1-KM GRID METEOROLOGICAL DATA SERVICE AND ITS USE TO REDUCE WEATHER AND CLIMATE RISKS IN FIELD CROP PRODUCTION

Hiroyuki Ohno and Kaori Sasaki

Institute for Agro-Environmental Sciences, National Agriculture and Food Research Organization (NARO), Tsukuba, Japan

E-mail: ohno@affrc.go.jp

ABSTRACT

Agriculture in Japan currently faces two major challenges: climate change, with effects on crop yield and quality, and a shrinking working population, as older farmers leave the industry leading to consolidation of farms. In an attempt to resolve these issues, we have developed a meteorological data service that provides daily meteorological data and covers the entire country in a 1-km grid. This dataset comprises 13 different 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 utilizes the dataset (hereinafter referred to as "today"). For all days before today, the dataset provides observed values. For today and for up to 26 days later, the dataset provides predicted values. From 27 days after today, the dataset provides climatological normal values, mean values for the past 30 years. The dataset is updated daily based on the latest weather forecast. The dataset has a unique distribution system that allows registered users to procure required data via an application program on demand. Combining accurate crop development predictions using this dataset with existing techniques and knowledge regarding crop responses to meteorological stress may reduce damage caused by stress as well as mitigate meteorological and climatic risks in farming by applying crop management techniques that anticipate weather changes and that take countermeasures into account.

Keywords**:** Grid square, weather forecast, crop management, climate change scenario, web-API

INTRODUCTION

Climate change is impacting agriculture in Japan. The latest statistical data show that the mean air temperature is increasing by 1.19°C per 100 years and that the number of days with a daily minimum temperature of ≥25°C significantly increases at a rate of 17 days per 100 years (Japan Meteorological Agency 2017). Due to these high temperatures, paddy rice, which is a staple element of diet in Japan, is more likely to form a chalky grain. Chalky grain is an issue that is prevalent throughout the nation. In 2010, a year that experienced extremely high air temperatures, Niigata Prefecture, which is a well-known for producing paddy rice of excellent flavor, experienced a significant decrease in the proportion of rice classified as 1st class, with only 20.3% of the rice produced in the prefecture being graded 1st class (Ministry of Agriculture, Forestry and Fishery 2011). This decrease in rice quality greatly shocked all stakeholders. Similarly, fruit production was affected by an increasing number of weather-related problems, including poor skin color of apples and grapes, peel puffing of Satsuma mandarins, and fruit flesh disorders in Japanese pears and peaches. In addition, dead flower buds of Japanese pears and freezing injury to Japanese chestnuts due to reduced freezing tolerance have also been reported (Sugiura *et al*. 2012).

Applying crop management, which minimizes damage to crops caused by high temperatures in real-time or in advance using weather forecasts is one of the most efficient measures to adapt agriculture to climate changes, as well as introducing heat tolerant cultivars and revising cultivation periods.

Another issue that agriculture in Japan faces is the declining working population due to an increasing aging population, particularly in the agricultural sector (MAFF 2018) As farmers give up agriculture, most farmlands become consolidated; these consolidated farmlands are then operated by locally active farmers or farming operation entities, the so-called *ninaite* farmers. As most consolidated farmlands are small in size, many *ninaite* farmers cultivate in numerous small but scattered fields. To efficiently farm such fields, leveling of demand (machinery and workforce) are more important than introducing large machinery. To realize this leveling, utilizing meteorological data is critical as it allows farmers to accurately predict the growth of diverse crops.

To face these challenges facing Japanese agriculture, namely climate change and a shrinking workforce, it is necessary to develop advanced and sophisticated crop management technologies that utilize meteorological data. 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 that farmers can understand which areas are suitable for cultivation of particular crops, (3) model the 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 facing Japanese agriculture using a multi-faceted approach. Firstly, technologies are being developed to handle problems such as reduced crop yields and poor crop quality due to high temperatures. Secondly, techniques are being established to combine different types of crop, varieties, 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, which can meet the high-specification demands from these technologies and techniques. AMGSD System can generate and deliver daily meteorological data, including weather forecast data (Ohno 2014).

