Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in Environmental Sustainability

Optimizing resource use efficiencies in the food–energy–water nexus for sustainable agriculture: from conceptual model to decision support system

Hanqin Tian[1,2], Chaoqun Lu[3,1], Shufen Pan[1], Jia Yang[1], Ruiqing Miao[4], Wen Ren[5,1], Qiang Yu[6,7], Bojie Fu[2], Fei-Fei Jin[8,9], Yonglong Lu[2], Jerry Melillo[10], Zhiyun Ouyang[2], Cheryl Palm[11] and John Reilly[12]

Increased natural and anthropogenic stresses have threatened the Earth's ability to meet growing human demands of food, energy and water (FEW) in a sustainable way. Although much progress has been made in the provision of individual component of FEW, it remains unknown whether there is an optimized strategy to balance the FEW nexus as a whole, reduce air and water pollution, and mitigate climate change on national and global scales. Increasing FEW conflicts in the agroecosystems make it an urgent need to improve our understanding and quantification of how to balance resource investment and enhance resource use efficiencies in the FEW nexus. Therefore, we propose an integrated modeling system of the FEW nexus by coupling an ecosystem model, an economic model, and a regional climate model, aiming to mimic the interactions and feedbacks within the ecosystem–human–climate systems. The trade-offs between FEW benefit and economic cost in excess resource usage, environmental degradation, and climate consequences will be quantitatively assessed, which will serve as sustainability indicators for agricultural systems (including crop production, livestock and aquaculture). We anticipate that the development and implementation of such an integrated modeling platform across world's regions could build capabilities in understanding the agriculture-centered FEW nexus and guiding policy and land management decision making for a sustainable future.

Addresses
[1] International Center for Climate and Global Change Research and School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL 36849, USA
[2] Research Center for Eco-Environmental Sciences, State Key Laboratory of Urban and Regional Ecology, Chinese Academy of Sciences, Beijing 100085, China
[3] Department of Ecology, Evolution, and Organismal Biology, Iowa State University, Ames, IA 50010, USA
[4] Department of Agricultural Economics and Rural Sociology, Auburn University, AL 36849, USA
[5] Department of Plant and Soil Sciences, University of Kentucky, Lexington, KY 40546, USA
[6] State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Northwest A&F University, Yangling 712100, China
[7] School of Life Sciences, University of Technology Sydney, Sydney 2000, Australia
[8] Department of Atmospheric Sciences at University of Hawaii, Manoa, Honolulu, HI 96822, USA
[9] Laboratory for Climate Studies, National Climate Center, China Meteorological Administration, Beijing 100081, China
[10] The Ecosystem Center, Marine Biological Laboratory, Woods Hole, MA 02543, USA
[11] Center for African Studies, College of Liberal Arts and Sciences, University of Florida, Gainesville, FL 32611-6450, USA
[12] Joint Program on Science and Policy of Global Change, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139, USA

Corresponding author:

Current Opinion in Environmental Sustainability 2018, **33**:104–113

This review comes from a themed issue on **System dynamics and sustainability**

Edited by **Bojie Fu** and **Yongping Wei**

Received: 22 January 2018; Accepted: 06 April 2018

https://doi.org/10.1016/j.cosust.2018.04.003

1877-3435/

The concept of food–energy–water nexus and sustainable agriculture

Food, energy, and water (FEW) are three most important resources to sustain human life and well-being [1,2]. Due to growing needs from human beings, these three types of resources are increasingly interconnected to influence social stability and economic development [3]. Agriculture is the primary sector affecting secure provision of food, energy, and water, but also one of the key sources releasing greenhouse gases to the atmosphere and moving nutrients into aquatic systems [4,5,6••]. Many studies have indicated that the increasing crop yield was obtained at the expense of losing some important ecosystem services [7••]. Agricultural production has been co-limited by the availability and accessibility of critical resources globally. Furthermore, excessive resource uses caused severe ecological and environmental consequences that affect the security of freshwater and energy [8]. Increasing water demand and conflicts among water uses in industry, urban households, and agricultural irrigation make water scarcity and water pollution a pressing issue in many regions. Agricultural practices contribute to an increasing proportion of global energy demand. To meet the growing demands for food, energy and water in a way that is ecologically and environmentally sustainable is a paramount challenge facing U.S., China, and beyond [9,10]. Although the Integrated Assessment Model (IAM) has been applied to understand the FEW nexus at the global level [11], it remains uncertain to what extent more efficient water and energy uses could improve the potential of food production while reducing its environmental damage over different regions.

