Foreword to the Special Issue on Digital Innovations in Agriculture Research and Applications

I. Introduction

SUSTAINABILITY of global agricultural and food systems is one of the prominent factors for peaceful future of the world in next few decades. Although agriculture is the main part of the global food supply chain, it is under rising pressure of global climate change, environmental deterioration, and falling per-capita arable land. Efficiency and sustainability management at all levels of agricultural planning and production appear as the most promising balancing factor for the short and medium terms. For this reason, timely and accurate information about the current conditions and future predictions in agriculture and the related resources become more important than ever.

We are living in an age that the annual production number of transistors in microprocessors is more than the number of wheat grains produced in the same year. This is an indication of increasing data processing capability and decreasing cost. On the other hand, the number of Internet connected devices is estimated to be more than 20 billion now and is increasing rapidly, and Intent-of-Things (IoT) devices have the highest share in this rising trend. While it may be not able to solve long-term global food sustainability issue, the rapid increase in data collection and processing capabilities for agricultural monitoring and prediction may remediate the issue at least in short and middle terms. Therefore, sensing and information technology have rising attraction and importance for agriculture.

Exponential increase of data availability is expected to continue with the recently launched communication technologies, including narrow-band IoT that enables ultralow power consumption for IoT application on GSM networks, and 5G networks that enable low latency for automation systems.

Machine learning applications and its own development have raised the gear with deep convolutional networks especially since 2016. Distributed data-processing requirement directs the applications of high data bandwidth consumptions to edge AI solutions as one of the new trends. Edge computing, cloud-based AI services, and enormous effort for the development of machine learning methods will clearly boost the digital innovations in agriculture due to vital needs about food security and sustainability. Context awareness, situational awareness, and reasoning are still improving capabilities of AI frameworks. When nonlinearity and the time-varying characteristics of agricultural production systems are considered, reinforcement learning and unsupervised learning are expected to take more attentions if the data with satisfactory features are available.

Recent explorations on quantum-level features of materials and interactions with single atomic layer materials such as graphene and carbon nanotubes open new ways for the development of novel sensors and sensing systems and the energy harvesting methods. These are important for new biosensors applications as well as reliable real-time measurements in agricultural information systems.

Although information and communication technologies are advancing rapidly, spatial, temporal, and the spectral accuracies are still the main restrictions in agricultural monitoring. For this reason, majority of the research works focuses on indirect measurements through adaptive or data driven models and the fusion methods in agro-geoinformatics.

JSTARS published the world's first Special Issue on agro-geoinformatics in 2013. This new JSTARS Special Issue on "Digital Innovations in Agriculture Research and Applications" provides some samples of recent progresses on agro-geoinformatic research and applications since the publication of the first Special Issue on this subject by JSTARS.

II. Special Issue for Digital Innovations in Agriculture Research and Applications

This Special Issue, containing 14 agro-geoinformatics related papers ranging from agricultural monitoring to machine learning based estimations, represent state-of-the-art in the agro-geoinformatics research and applications. A prominent application field of long-term remote sensing datasets is global climate change related vegetation investigations in different contexts. The article authored by Xu *et al.* used Advanced Very High Resolution Radiometer (AVHRR)-derived Vegetation Condition Index (VCI) data and concluded that long-term AVHRR records provide important historical perspective on vegetation activities necessary for global change research in item 1) of the Appendix. They have also determined mean duration for a piecewise trend as 7–9 years which they thought was not accidental and might be related to the global El Niño and La Niña phenomena.

Convolutional neural networks had great impact on improvement of machine learning applications especially after 2015. Chlorophyll content is one of the essential parameters in growth process assessment of the fruit trees. Paul *et al.* presented use of convolutional autoencoder (CAE) on Hyperspectral data for Chlorophyll Content Prediction of Pear Trees in item 2) of the Appendix. This article demonstrates that CAE features provides better prediction of canopy averaged chlorophyll content with respect to direct use of hyperspectral bands or vegetation indices as predictors.

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Leaf area index (LAI) is a valuable indicator used in vegetation growth monitoring. Optimization of the index selection according to the type of remote sensing data improves the inversion accuracy of LAI. Liang *et al.* have analyzed the influence of different bandwidths on the accuracy of the inversion model based on vegetation indices in item 3) of the Appendix. They have investigated the influence on different vegetation indices in three bandwidth-based categories. Their results show that bandwidth is one of the most important factors in determining the accuracy of LAI inversion.