The AMGSD

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

AMGSD is composed of 13 meteorological elements (Table 2). It includes not only data that are commonly used for crop management, such as air temperature, precipitation, and sunshine duration, but also humidity, solar radiation, atmospheric radiation, and 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 to 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 the aero-dynamical method. AMGSD is a unique dataset because it provides long-term data (approximately 40 years) that includes weather forecasts and a variety of meteorological elements (13 elements) in a fine-grid size (1-km grid).

Table 1. Japan Meteorological Agency (JMA) meteorological products used to generate Agro–Meteorological Grid Square Data (AMGSD)

Name of Data	Abbreviation	Overview
Automated Meteorological Data Acquisition System	AMeDAS	Land weather observation network operated by JMA. Approximately 1,300 observational devices/facilities are located throughout Japan.
Grid Point Value of the Meso Scale Model	MSM-GPV	The MSM model covers the area around Japan on an approximately 5-km grid and predicts up to 1.5 days (39 h) in the future.
Grid Point Value of JMA Global Spectral Model (Japan area)	GSM-GPV	The GSM model covers the globe on an approximately 20-km grid and predicts up to 11 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, predicting the deviation from the climatological normal value by an area up to 4 weeks in the future.

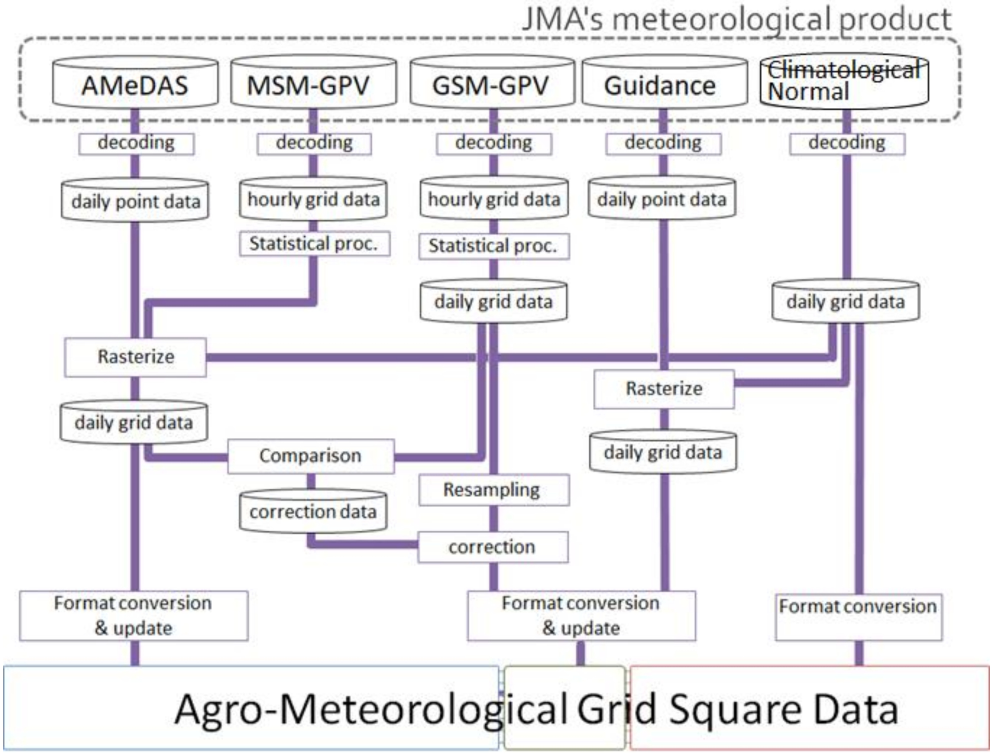


Fig. 1. Process to generate Agro–Meteorological Grid Square Data (AMGSD).