Prominent cases with growing conflicts within the FEW nexus

Driven by rapid global changes such as frequent climate extremes (drought, flooding, heat wave, etc.), urbanization, and growing population, increasing pressure on available resources (e.g. land, water, energy, and nutrient) has led to more conflicts in the food–energy–water nexus across the world. As the conflict extent as well as primary drivers for FEW provisions vary over regions, stakeholders need region-specific solutions in order to maintain a sustainable agriculture system. Here we have provided three prominent cases from China, the United States and Africa to illustrate these conflicts within the FEW nexus:

China

We take the Yellow River Basin (YRB, including irrigated area of Yellow River) in China as an example. YRB is the largest river basin in northern China, draining 11.5% of national land area, which is a key food and energy-producing region in China [12,13]. Half of national coal reserves and 18% of national crop production were located in the YRB [14]. However, water shortage is a severe problem in the YRB, which has only 4% of national water resources. Agricultural water use accounts for 75% of total water consumption in this region in 2015. Over the past three decades, one third of national total crop production increase came from the YRB, which can be attributed to a 2.4-fold fertilizer use, and an 80% increase in agricultural water use. In the meantime, however, total water resources in this region declined by 11%, accompanied by serious water contamination. The annual nitrogen-related grey water footprints (water required to assimilate pollutants) of crop production grew by 24 folds [13]. The storage volume of present reservoirs along the Yellow River can irrigate 24% of cropland, but only generate 0.12‰ of the total agricultural energy consumption in its basin. More energy demand was met by coal electricity generation, which is a high water-consuming and polluting industry [15]. This FEW conflict would be worsened as the area of mechanized, irrigated agricultural land continues increasing in the YRB.

USA

Another example of growing FEW conflicts is the Mississippi-Atchafalaya River Basin (MARB), the world's third largest river basin, draining about 41% of the conterminous U.S and most area of the U.S. Corn Belt [16]. With 58% of the basin area being covered by cropland, MARB is the basis of a $100 billion annual agriculture economy [17]. Over the past half century the U.S. average corn yield has increased by three folds with a 20-fold increase in nitrogen fertilizer input [18]. A large fraction of corn grain is used for ethanol production in the U.S. [19], and this rate might be further raised because of growing biofuel demands [20••]. Roughly 36% of U.S. corn is used as animal feed [21], and animal manure contributes to 5% and 37% of nitrogen and phosphorous delivered to the Gulf of Mexico, respectively [22]. Fueled by growing bioenergy and livestock feed demands, increasing agricultural water demand, water pollution, and the consequent eutrophication and hypoxia, and damaged aquaculture and coastal ocean fisheries became a growing problem for this region [16,23,24•]. Rise in energy demand makes the conflicts between food and water even sharper. Modeling study predicts that a target of 15 billion gallons of corn ethanol would increase land-to-aquatic nitrogen export by 10–18% in the MARB [25]. Meanwhile, energy consumption in agricultural practices such as harvesting, tillage, fertilizer application, as well as water pumping and irrigation also affect crop production by limiting availability of other resources.

Africa

The African countries, where are currently experiencing food and water crisis, inadequate energy provision, and the world's fastest population growth rate, especially need renewable FEW resources [26••], but they also need to improve their livelihoods and reduce the negative environmental and social impacts [27]. To meet the food needs, large area of forest and savanna ecosystems were converted to cropland for growing food crops, with more than 80% of vegetation loss was for fuel and food production during the past several decades [28•]. The expansion of cropland area and increasing crop yield due to intensive management will in turn result in more water use through irrigation and vegetation evapotranspiration, and affect water quality through enhancing nutrient exports to the riverine systems, leading to or worsening water shortage in Africa [29]. More than 40% of its population lives in arid and semiarid regions, where insufficient rainfall limits agricultural and plant productions. Africa's agricultural systems are particularly vulnerable to climate change and climate extremes [30]. A large fraction of Africa's crop production depends directly on rainfall. Except for climatic factors, the less intensive cropland management practices (e.g. fertilizer use, irrigation, seedling improvement) are major contributors to low crop yield in the Sub-Saharan Africa as compared to other continents [31•]. The irrigated cropland area is barely 3.7% in Sub-Saharan Africa, while it is about 10%, 28%, 29%, and 41% in South America, United States, East and Southeast Asia, and South Asia, respectively [32]. The global average