A 1-KM GRID METEOROLOGICAL DATA SERVICE AND ITS USE TO REDUCE WEATHER AND CLIMATE RISKS FOR FIELD CROP PRODUCTIONS

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ABSTRACT

Agriculture in Japan now faces two major challenges: climate change and a shrinking working population. To help resolve these issues, we have developed a meteorological data service that serves daily meteorological data and covers the entire country in a 1-km grid. This dataset is composed of 13 different kinds of meteorological elements, including daily mean air temperature, daily accumulated global solar radiation, daily mean humidity, and snow water equivalent. The dataset spans from 1980 (or 2008 for some elements) to one year after the day on which a user uses the dataset. (Hereinafter the use date is referred to as "today"). For all days before today, the dataset provides observed values. For today to up to 26 days later, the dataset provides predicted values. From 27 days after today, the dataset provides climatic normal values. The dataset is updated daily based on the latest weather forecast. The dataset has a unique distribution system that allows registered users to obtain only needed data from an application program on demand. Combining accurate crop development predictions using this dataset with existing techniques and knowledge about crops' responses to meteorological stress should reduce damage caused by stress as well as mitigate meteorological and climatic risks in farming by realizing crop management that anticipates weather and takes countermeasures in account.

Keywords: Grid square, Weather Forecast, Crop management, Climate Change Scenario, Web-API

INTRODUCTION

Climate change is now impacting agriculture in Japan. The latest statistical data shows that the mean air temperature increases 1.19℃ per 100 years and that the number of days with a daily minimum temperature at or above 25 ℃ significantly increases at a ratio of 17 days per 100 years (JMA 2017). Due to the high temperatures, paddy rice, which is a staple in Japan, is more likely to form a chalky grain. Chalky grain is a problem nationwide. In 2010, a year with extremely high air temperatures, Niigata Prefecture, which is a well-known excellent tasting paddy rice production area, experienced a significantly decrease in the proportion of rice classified as 1st class; only 20.3% of the rice produced in the prefecture was considered 1st class (MAFF 2011). This greatly shocked all stakeholders. Similarly, fruit production also faces an increased number of problems, including poor skin color in apples and grapes, peel puffing in Satsuma mandarins, and fruit flesh disorders in Japanese pears and peaches. Moreover, dead flower buds in Japanese pears and freezing injury in Japanese chestnuts due to reduced freezing resistance have also been reported (Sugiura *et al*. 2012).

To adapt Japanese agriculture to climate change, planting plans need to be reviewed by reexamining areas conducive for crop cultivation and accurately understanding the current situation and trends in the suitable times for growing crops based on long-term climatic conditions. Namely, crop management, which suppresses damage to crops due to high temperatures in real-time or with advanced weather forecasts, is needed.

Another issue facing agriculture in Japan is the declining working population due to an aging population. The continuously and rapidly aging workforce in the agricultural sector (MAFF 2018) suggests that the reduction in the working population in the sector will continue. As farmers give up agriculture, most of the farmlands are consolidated. Consolidated farmlands are operated by local active farmers or farming operation entities, the so-called *ninaite* farmers. As most consolidated farmlands are small sized, many *ninaite* farmers cultivate numerous small but distributed fields. To efficiently farm such fields, level resources (machinery and workforce) are more important than introducing large machinery. To realize such leveling, meteorological data is critical as it allows farmers to accurately predict the growth of diverse crops.

Thus, to resolve challenges facing Japanese agriculture, namely climate change and a shrinking working population, it is necessary to develop advanced crop management technologies that utilize meteorological data in a sophisticated manner. For practical implementation by farmers, such management technologies must (1) employ timely meteorological data that spans the entire country, (2) provide long-term data so farmers can understand which areas are suitable for cultivation, (3) model times of future harvests, and (4) incorporate weather forecasts that effectively anticipate abnormal weather conditions. Given this need, the National Agricultural Research Organization (NARO) has developed a new crop management supporting technology that utilizes meteorological information in a sophisticated manner and a meteorological data service system that facilitates use of technology.

1-KM GRID METEOROLOGICAL DATA SERVICE

NARO has been tackling the challenges of Japanese agriculture using a multi-faceted approach. First, technologies are being developed to handle problems such as reduced production and poor crop quality due to high temperatures. Second, techniques are being established to combine different kinds of crops, varietal species, and cultivation periods in a complex manner. As a part of such efforts, we have been developing a meteorological data system, called the Agro-Meteorological Grid Square Data (AMGSD) System, that can meet the high-spec demands from these technologies and techniques. AMGSD System can generate and deliver daily meteorological data, including weather forecast data (Ohno. 2014).

