State of the Art of Water for Food within the Nexus Framework

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Abstract

The purpose of this review is to inform discussion at the January 2017 Water-Energy-Food Symposium at Texas A&M University. It evaluates the state of knowledge regarding water for food within the WEF nexus framework. Four topics are considered: improved plant genetics; irrigation technology and practices; urban agriculture; and food processing.

Recent research in plant genetics has sought to understand plant mechanisms that produce higher yielding crops, identify and map genetic loci regions responsible for desirable plant traits, and introduce new and safe methods of precision plant breeding. In addition, new discoveries in irrigation practices are crucial in sustaining and further increasing yields as a result of improved irrigation water use efficiency through near-real time spatio-temporal monitoring of soil moisture, evapotranspiration, and rainfall. Urban agriculture, which has been gaining ground in recent years, have identified the role it plays in the international food portfolio and how city regulations can limit or encourage its adoption. Also, breakthroughs in food processing have focused on water reuse by treatment and decreasing waste in order to minimize water use.

Opportunities remain to increase water use efficiency and/or decrease water usage throughout the food supply chain. Food producers and processors need to achieve greater value from the water used through enhanced management supported by new technology and guided by scientific findings evolving from multi-disciplinary research. To achieve this, constant exchange is needed between regulatory agencies, farmers, food manufacturers, and researchers to ensure all stakeholders are up to date on the issues, policies, technologies, and discoveries related to water and food production sustainability.

Introduction

This review evaluates the state of knowledge and opportunities regarding water for food within the WEF nexus framework. Food, feed, and fiber production is globally the highest water user, accounting for 70% of all water consumed compared to 10% for domestic use and 20% for industry (http://www.worldometers.info/water/; Clay,2004). Many facets of food production involve consumptive water use ranging from crop, livestock production, and processing food. Although, production of animal products can demand high amounts of water (Chapagain and Hoekstra 2003), water for livestock will not be specifically discussed as the feed component is addressed in the plant genetics and irrigation practice sections, the food manufacturing component is addressed in the food processing section, and the livestock drinking water component is negligible (i.e. 1.6% of annual water demand in Texas). As a result, this review primarily focuses on non-animal production. Further, this assessment attempts to address water for food from a global perspective but recognizes that solutions must be localized. Research questions stem from the challenges that could be addressed with a combination of new and available data. Finally, solutions are suggested along with possible implications on science and society.

Key Challenges/Research Questions

Four key research challenges are considered: improving plant genetics; irrigation technology and practices; urban agriculture; and food processing.

(a) Plant Genetics:

<u>Key Challenges</u>

The main goal of plant genetics research is to identify desired plant traits (e.g. drought tolerance, pest resistance, salt tolerance, and heat tolerance) to produce higher yielding crops in both dryland and irrigation agricultural systems, to understand the plant mechanisms that control these traits, and to single out these traits through precise plant breeding methods. The key challenges in plant genetics reside in closing the knowledge gaps of comprehensively understanding these plant characteristics and identifying their DNA regions. Additionally, there are knowledge gaps in the decision-making processes regarding best cropping scenarios of genetically favorable crops for localized conditions.

Research Questions

How can methods of modern biotechnology (genetically modified organisms or GMO, genetically edited crops or GEC, and marker-assisted breeding) be used to introduce the best gene combination into elite crop cultivars to produce drought-tolerant, heat tolerant, pest resistant, salt tolerant, and higher yielding crops? GEC is a new method of precision breeding alternative to GMO (Huang et. al., 2016); how can this method be widely utilized in our food portfolio, and will it be receive less backlash than GMO technology? How can these (GMO or GEC) crops be best integrated into localized cropping scenarios? Analytic crop selection based on climate, soil-quality, and water availability is becoming increasingly pertinent for water-food decisions that promote sustainability of commercial farming.

(b) Irrigation technology and practices:

Key Challenges

A major challenge lies in developing effective and easy to use irrigation equipment (e.g. controllers, sensors, etc.) and software/smart device Apps (e.g. irrigation scheduling) by taking in consideration the location and environment of the application (developing and developed countries, climate, and soil type) and achieving their widespread adoption by irrigators (farmers, ranchers, or urban irrigation). Furthermore, to expand the acceptance of the new-water sources available for irrigation. In other words, the stigma associated with non-traditional water should be addressed by scientists in order for food growers and consumers to be conscience about the appropriate application of the "new water".