Table 2. Meteorological elements included in Agro–Meteorological Grid Square Data (AMGSD) and terms available for each element

Meteorological parameters	Time domain of the data		
	Observation-based values	Forecasting-based values	Climatological normal values
Mean air temperature	1/1/1980–*yesterday	*today–26 days in the future	27 days in the future–end of the next year
Maximum air temperature	1/1/1980–yesterday	today–26 days in the future	27 days in the future–end of the next year
Minimum air temperature	1/1/1980–yesterday	today–26 days in the future	27 days in the future –end of the next year
Total precipitation	1/1/1980–yesterday	today–26 days in the future	27 days in the future–end of the next year
Occurrence of >1 mm precipitation	1/1/1980–yesterday	today–9 days in the future	8 days in the future–end of the next year
Sunshine duration	1/1/1980–yesterday	not available	8 days in the future–end of the next year
Global solar radiation	1/1/1980–yesterday	not available	today–end of the next year
Atmospheric radiation	1/1/2008–yesterday	today–9 days in the future	not available
Mean relative humidity	1/1/2008–yesterday	today–9 days in the future	not available
Mean wind speed	1/1/2008–yesterday	today–9 days in the future	not available
Snow depth	1/10/1980–yesterday	today–9 days in the future	not available
Deposited snow water equivalent	1/10/1980–yesterday	today–9 days in the future	not available
Newly fallen snow water equivalent	1/10/1980–yesterday	today–9 days in the future	not available

*"Today" corresponds to the day on which AMGSD is used, whereas "Yesterday" corresponds to the day before "today"

Data delivery service

In most cases, meteorological data services provide their own websites, which users visit, and select and download the desired data via CSV or another format. In most cases, the data obtained from such servers are provided by month or year in separate files. If a user needs data for a different range (e.g., over 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 are renewed daily and users who use meteorological data by converting them into agricultural data through defined procedures have to repeatedly perform the conversion processes.

In contrast, our data service system 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 the data needed on demand. Considering that the working population in agriculture is not always familiar with computer programming, 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 obtaining 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 the 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 predicted and processed data.

Another support measure is the provision of a Python Library. Python is a powerful programming language, which is user-friendly for those who are not familiar with programming. We have developed a function that acquires the needed data by communicating with 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).