The gro-eteorological Grid Square Data

AMGSD is a set of daily meteorological data spanning from January 1, 1980 to December 31 of the following year after AMGSD is used. Hereafter, the use day of AMGSD is called today. AMGSD covers all of Japan with a grid square size of 30 seconds of longitude × 45 seconds of latitude (about 1 km × 1 km). Data for the term from January 1, 1980 (or partial data for some elements from January 1, 2008) to the day before today (yesterday) is created based on meteorological observations conducted at approximately 1300 points. Data for the term from today to nine days in the future is created based on forecasted values. Data for the term from 10 days after today to up to 26 days after today is created based on long-term forecast guidance. For the term from 27 days after today and beyond is based on daily climatic normal values. AMGSD is updated daily to reflect the latest observed and predicted values (Ohno *et al.* 2016). Namely, AMGSD is a dynamic dataset that includes predicted values. Both the observed and predicted values published by the Japan Meteorological Agency (JMA) are used to update AMGSD. Table 1 shows the data resources used to generate AMGSD. Figure 1 shows the procedures to create the data for AMGSD using the observed values and the predicted values provided by JMA.

AMGSD is composed of 13 meteorological elements (Table 2). It includes not only data that has been commonly used for crop management such as air temperature, precipitation, and sunshine duration but also humidity, solar radiation, atmospheric radiation, snow water equivalent data. Atmospheric radiation data can be effectively used to predict frost damage and snow water equivalent data can be used as an indicator to predict snow damage of agricultural facilities in the winter. It also includes all meteorological elements that are necessary to calculate the heat budget of the land surface, allowing users to estimate the water temperature of paddy fields with aero-dynamical method. AMGSD is a unique dataset because it provides long-term data (up to 40 years) in which weather forecasts are included, and a variety of meteorological elements (13 elements) in a fine-grid size (1 km).

Table 1. The JMA's Meteorological product used to generate the AMGSD.

Name of data	Abbreviation	Overview
Automated Meteorological Data Acquisition System	AMeDAS	Land weather observation network operated by the JMA. Observational devices / facilities are located approximately 1,300 throughout Japan.
Grid Point Value of the Meso Scale Model	MSM-GPV	The MSM model covers the area around Japan on an approx. 5 km grid and predicts up to 1.5 days (39 hours) in the future.
Grid Point Value of JMA Global Spectral Scale Model (Around Japan)	GSM-GPV	The GSM model covers the globe on an approx. 20 km grid and predicts up to 9 days in the future.
The guidance for 1-month forecast	Guidance	The guidance is based on the result of the long-range forecast edition of GSM, this predicts the deviation from the norm by area up to 4 weeks in the future.

