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The Food-Energy-Water Nexus and Emerging Agricultural Technologies

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The world population is expected to reach 9.7 billion by 2050 (United Nations 2019), resulting in grand demand for food, energy, and water (FEW) to sustain human life and well-being. As the leading food producing country in the world, the United States therefore faces increasing pressure to meet this grand demand. Since food production requires tremendous amount of water and energy and since the chemical uses in crop production reduce water quality, how to optimize resource utilization in the FEW nexus arises as a pressing issue in the realm of agricultural production and resource management.

A recent article published in *Annual Review of Resource Economics* presents a new perspective to address this issue: It places emerging technologies at the center of enhancing the FEW nexus. The emerging technologies discussed in the article include: gene editing, second-generation biofuels, agrivoltaics, and precision agriculture coupled with big data and machine learning. Based on a comprehensive review of the literature on the FEW nexus and on the four types of new technologies, the article documents the opportunities and barriers of harnessing these technologies to optimize resource utilization in the FEW nexus and provides an outlook for future research, which are briefly summarized in the remaining of this article.

Gene editing technologies, when applied to either conventional crops or bio-energy crops, can provide farmers with novel crop varieties that have increased yield, higher biotic or abiotic stress tolerance, and enhanced nutritional properties. As a result, water and energy demand for food production can be reduced. The key barriers for the technologies to be fully utilized, however, are policy regulations and social acceptance. For instance, the European Union (EU) put gene-edited crop varieties under the same regulations as those on traditional genetically-modified organisms (Court Justice EU 2018). Moreover, although about 88% of scientists believe GMOs are safe to humans, no more than 40% of the public hold the same opinion (Pew Research Center 2015).

Second-generation biofuels have large potential for greenhouse gas (GHG) emission reduction and can be produced by using feedstock that grow well on marginal land, which enhances both energy and food security. Agrivoltaics, in which agricultural crops and solar panels share the same tract of land, have the potential to fully utilize solar radiation on the shared land and thereby mitigate land competition between crop production and commercial-scale solar panel deployment. Because they are in a nascent stage, the challenges facing second-generation biofuels and agrivoltaics include immature technology, larger upfront investment costs, and uncertain market and policy environment.

Recent technology development such as unmanned aerial vehicles, remote sensing, robotics, internet infrastructure, sensors, machine learning, and big data has revolutionized precision farming technologies and led agriculture production into a new age: Agriculture 4.0. For instance, based on advanced sensor technology and machine learning, a start-up company named Blue River Technologies has developed a "see & spray" technology that varies agricultural chemical application at plant level (Rausser et al. 2018). Not only do these technologies have the potential to provide field management (e.g., irrigation and fertilization) down to the plant level, but they also allow farmers to manage their fields in real time at any locations. Particularly, the adoption of these technologies would significantly reduce the demand for irrigation water on a per-acre basis and would mitigate water pollution caused by agricultural chemical application and soil erosion, mitigating the tension within the food-water nexus.

In addition to barriers such as high capital investment and farmers' limited capacity for mastering these advanced technologies, a major barrier to harnessing the benefit of advanced precision farming technologies lies in big-data infrastructure and regulation. The precision technologies can collect fine-scale data in real time farm management -- big data. However, how to manage and utilize the data is an emerging issue in the realm of precision agriculture. Regulations of data ownership, accessibility, as well as data sharing and analyzing are yet to be developed.

Based upon the considerations of the aforementioned opportunities and barriers, the study contends that public policies will play a critical role in incentivizing the development and adoption of these technologies. It also present an outlook for future research centered on harnessing advances these emerging technologies for enhance the FEW nexus. Specifically, due to the complexity of the FEW nexus, holistic approaches (i.e., "nexus thinking") should be employed to address the issues in the nexus when conduction economic modeling and analyses for policy designs. Addressing issues in the FEW nexus call for synergies among from economists, ecologists, solar engineers, plant physiologists, extension specialists, and many other experts in various fields. Moreover, behavioral factors should be incorporated into the economic and policy analyses.

Complete citation for the study discussed here is:

Miao, Ruiqing and Madhu Khanna. 2020. "Harnessing Advances in Agricultural Technologies to Optimize Resource Utilization in the Food-Energy-Water Nexus." *Annual Review of Resource Economics* 12. https://doi.org/10.1146/annurev-resource-110319-115428

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