As the GPU capacity in computational systems exponentially increased within the last decade, deep learning methods have become efficient tools for classification problems. Actual crop acreage and the crop status monitoring through remote sensing over large regions are two major concerns for the agro-geoinformation systems. Sun *et al*. presented the use of deep learning for in-season crop types classification in North Dakota in item 4) of the Appendix. Their deep neural network (DNN) application reached same pixelwise overall accuracy for all land types, with the same level of accuracy as the U.S. Department of Agriculture Cropland Data Layer.

High-throughput phenotyping of crop leaves is of great significance for breeding, growth monitoring, and increasing crop yield. Automated and accurate leaf segmentation and phenotypic feature extraction are not easy tasks due to complex and diversified plant structures. Li *et al*. proposed a novel five-stage framework for the multiview stereo plant point clouds in item 5) of the Appendix. Average accuracy of the calculated leaf area of two species reached 97% level in their experimental study.

Maize nitrogen uptake maps can provide valuable information regarding the efficiency of nitrogen usage in the field. Sharifi presented prediction performance of nitrogen uptake in maize crop by using Sentinel-2 data in item 6) of the Appendix. His results confirmed that near-infrared and red-edge bands in vegetation indices provide higher correlation up to $R^2 = 0.91$ for maize nitrogen uptake.

Crop yield estimation is probably one of the ultimate goals for agricultural information systems. Depending on spatial and temporal accuracy requirement and the feasibility factors, there are several different approaches for the crop yield estimation.

Liu *et al.* evaluated the utility of Terra/MODIS-derived crop metrics for yield estimation across the Canadian Prairies in item 7) of the Appendix. They have shown advantages of enhanced vegetation index 2 (EVI2) with respect to NDVI and demonstrated that vegetation indices at crop peak growing stages were better predictors of yield than gross primary productivity or net primary productivity.

Depending on higher yield efficiency demand and logistic costs in transportation, percentage of greenhouse-based production in total agricultural production continues to increase. Balcik *et al.* classified greenhouse from Sentinel-2 MSI and SPOT-7 Images with object-based methods in item 8) of the Appendix. They compared *k*-nearest neighbor (KNN), support vector machine, and the random forest methods as three different classifiers in their application. Results have shown that KNN provided slightly higher overall accuracy for both SPOT-7 and Sentinel 2 by using the images from Anamur-Mersin region in Turkey.

Plants' phenological stage transitions are strictly related to term based maximum, minimum, and the accumulated values of temperature and the precipitation. For this reason, long term change in climatic variables affects regional vegetative patterns especially in arid and semiarid zones. Muthoni presented spatial-temporal trends of rainfall, maximum, and minimum temperatures over West Africa by using 37-year time series data in item 9) of the Appendix. Results indicate significant warming trend across all observed agro-ecological zones and months with some cooling exceptions in August and September over the Sahel and Sudan Savanna.

Another effect of climate change is the growth of infected areas and damage levels due to crop pest and disease. On the other hand, accurate timing of protective applications in agriculture is important for reduction of total chemical use as a part of food safety. Dong *et al.* proposed an automatic system for crop pest and disease dynamic monitoring and forecasting in item 10) of the Appendix. They released the pest and disease forecasting thematic maps and forecasted the infected areas of yellow rust and locust in China, in 2019, with *R*-square values higher than 0.87.

Invasive weed mapping is important for the management of influence on agricultural regions and also consequences on ecosystem including fire intensity especially in arid and semiarid zones. Shendryk *et al.* presented a machine learning method for invasive weed mapping with very high-resolution satellite images in item 11) of the Appendix. For this purpose, they proposed a gradient boosting method for classification of Worldview 3 satellite images. Results show that gamba grass presence in Australia can be mapped from space with an accuracy of up to 91% under optimal environmental conditions.

Water is the vital and the most important component for efficiency management in agriculture. Soil moisture monitoring and mapping is important for optimal irrigation planning over large areas. *In situ* measurements at root zone may not be feasible for large application regions. However, local direct root-zone soil moisture measurements cannot be reliably interpolated due to the spatial variability of soil structure and the vegetative content. Remote sensing methods for measuring root-zone soil moisture are often impacted by vegetation coverage. Aktaş *et al.* proposed a root-zone soil moisture estimation method utilizing a context-aware data clustering process, depending on use of crops' phenological stages and soil–air temperature differences as the two contexts in item 12) of the Appendix. Their results show that correlation value of the overall season soil moisture measurements can be increased from weak level to higher levels as 0.8 or above.

Leaf area index (LAI) is used in several agricultural management processes including crop growth and yield prediction models. Santos *et al.* evaluated structure from motion (SfM) algorithm and digital images recorded by a camera on an unmanned aerial vehicle to obtain LAI data of the fields covered by coffee crop in item 13) of the Appendix. They also used the same data for classification of percentage of land cover. R^2 of their LAI estimation is found to be 0.88.