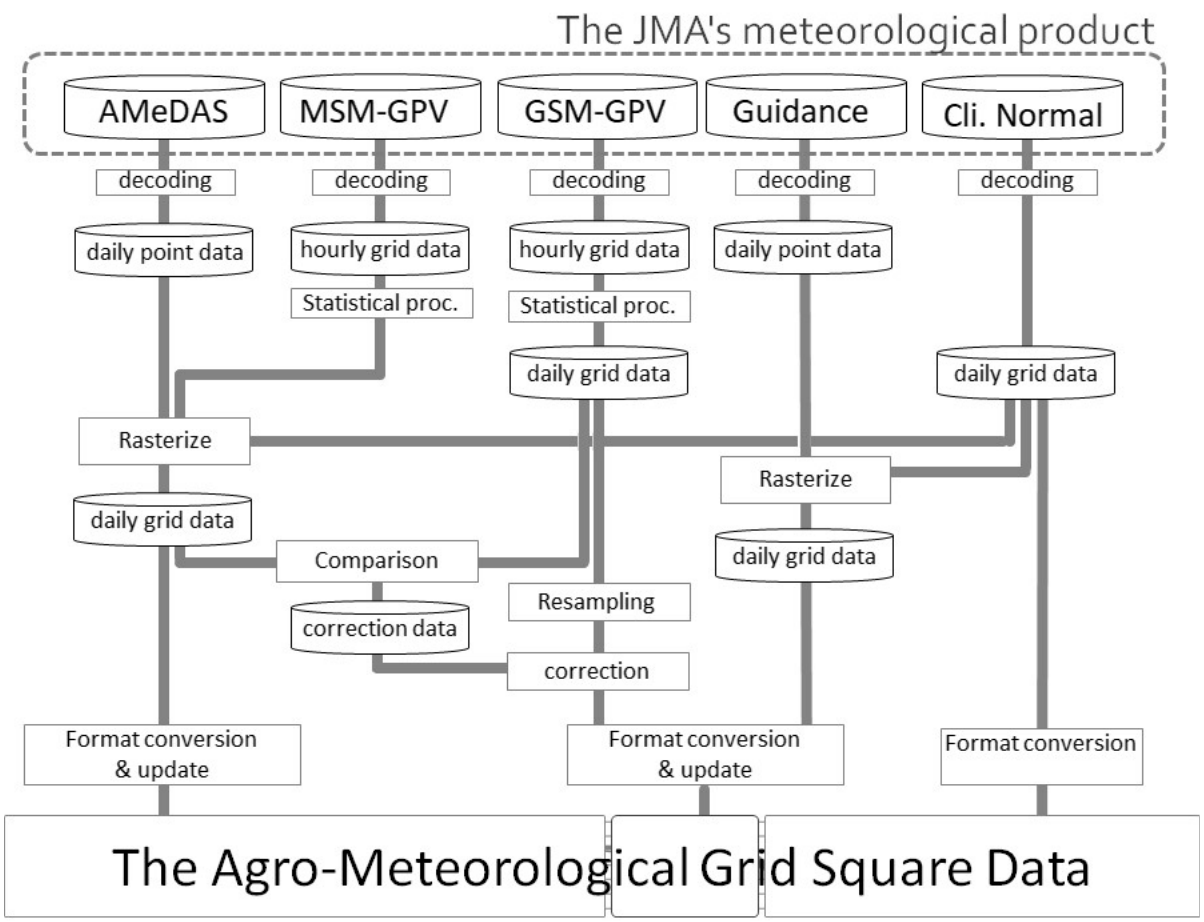

Fig. 1. Process to generate AMGSD

Table 2. Meteorological elements included in AMGSD and terms available for each element

Met. Elements	Time domain of the data		
	Observation based values	Forecasting based values	Climatic normal values
mean air temperature	1980.1.1 - yesterday	today - 26 days in the future	- end of the next year
maximum air temperature	1980.1.1 - yesterday	today - 26 days in the future	- end of the next year
minimum air temperature	1980.1.1 - yesterday	today - 26 days in the future	- end of the next year
total precipitation	1980.1.1 - yesterday	today - 26 days in the future	- end of the next year
occurrence of precipitation more than 1mm	1980.1.1 - yesterday	today - 9 days in the future	- end of the next year
sunshine duration	1980.1.1 - yesterday	not available	- end of the next year
global solar radiation	1980.1.1 - yesterday	not available	- end of the next year
atmospheric radiation	2008.1.1 - yesterday	today - 9 days in the future	not available
mean relative humidity	2008.1.1 - yesterday	today - 9 days in the future	not available
mean wind speed	2008.1.1 - yesterday	today - 9 days in the future	not available
snow depth	1980.10.1 - yesterday	today - 9 days in the future	not available
deposited snow water equivalent	1980.10.1 - yesterday	today - 9 days in the future	not available
newly fallen snow water equivalent	1980.10.1 - yesterday	today - 9 days in the future	not available

Data delivery service

In most cases, meteorological data services provide their own websites, which users visit, select, and download desired data via CSV or another format. In most cases, the data obtained from such servers is provided by month or year in separate files. If a user needs data for a different range (e.g., three months), he or she must download a file multiple times to obtain the desired range. The geographical unit is similarly divided. Furthermore, data downloaded from such servers is already named. Users who process the obtained data must refer to the given file name in the intended application or program. Repeating such procedures is extremely inefficient because meteorological data is renewed daily and users who use meteorological data by converting it into agricultural data through defined procedures have to repeatedly perform the conversion processes.

In contrast, our data service system, AMGSDS, delivers AMGSD to the user via a dedicated server.
AMGSDS can respond to requests from application programs (e.g., spreadsheet software and programming languages) and provide needed data on demand. Considering that the working population in agriculture is not always familiar with computer programing, we offer two support measures for users to obtain data from AMGSDS. One is the provision of a Microsoft Excel workbook, which is dedicated to obtain data from AMGSDS. This Excel workbook incorporates a Visual Basic for Applications (VBA) program. When a user inputs the desired latitude, longitude, year, and meteorological elements and then clicks the Submit button, the VBA program communicates with AMGSDS and writes the requested data in stipulated cells (Fig. 2). If a user adds any function that refers to cells with meteorological data, just clicking the Submit button of this Excel workbook provides meteorological data

based on the latest prediction and processed data.