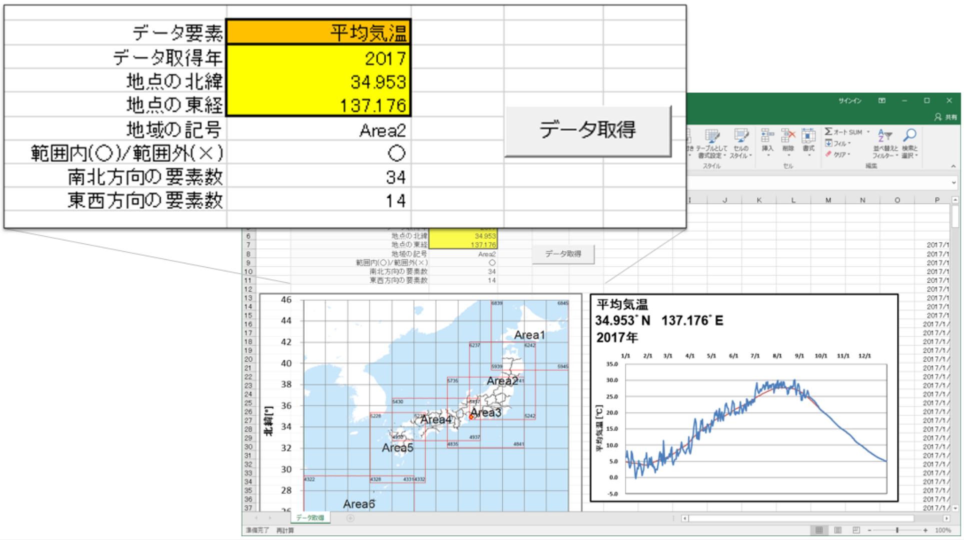
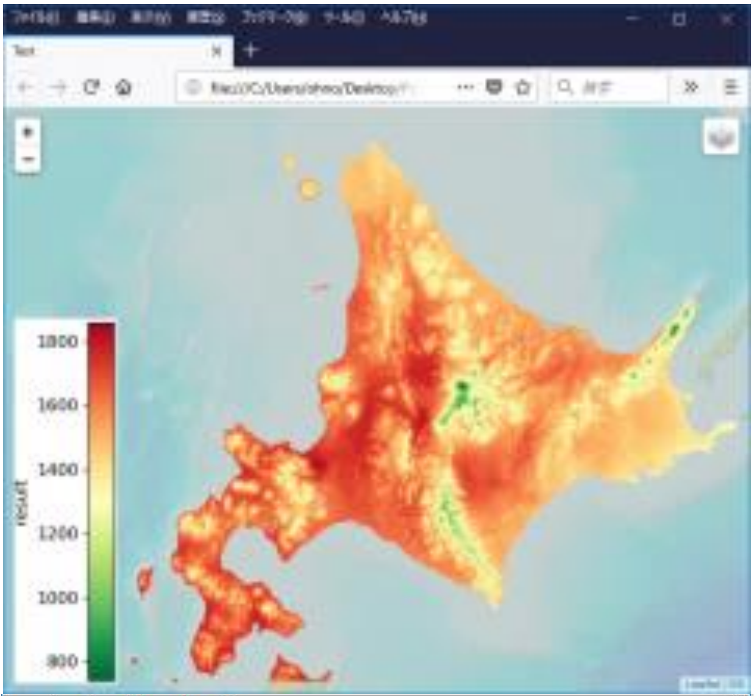


Fig. 2. Microsoft Excel workbook that facilitates obtaining data from Agro–Meteorological Grid Square Data provided by the National Agricultural Research Organization.




```
1  # -*- coding: utf-8 -*-
2  """
3  北海道における2017年6～8月の有効積算気温の分布図を計算し、
4  国土地理院の地図サービス上に表示できるファイルを作成する
5  プログラム。
6  積算期間は変数kikan(12行目)に与える、
7  基準温度は変数To(16行目)に与える。
8
9  """
10 import numpy as np
11 import AMD_Tools3 as AMD
12 # 基本的な設定
13 youso = 'TMP_mea'                #気象要素の指定。TMP_meaは日平均気温。
14 kikan = [ "2017-06-01", "2017-08-31" ]  #期間の設定。
15 area = [41.350,45.533, 139.327,146.000]   #領域の設定。北海道がすっぽり収まる範囲。
16 To = 15.0  #有効積算気温の基準(それより低い値は積算しない)
17
18 # 気象データの読み込み
19 Ta,tim,lat,lon = AMD.GetMetData(youso, kikan, area)
20
21 # 有効積算温度の計算
22 valimesh = ~np.isnan(Ta)
23 Ta[valimesh] = np.where(Ta[valimesh] > To , Ta[valimesh]-To, 0.0)
24 Tacc = np.sum(Ta, 0)
25
26 # 地理院地図にオーバーレイするファイルの出力
27 AMD.PutGSI_Map(Tacc,lat,lon)
28 [EOF]
```

Fig. 3. Distribution of the accumulated air temperature in the Hokkaido area of Japan from June to August 2017 created using a Python program (left). The Python program was 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, and evaluation of the impacts of the utilization of forecast data as well as 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 the service, 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 change 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 the data server to their local disks.

The Climate Change Scenario Grid Square Data (CCSGSD)

In addition to AMGSD, we have developed the 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). Currently, CCSGSD consists of four datasets, which are created from four climate change evaluations which, in turn, are based on two models (MIROC-5 and MRI-CGCM3) and two scenarios (RCP2.6 and RCP8.5). Each dataset is composed of six meteorological elements, namely daily air temperature, daily maximum air temperature, minimum air temperature, precipitation, global solar radiation, 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 periods. 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 emergence in rice and wheat crops is an important indicator for determining the appropriate date to apply fertilizer or pesticides. Meteorological data are commonly used to predict ear emergence. Conventionally, the meteorological dataset for its purpose is prepared just connecting those of observed and climatological on the day of prediction.

