Emerging research topics in agricultural meteorology and assessment of climate change adaptation

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Abstract

Climate change is virtually certain and efforts for adaptation is essential not only to decrease the negative consequences but also to increase the opportunities. To achieve the goal, we need to address emerging research topics in the field of agricultural meteorology with regard to climate change adaptation. We touch upon how harvesting insights from crop models with different complexities can be improved, the detection and attribution of impacts on agricultural ecosystems associated with climate and technological changes, and how crop and weather datasets can be improved. We conclude by discussing important knowledge gaps that need to be addressed in future research.

\textbf{Key words:} Adaptation, Climate change, Crop model, Detection and attribution, Diffusion of technology

1. Introduction

This article focuses on emerging research topics that are expected to become important in coming years in the field of agricultural meteorology. These research topics were discussed at the Organized Session entitled “Detection, Analysis and Prediction of Environmental and Technological Impacts on Long-term Food Production over Large Areas”, held on March 27 in the Annual Meeting of Society of Agricultural Meteorological of Japan 2017 (SAMJ2017) (March 27–30 at Towada Campus, Kitasato University).

2. Emerging research topics

2.1 Improving harvesting insights using crop models with different complexities

2.1.1 Model complexity

It is critical for crop modelers to determine the complexity of a crop growth model and/or yield prediction model (hereinafter simply referred to as crop model) (Tatsumi, 2017). The modelers’ decision in this regard strongly depends on the potential application of the model, because there is no single versatile model that can meet all requirements of various applications. The availability of model inputs (e.g., management information) is also a known constraint on model complexity, particularly in large-area crop modeling.

Each crop model therefore has own complexity, depending on its specific application. If a given purpose is to simulate the balances of heat, water, and energy in cropland and their feedback to the atmosphere in a physically consistent manner, a crop model embedded into a land surface model (Masutomi \textit{et al}., 2016a, b) that allows one to couple it with atmospheric models meets that purpose (and the purpose determines the model complexity). When predicting year-to-year variations in yields worldwide using monthly climate data and crude crop calendar information, statistical yield models (e.g., Iizumi \textit{et al}., 2013, Chun \textit{et al}., 2016) fit that purpose better than process-based models with intensive input requirements. There is a unique model that predicts the amylose content of specific varieties of rice using only weather data (Hirota \textit{et al}., 2014), so that it can be applied to a large spatial domain (over Hokkaido region). A “reduced” model on simplified nitrogen (N) dynamics and crop growth stress associated with N deficits was useful in the application to rice producing areas across China, where only yearly N application rate was available as the management information (Sawano \textit{et al}., 2015). Thus, large-area crop models range in complexity from empirical to complex process-based approaches, depending on the purpose of the model application.

The observation that model complexity is determined by model objectives is likely true for field-scale crop models as well, although in many cases the purpose of field-scale models is to understand growth processes in a more detailed manner. For example, in the International Symposium on Agricultural Meteorology 2015 (ISAM2015), Evers (2015) introduced a model which describes the three-dimensional structure of a crop plant and explicitly simulates the morphological effects of plant structure on light interception. A suite of complex process-based...
models, including a canopy heat balance model to simulate water temperature as well as the temperature difference between the inside and outside of rice plant canopies (Maruyama and Kuwagata, 2010) and a model simulated panicle temperature (Yoshimoto et al., 2011), has been developed to understand the processes related to heat-induced sterility. A model to simulate the appearance quality of rice grains in a more process-based manner than previously has also been developed (Yoshida et al., 2016).

2.1.2 Time and spatial scales contribute to the model complexity

It is also true that the system boundary for a crop model varies by the time and spatial scales. That is, different scales in time and space require different model complexities. This is because the relative importance of yield-determining factors differs by time and spatial scales. If simulation of average yield across a large spatial domain is of interest, models need to represent yields in major producing regions with extensive harvested areas which largely contribute to the domain mean crop yield. Porwollik et al. (2017) reports that the difference in calculated global mean yields associated with the use of different global harvested area maps is substantial as large as the use of different crop models. Furthermore, in depicting the future of global food production, it will become increasingly important to account for the changes in the irrigated area and N fertilizer use in developing countries, where the cropland area is projected to expand greatly in coming decades (Iizumi et al., 2017). These factors are not considered in most crop model simulations at present.