Another support measure is the provision of a Python Library. Python is an extremely strong programming language, which is friendly for those who are not familiar with programming. We have developed a function that acquires the needed data by communicating AMGSDS as well as a function that visualizes the calculation results. We have compiled these and other functions into a library, called a Python Library. This Library is provided for public users. When a user develops a program to process meteorological data using this Library, he or she can obtain the calculation results based on the latest meteorological prediction only by executing this program (Fig. 3).

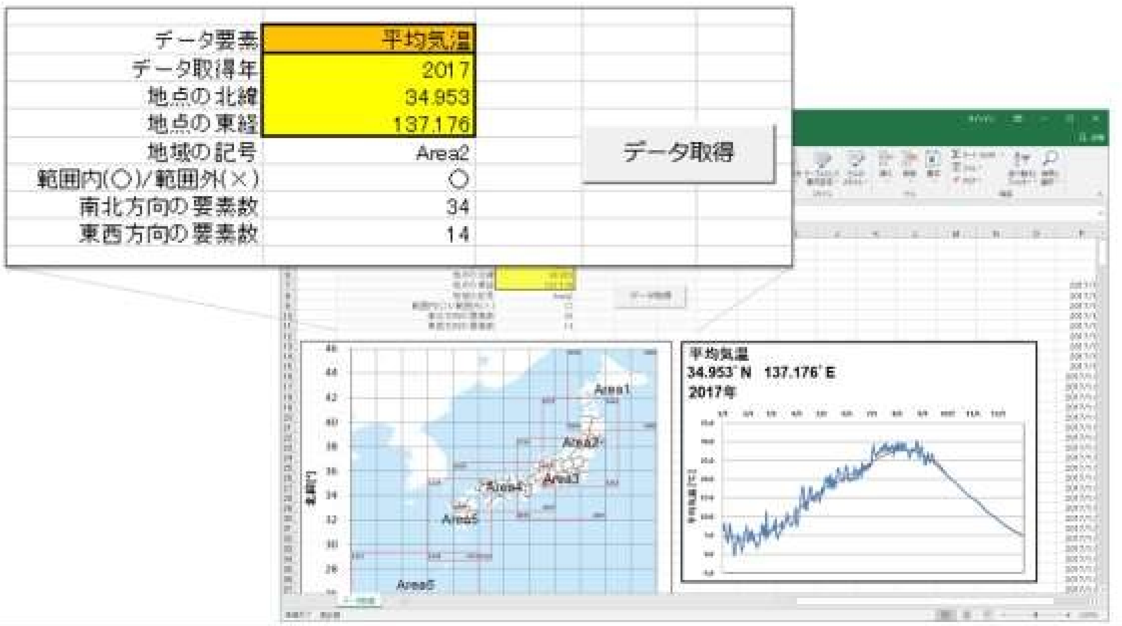

Fig. 2. Microsoft Excel workbook that facilitates obtaining data from AMGSDS provided by NARO

Fig. 3. Distribution of the accumulated air temperature in the Hokkaido area of Japan from June to August created with a Python program (left) and the Python program used to create the distribution figure (right). With the Library, only 11-line scripts (excluding comment lines) complete the necessary calculation and visualization.

In a real agricultural setting, data, including weather forecasts, should be kept up-to-date. However, research and development on how to utilize meteorological data, evaluation of the impacts of utilization of forecast data and its efficacy are important as well. The evaluation process requires that the forecast data from a previous time be reproduced. To meet such demands, as part of the daily update, we compress and archive AMGSD. For users who need to reproduce data previously obtained from AMGSDS, we send them the relevant archived files offline and a Python program to extract these files, which reproduces AMGSD on the users' hard disks. As the data acquisition function provided by the Python Library can easily be changed the destination of the data source, users can execute programs developed for practical farming purposes with the reproduced data by changing the destination of the function from AMGSDS to their local disks.

The Climate Change Scenario Grid Square Data

In addition to AMGSD, we have developed the Climate Change Scenario Grid Square Data (CCSGSD), which is delivered by AMGSDS. CCSGSD is a set of daily meteorological data for the period from 1981 to 2005 (current climate) and from 2006 to 2055 (predicted future climate). As of today, CCSGSD consists of four dataset, which are created from four climate change evaluations which are based on two models (MIROC-5 and MRI-CGCM3) and two scenarios (RCP2.6 and RCP8.5). Each datasets is composed of 6 meteorological elements, i.e. daily air temperature, daily maximum air temperature, minimum air temperature, precipitation, global solar radiations, and relative humidity.