Comparing the predicted date of ear emergence obtained in this conventional way with that obtained from AMGSD can validate the impact of the weather forecasts on the prediction of crop development.

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

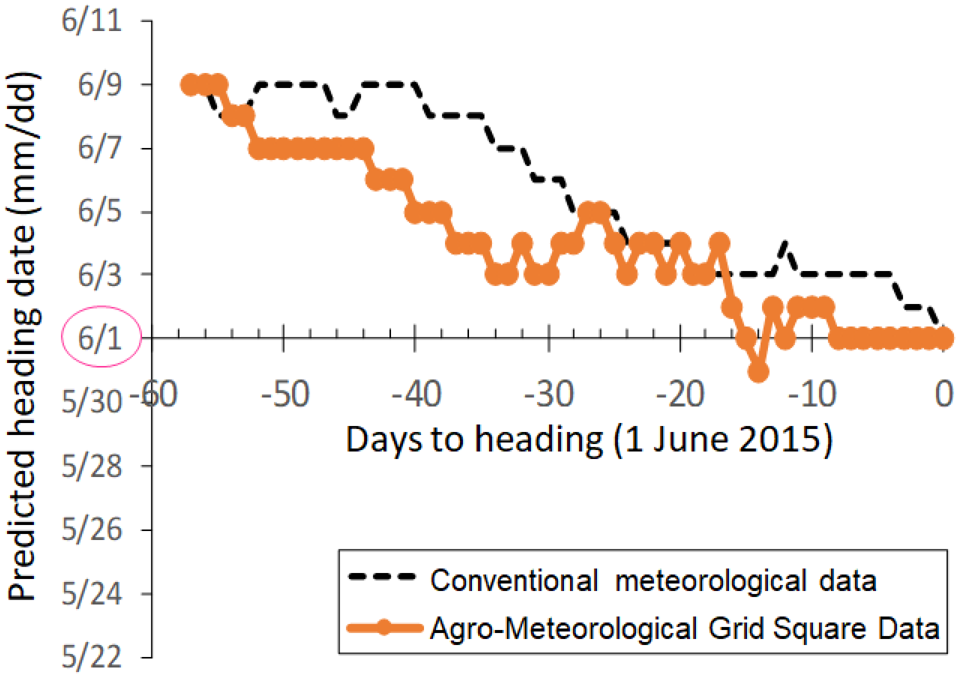


Fig. 4. The results of the day-by-day prediction of date of ear emergence (heading) of wheat using two meteorological datasets from April 5 (57 days to the heading date) to June 1 (the actual heading date) 2015 (Tokachi region, Hokkaido Prefecture).

Reducing the occurrence of chalky rice resulting from high temperature

When the mean air temperature is above 26°C for 20 days from heading, rice grains start to become opaque or white due to loosely packed starch granules. Such rice grains are called chalky rice. Chalky rice is easy to break and has a poorer flavor than non-chalky rice (Morita *et al*. 2016). With the recent global warming trends, chalky rice has 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 applied cannot be unconditionally increased because the proportion of protein in the rice grain increases if the air temperature does not remain high after fertilizer application, resulting in a poorer taste and/or crop 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 of fertilizer 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 amount of top dressing based on the air temperature and leaf color.
5. Apply top dressing.

Fig. 5 shows these processes. This approach, which minimizes 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.

