996). The main basis of this concept is that crop growth is proportionate to the quantity of light intercepted by canopy (Bouman et al. 1996).

$$\text{Yield equation of LINGRA}; \int_{t=1}^{n} ft * PARt * Et * HI$$

**ft*: fraction of PAR intercepted by the leaves or foliages
**PARt*: active radiation of photosynthesis
**Et*: utilization of light efficiency during dry matter transformation
**HI*: dynamic grass specific fractioning

Wheat, rice, corn, soybeans have a very important place in human nutrition. Over time, global temperature rise will be inevitable. It is very important to evaluate the effects of temperature rise on these nutrients, which are important for human calorie intake. However, different studies have yielded different results. Zhao et al. (2017) used four analytical methods to investigate the effect of temperature on these products and compiled the results. These analytical methods are global grid based, local point based models, statistical regressions and field warming experiments. According to the results obtained in this study, it has been found that temperature increase has negative effects on these products and the results obtained from different methods were obtained in a similar manner. If the plant is not genetically developed as a result of every 1 degree increase in average temperature as a result of climate change, average global yield will decrease by 6% in wheat, 3.2% in rice, 7.4% in corn, and 3.1% in soybeans. Apart from the main crops, some positive results were also obtained. Thus, the reliability of modeling of multi-method analyzes was provided and the adaptation studies specific to the region or crop were initiated in order to ensure future food safety.

Agricultural production climate change and yield estimates are determined by the establishment of climate change scenarios or by statistical modeling of climate change forecasts from year to year. Many factors in agriculture are affected by climate change, and the number of crops per seeding area and the season also affects yields. In 2016, in Brazil, which is a very important agricultural region, the response of crop area and product frequency to climate change and how crop yields change as a result were modeled (Cohn et al. 2016). In this modeling, climate change resulted in approximately 70% frequency and area changes. Losses in hot and wet areas when an association is made; gains were obtained in cold and dry regions. It is not right to look directly at efficiency in climate change. In order to minimize these effects, it is necessary to consider not only the yield decreases but also the frequency of the area and crop.

Due to the limited water resources in the world, agricultural water use efficiency should be increased. Crop simulation models play an important role in assessing the change in water use and yield and in developing strategies for improving water use efficiency. Many agricultural models already exist, but the use of the model becomes difficult due to the limit of access to the model source code. Together with the study conducted by Foster et al. (2017), An open-source version of the model FAO AquaCrop, which simulates product production based on the amount of water, can be used in multiple languages and operating systems. Parallel application support can be used with this model and provides convenience in large geographical frameworks.

In conclusion, the need to predict the effects of climate change on agricultural production is an essential element in the development and analysis of scenarios that affect farmers' income and food safety. Owing to both the need to address the impact of climate change and the interest in increasing the ability to supply predictions globally, there has been a change in the type of model required to predict the amount of yield loss requiring models with broader workableness. Modelers overcome the scarcity of reference data and the need to develop the robustness and operability of modelling systems under these conditions in order to meet both requirements. We believe that agricultural modeling and forecasting systems provide a critical opportunity to overcome these obstacles, and we also believe, therefore, a vital need to develop modeling and forecasting capabilities to address all challenges based on climate change by 2050.

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