USE OF DATA TO REDUCE WEATHER AND CLIMATE RISKS

AMGSDS has facilitated the utilization of meteorological data, including diverse meteorological elements, at arbitrary locations and for arbitrary terms. Furthermore, AMGSDS has improved the accuracy of agricultural predictions based on meteorological information because it contains weather forecast data.

Effect of weather forecast on prediction of crop development

Ear emergences of paddy rice and wheat are important indicators for determining the appropriate date to apply fertilizer or pesticides. Meteorological data is commonly used to predict ear emergence. In traditional manner, the observed air temperatures for days before the day the prediction is performed and the normal year temperatures for the following term are combined. Comparing the predicted ear emergence day obtained in this conventional way with that obtained with AMGSD can validate the effect of the weather forecasts on the prediction of crop development.

Fig. 4 shows the results of the daily prediction of the ear emergence (heading) date of wheat in the Tokachi region of Hokkaido Prefecture using two different meteorological datasets between April 5 to June 1, 2015. Note that June 1 is the real heading date. One meteorological dataset is the conventionally combined meteorological data discussed above, and the other is AMGSD. Although both meteorological datasets provide the correct heading date with a crop development model, the predicted day from AMGSD, which incorporates the weather forecast data, is closer to the real heading date earlier than that from the conventional meteorological data. Figure 4 shows that weather forecast data helps correct the prediction of heading date of wheat about two weeks earlier than the conventional method.

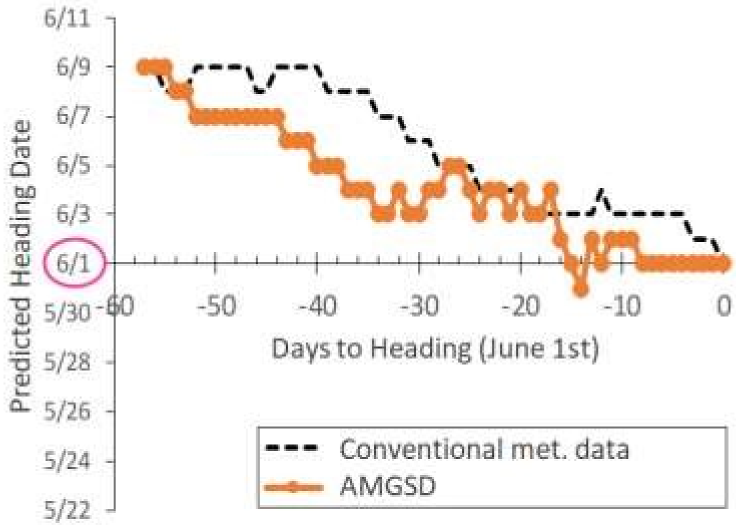

Fig. 4. The results of the day by day prediction of the ear emergence (heading) date of wheat using two different meteorological datasets from April 5 (57 days to the heading date) through June 1 (the heading date), 2015. (Tokachi region, Hokkaido Prefecture, 2015)

Reducing chalky rice occurred by high temperature

When the mean air temperature is above 26℃ for 20 days from heading, rice grains start to become opaque white due to loosely packed starch granules. Such rice grains are called chalky rice. Chalky rice is easy to break and tastes worse than non-chalky rice (Morita *et al*. 2016). With the recent warming trends, chalky rice is becoming more prevalent and is a problem facing farmers across Japan. Increasing the amount of top dressing one week before heading can reduce the occurrence of chalky rice. However, the amount of additional fertilizer cannot be unconditionally increased because the proportion of protein within rice grains increases if the air temperature does not remain high, resulting in a poorer taste and/or lodging. Consequently, we have developed a way to utilize the weather forecasts to determine the amount of fertilizer to be added as follows:

1. Determine the date to top dressing by predicting the heading date using meteorological data and a crop development model.
2. On the day prior to top dressing, predict the mean air temperature for 20 days after heading.
3. On the day prior to top dressing, observe the leaf color.
4. Calculate the appropriate the amount of top dressing based on the air temperature and leaf color.
5. Apply top dressing.

Fig. 5 shows these processes. This approach, which suppresses the occurrence of chalky rice grains due to high temperature, has been realized for the first time by AMGSDS because AMGSD incorporates the latest weather forecasts at cultivated fields.