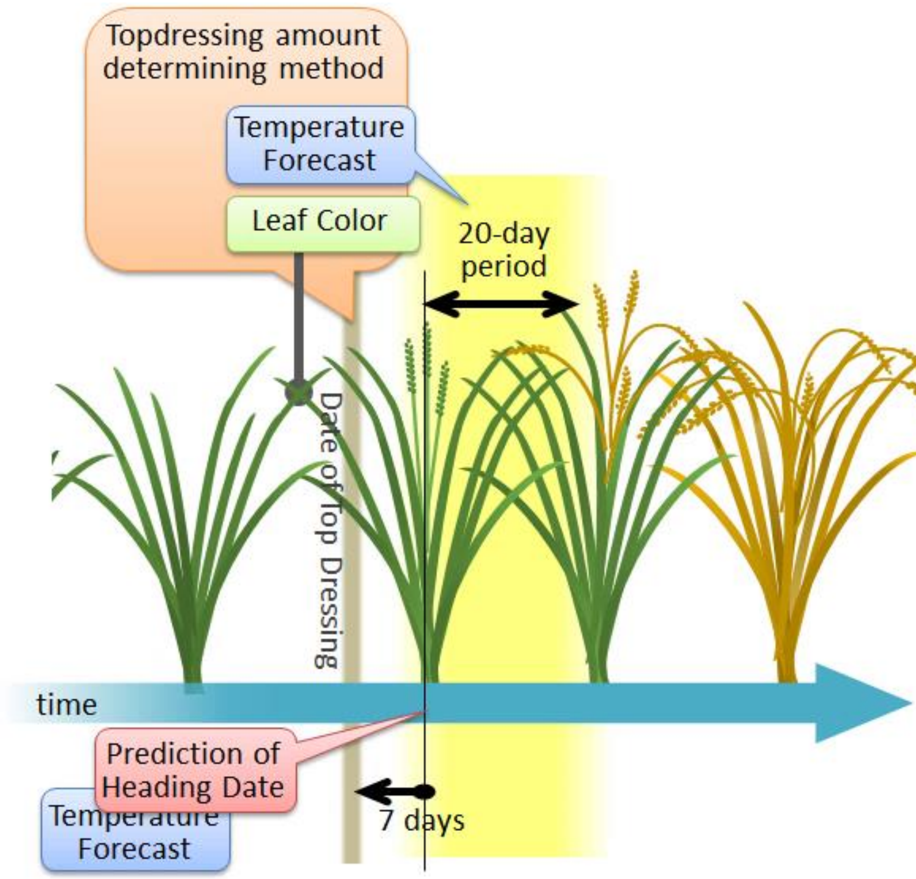


Fig. 5. Concept of the technique to predict and minimize the risk of chalky grain occurrence by controlling the amount of fertilizer top dressing.

Support information to reduce weather and climate risks associated with crop management

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

In general, a prediction requires initial values. This is also held true for crop management using weather forecasts. In the case of crop management, the initial values include the types and varieties of crops to be cultivated, location of farmland, and date of planting. Thus, the users of crop management technologies that are based on weather forecasts must input or register values pertaining to subject crops into the relevant support system. Those who manage approximately ten cultivation obtaining support information via a dedicated website, which allows each farmer to identify their field locations with a mapping service and to select the type and variety of crop using drop-down lists or radio buttons, should be convenient. However, those who manage crops in several hundred different fields, such website-based support is not practical. This is because such organizations already tend to employ farm management software to manage fields and cultivations, and we think that utilizing such software to enter initial values for cultivating subject crops should be efficient and helpful in obtaining support information. Based on this idea, we conducted 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 items provided on 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	Completed
cold regions)	Completed
Recommendation of weather-adaptive nitrogen top	Tentative
dressing technique	Tentative
Recommendation of basal dressing (for cold regions)	Completed
Recommendation of nitrogen fertilization	Completed
Recommendation of suitable cropping seasons	Completed
Rice false smut forecasting	under
Rice sheath blight forecasting	development
Rice blast forecasting	
Wheat	
Prediction of crop phenology	Completed
Prediction of optimal harvesting date (for temperate regions)	Completed
Soybean	Completed
Prediction of crop phenology	Completed
Estimation of soil moisture content	

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

CONCLUSION

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

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