2.1.3 Deriving insights from crop models with different complexities

As mentioned above, model complexity differs by purposes of the model application. This observation leads to a series of questions. First, how can we synthesize the outputs across different crop models with varying complexity to derive a coherent insight into the issue of concern such as climate change adaptation? There are various approaches to answering this question; Makowski et al. (2015) infers the climate change impacts on yields at a global scale by using multiple field-scale crop model ensemble data at a limited number of locations. Zhao et al. (2017) combines estimates of crop yield response to temperature increase from global gridded crop models, field-scale crop models, statistical yield models and field experiments to inform about adaptation more confidently. A second, more specific, question is how we can utilize research findings at different spatial scales. Useful approaches include to develop a system that combines areal information derived from satellite remote sensing with a field-scale crop model (e.g., Homma et al., 2017, Maki et al., 2017) and machine learning techniques (e.g., Tatsumi et al., 2016); this is methodologically straight-forward. The same questions should arise, if we would try to utilize results of the quantitative trait locus (QTL) analysis to field-scale models or to use field experimental results and/or field-scale crop model outputs to improve global gridded crop models. We should be better prepared for answering these questions.

2.2 Detection and attribution of climate change impacts

2.2.1 Agronomic technology and adaptation to climate change

Agronomic technology changes in interaction with the socioeconomic and climatic variables surrounding the farmers’ decision-making. An important research topic in the field of agricultural meteorology would therefore be the description and understanding of changing technologies under the changes in climate and society (Kobayashi et al., 2007; Tanaka et al., 2013; Shimoda et al., 2015). The research developments in this respect point a way forward for agricultural meteorology to transform itself into a field of interdisciplinary research covering both agronomy and meteorology, rather than a marginal area between the two research fields.

Such a new direction of research can also be seen in the discussion among vineyard owners, wine makers, and researchers on wine production in Hokkaido (Nagata et al., 2014; Hirota et al., 2016; Nemoto et al., 2016). Fukuhara and Kobayashi (2017) reports that the temperature rise and the dissemination of nursery technology facilitated the use of longer-season rice varieties and thereby contributed to the rapid increase of rice production in Heilongjiang Province, China. Takimoto et al. (2017) reports that the deterioration of rice grain quality due in part to the temperature rise was greater in the farmers’ fields than their model estimates, and mentions that the recent decline in N application rate in the farmers’ fields may explain the underestimation by the model. It is known that decrease in N application exacerbates the grain quality decline due to heat stress, but this effect has not been accounted for by the model, which has been calibrated against experimental data under a constant N application rate across years.

Existing crop models use information on technology as an input parameter. However, processes related to diffusion of technology need to be explicitly considered in crop models to derive insights allowing users to overcome climatic constraints and adapt to climate change. It is therefore more reasonable to understand changes in crop production through the diffusion of technology and associated changes in varieties and available climatic resources than to directly explain yield change through changes in climatic variables. Most impact assessments explore measures to reduce climate change risk without taking future changes in technologies into account (e.g., Tanaka et al., 2013), although accurate accounting for such changes is challenging. The Agricultural Model Intercomparison and Improvement Project (AgMIP) has begun to develop future scenarios on agricultural development and adaptation (Valdivia et al., 2015).

2.2.2 Multi-crop analysis

In Japan, many studies analyzing the climate change impacts on paddy rice are available, but analyses for other cereals, fruits, vegetables, livestock, and fisheries are relatively limited. The tendency toward substantial research on major crops (e.g., maize, rice and wheat) against limited research on minor crops is common for the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (AR5) (Porter et al., 2014). It is therefore beneficial to consider production of rice, fruit, and livestock in the northern part of Tohoku region with the common theme of cold weather-induced damages. At SAMJ2017 Public Symposium, Ito (2017) reported that rice production in the
northern part of Tohoku region is unstable due to Yamase (cool easterly wind in summer), and that this has motivated the farmers to expand production of apple, which is more tolerant to cold weather than rice. Such an overview across crops is important when discussing climate change adaptation, as mentioned in Hirota et al. (2012; 2014; 2017a). Efforts to increase the coverage of crop types (e.g., Japanese chestnuts (Sakamoto et al., 2015)) need to be encouraged.