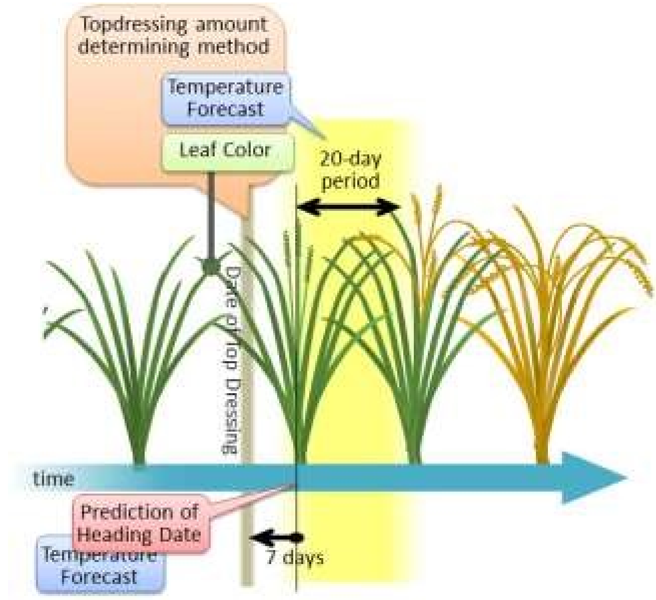

Fig. 5. Concept of the technique to predict and suppress the risk of chalky grains by controlling the amount of top dressing

Support information to reduce weather and climate risks on crop management

The examples discussed above indicate that combining agricultural knowledge or techniques accumulated to date with weather forecasts and crop models can create brand new crop management technologies. With the aim of reducing meteorological and climatic risks in agriculture, we are currently developing innovative technologies to create information that supports farmers who cultivate rice, wheat, and soy based on crop management techniques like the example discussed above. We are also developing a website that validates the efficacy of such supportive information. The website will contain information to support farmers' crop management (Table 3).

In general, a prediction requires initial values. This is also applicable for crop management using weather forecasts. In the case of crop management, initial values include the kinds and variety of crops to be cultivated, location of farmland, and date of planting. Thus, users of crop management technologies based on weather forecasts must input or register such values of the subject crops into the relevant supporting system. For farmers who operate around 10 cultivation, support via a dedicated website, which allows farmers to identify their fields' location with a mapping service and to select kind and variety of crops using drop-down lists or radio buttons should be convenient to obtain supportive information. However, for agricultural management entities that operate several hundred cultivations, such website-based support is not practical. Because such entities tend to employ farm management software to manage fields and cultivation, we think that utilizing such software to enter the initial values for cultivation of the subject crops should be efficient and helpful to obtain supportive information. Based on this idea, we have worked on an experiment to provide information supporting crop management via Web-API in cooperation with a vendor that develops agricultural management solutions (Table 3).

Table 3. List of information to support crop management provided via our website

Items	[a] Development Status
Rice	
prediction of crop phenology	completed
auto-tuning for phenology model	tentative
prediction of optimal harvesting date	completed
prediction of spikelet sterility due to cold weather (for cold regions)	completed
recommendation by weather adaptive nitrogen top dressing technique	completed
recommendation for basal dressing (for cold regions)	tentative
recommendation for nitrogen fertilization	tentative
recommendation for suitable cropping seasons	completed
rice false smut forecasting	completed
rice sheath blight forecasting	completed
rice blast forecasting	in development
wheat	
prediction of crop phenology	completed
prediction of optimal harvesting date (for temperate regions)	completed
soybean	
prediction of crop phenology	completed
estimation of soil moisture condition	completed

[a] completed: content already installed in the system; tentative: tentative content was installed and will be improved; in development: content is under construction.

CONCLUSION

Agriculture in Japan now faces two major challenges: climate change and a shrinking working population. To help address these challenges, we have developed AMGSDS. This system provides daily meteorological values, including weather forecasts spanning the entire country with a 1-km grid on demand. By applying the data provided by AMGSDS to crop development prediction models, crop development can be predicted two weeks earlier than conventional prediction techniques. In addition, we have worked to develop a new approach for crop management that combines knowledge about responses of crops to meteorological stress and techniques to reduce damage by accurate predictions using meteorological data. We have developed a way to predict risks of decreased quality of paddy rice due to high temperatures after heading using air temperature forecasts to determine the amount of top dressing necessary to suppress chalky grains. To socially implement such supportive information for crop management, scalable techniques such as Web-API are promising.

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