Nitrogen is a key nutrient for crop growth. Accurate measurement of soil Nitrogen (N) content is a prerequisite for scientific fertilization, which can increase the crop yield and reduce pollution and waste. In the last article of this special issue, Patel *et al.* explored the use of the derivative analysis for spectral unmixing (DASU)-based deep learning (DL) network to estimate the abundance of urea fertilizer mixed soils quickly from spectroradiometer data in item 14) of the Appendix. They tested the proposed approach with silt clay and loamy types of soils and identified that spectral regions of 1899.2 nm for urea and 2195.1 nm for soils were the optimum spectral absorption features. At 1899.2 nm, the coefficient of determination (R2) for mixed samples of urea and silt clay soil was 0.945, and for urea mixed loamy soil, 0.954. Similarly, at 2195.1 nm, R2 was 0.953 for urea mixed silt clay soil and 0.944 for urea mixed loamy soil. The results show that DASU-based DL network performed much better than the sole use of DASU for deriving soil Nitrogen content.

III. Conclusion

We have entered an era that importance of data driven management and decisions increases in agricultural processes. Data were mainly important for calibration and test of analytical models in near past. Increasing amount of data and processing power, now, makes both big data driven models and small data AI solutions take the place of conventional systems. Current global trend indicates that agro-geoinformatics and the relevant digital innovations will become an inevitable part of agricultural production systems and the food supply chain management.

As the Guest Editors of this Special Issue, we thank authors for contributing their papers and reviewers for their valuable reviews and comments. We hope readers of this Special Issue enjoy the articles on agro-geoinformatics.

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Appendix
Related Works

1) Z. Xu *et al.*, "Trends in global vegetative drought from long-term satellite remote sensing data," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 13, pp. 815–826, 2020.
2) S. Paul, V. Poliyapram, N. İmamoğlu, K. Uto, R. Nakamura, and D. N. Kumar, "Canopy averaged chlorophyll content prediction of pear trees using convolutional autoencoder on hyperspectral data," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 13, pp. 1426–1437, 2020.
3) L. Liang *et al.*, "Influence of different bandwidths on LAI estimation using vegetation indices," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 13, pp. 1494–1502, 2020.
4) Z. Sun, L. Di, H. Fang, and A. Burgess, "Deep learning classification for crop types in North Dakota," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 13, pp. 2200–2213, 2020.
5) D. Li, G. Shi, W. Kong, S. Wang, and Y. Chen, "A leaf segmentation and phenotypic feature extraction framework for multiview stereo plant point clouds," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 13, pp. 2321–2336, 2020.
6) A. Sharifi, "Using Sentinel-2 data to predict nitrogen uptake in maize crop," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 13, pp. 2656–2662, 2020.
7) J. Liu *et al.*, "Crop yield estimation in the Canadian prairies using terra/modis-derived crop metrics," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 13, pp. 2685–2697, 2020.
8) F. Bektas Balcik, G. Senel, and C. Goksel, "Object-based classification of greenhouses using Sentinel-2 MSI and SPOT-7 images: A case study from Anamur (Mersin), Turkey," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 13, pp. 2769–2777, 2020.
9) F. Muthoni, "Spatial-Temporal trends of rainfall, maximum and minimum temperatures over West Africa," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 13, pp. 2960–2973, 2020.

10) Y. Dong *et al.*, "Automatic system for crop pest and disease dynamic monitoring and early forecasting," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 13, pp. 4410–4418, 2020.
11) Y. Shendryk, N. A. Rossiter-Rachor, S. A. Setterfield, and S. R. Levick, "Leveraging high-resolution satellite imagery and gradient boosting for invasive weed mapping," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 13, pp. 4443–4450, 2020.
12) A. Aktas and B. B. Üstündağ, "Soil moisture monitoring of the plant root zone by using phenology as context in remote sensing," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 13, pp. 6051–6063, 2020.
13) L. M. Santos *et al.*, "Determining the leaf area index and percentage of area covered by coffee crops using UAV RGB images," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 13, pp. 6401–6409, 2020.
14) A. K. Patel, J. K. Ghosh, S. Pande and S. U. Sayyad, "Deep-learning-based approach for estimation of fractional abundance of nitrogen in soil from hyperspectral data," in *IEEE J. Sel. Topics in Appl. Earth Observ. Remote Sens.*, vol. 13, pp. 6495–6511, 2020.

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