2.2.3 Detection and attribution

For adaptation planning, it is necessary to understand the impacts of past climate change on the variables of interest, in addition to future projections. Detection and attribution analyses (DA) have become more popular in the field of climate modeling; these analyses identify changes in climate variables using observed meteorological data and then quantitatively evaluate the influence of human activities on detected changes in climatic variables using ensemble climate model simulations (Mori et al., 2013). Findings obtained from DA analyses have been accumulated toward the IPCC 6th Report (AR6) (e.g., Shiogama et al., 2016). A large ensemble climate model simulation dataset for DA analysis, the “database for Policy Decision making for Future climate change (d4PDF)”, recently became available (http://www.miroc-gcm.jp/~pub/d4PDF); both global data and regional data for Japan are available in this database. The d4PDF database offers tremendous opportunities for researchers in the field of agricultural meteorology to identify impacts on managed ecosystems associated with past climate change.

At SAMJ2017, Hirota et al. (2017b) presented an example of DA analysis which demonstrated that harvests of Pinot Noir grapes had failed until 1997 but became feasible since 1998 due to climatic change. Hirota et al. (2017b) collected data on both failures and successes in grape harvesting, implying no bias in data sampling: this is always good practice in DA analysis.

2.3 Improvements to crop and weather datasets

2.3.1 Crop datasets

In general, crop data are often hard to access compared to weather data. Therefore, the global crop calendar dataset introduced in Iizumi (2017) is expected to be useful if publicly released. Global agricultural datasets have become increasingly available over the last decade. However, no global agricultural datasets other than crop yields (Ray et al., 2012; Iizumi et al., 2014) and irrigation-equipped areas (Siebert et al., 2015) allows time-series analysis.

Although governmental agricultural statistics are a major source of data in developing global agricultural datasets, additional data sources are desirable. Takimoto et al. (2017) collected data on fertilizer management through farmer interviews and crop experimental reports published by the prefectural agricultural experiment stations. Terms and conditions on use of data should be respected, of course, but sharing of data through public data repositories such as DIAS (http://www.diasjp.net/) PANGAEA (https://www.pangaea.de/) and Figshare (https://figshare.com/) is becoming common in geophysical sciences communities. This is avoidable to increase the transparency. For instance, Fukui et al. (2015) uses a huge rice variety trials dataset which covers over 15 cultivars at more than 120 locations across Japan from 1980 to 2009 to calibrate and validate a rice phenology model. This dataset is useful for other researchers, but it is unclear how one can access this dataset. A similar trend with geophysical data is found for satellite data, such as the EOS Land Viewer (https://lv.eosda.com) which allows users to freely obtain high-resolution satellite images. Some private companies have a large amount of agricultural statistics and crop experimental data, but those data are often only available for a fee, or are not open to the public. Interestingly, van der Velde et al. (2012) reports that the timing of increased Internet searches using keywords related to the sowing date of corn can be used as a surrogate of actual sowing dates in the United States. Such a new source of information is worth to be explored for improvements to the data acquisition techniques in the field of agricultural meteorology.

2.3.2 Weather datasets

Although weather and climate data are more widely available than crop data, there is still room for improvement. More sophisticated weather datasets, with unified daily boundaries (Yatagai et al., 2017), finer spatial and temporal resolution (Ueyama et al., 2015), variables more relevant to cropland, such as paddy fields (Kuwagata et al., 2011), and better representation of climate conditions for cropland are useful for crop modeling and DA analysis in managed ecosystems. A new gridded precipitation dataset, which will be developed in the APHRODITE-2 project (Yatagai et al., 2017), is one such dataset. The selection of weather observatories which represent mean climate in cropland and avoid the effects of urbanization on observed air temperature (Kuwagata et al., 2014) is useful and expected to be incorporated into the next generation of gridded datasets. For Japan, several gridded datasets (Seino, 1993; Ohno et al., 2016) on historical weather are available. For precipitation, the APHRO-JP dataset (Kamiguchi et al., 2010) is also used in the fields on meteorology and hydrology. An objective intercomparison of these datasets in parallel with their improvement is awaited.

3. Concluding remarks

In this article, we summarized the discussion made in the Organized Session on three emerging research topics in agricultural meteorology for climate change adaptation: (1) better insights from synthesis across crop models with different complexities; (2) detection and attribution of impacts on managed ecosystems associated with climate and technological changes; and (3) improvements in crop and weather datasets.

The IPCC is preparing three special reports. Researchers in SAMJ can contribute to at least two of them: one, entitled “Climate Change and Land”, covers desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (http://www.ipcc.ch/report/sr2) and the other, entitled “Global Warming of 1.5°C”, covers the impacts of 1.5°C warming above pre-industrial levels (http://ipccch/report/sr15/). We emphasize that producers’ adaptation practices reported to SAMJ as well as the research topics discussed here can be unique contributions to the special reports and upcoming IPCC AR6.
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