Research Questions

How can we globally optimize water use through innovative and integrated water management solutions (technology, non-traditional water resources, etc.)? How can we spread the scientific discoveries and the advanced technology around the world? By 2025, approximately 2 billion people will be living in regions under complete water scarcity, and two-thirds globally could be living in water stressed countries [Food and Agriculture Organization (FAO), 2012]. At the global scale, much of the water used in irrigation is "blue" water directly withdrawn from aquifers causing their depletion when they are not managed properly. Irrigated agriculture plays a major role in the food production sector as it accounts for 40% of the total food produced worldwide (FAO, 2012).There is an urgent need to better use untapped water resources and adopt new technologies to enhance water use efficiency. Using non-traditional water sources for irrigation such as grey water, treated wastewater, brackish groundwater, and water from the oil and gas industry are being explored as potential replacements for or supplements to freshwater. For example, irrigation with recycled wastewater has been successfully applied in Texas as well as globally (e.g. Spain, Tunisia, Greece, Italy, Cyprus, Jordan, and Israel). An estimated 20 million hectares are irrigated with undiluted (raw) or partially diluted wastewater globally (United Nations, 2003). However, the application of raw wastewater is mostly in developing countries as a result of having no alternative irrigation water. Undiluted wastewater is harmful on many levels (human health and environment) because it contains toxic substances (e.g. pathogens, heavy metals) (Quadir et al., 2007). Agricultural productivity is enhanced by irrigation; however, the current intensity of freshwater withdrawals will not be sustained in many regions. Therefore, technological progress is on the rise for irrigation methods designed to conserve water and sustain agriculture. Improving water efficiency while maintaining or increasing yields is the main objectives for advances in irrigation and soil moisture technologies. Advances such as that in sensor and controller technology will allow irrigators to better target their water usage. Soil moisture and plant stress monitoring using a variety of in field and remote sensing techniques are being tested and improved. Different sensor types have been used in smart agriculture, e.g. in-situ, air born and remotely sensed. Several products (e.g., maps, tabled data and text data) have been generated that help identify different soil properties vital in soil management which leads producers to better water management by managing irrigation events. Resulting improved water management will improve water use efficiency and allow production of more crops per unit of water used.

(c) Urban Agriculture:

<u>Key Challenges</u>

Challenges associated with the growth and sustainability of urban agriculture are the lack of suitable land and economic incentives (in developed countries), the effects on crop yield of air and soil pollution in urban areas (especially “slum” areas), the illegality of urban farming within some cities (which is the case in many developing countries). Another key challenge resides in capturing the true global quantities of food produced and water used in urban agriculture.

<u>Research Questions</u>

For urban agriculture, the primary question is, can the contribution of urban agriculture be enhanced sufficiently to be considered as part of the food production portfolio (considering its potential to optimize water resources in agricultural production)? By 2050, an estimated 70% of the world’s total population will reside in urban areas (FAO, 2016). While food production data regarding urban agriculture is hard to come by, there is evidence that it contributes significantly to the world's food supply. Data from 1993 indicate that urban agriculture produced up to 15 to 20% of the world's food supply (Armar-Klemesu, 2000), and the FAO cites in their "Food for Cities" initiative that 800 million people practice urban agriculture world-wide. Irrigation for urban agriculture is typically small scale and highly efficient and is a possible water-saving solution. Thus, it is important to consider urban agricultural practices as pertinent in the portfolio of water for food. Urban agriculture is more relevant in developing countries, where it already constitutes a significant portion of the total food supply. However, it only plays a minor role in developed countries due to a lack of economic incentives and space (Corbould, 2013). Urban agricultural practices could be prolific in urbanized regions if regulations accommodated it. For example, in the city of San Antonio, Texas, in December 2015, urban agriculture became legal in most zones of the city (San Antonio City Council, 2016), and while production numbers are still being quantified, the practice is proliferating. Well suited technologies for irrigating urban agriculture include drip irrigation and simple hydroponics.

(d) Food Processing:

Key Challenges

The main challenge is to assist food and beverage companies in decreasing their water usage and converting to more water efficient processes.

Research Questions

What are practical practices for food manufacturers to optimize their water use and reduce their water footprint, including direct water used in food processing and indirect water used by their suppliers/farmers for crop production? The water footprint is a measure of the volume of freshwater used along the entire food chain, from production to waste disposal. The water footprint includes the use of rainwater ("green" water), water withdrawn from groundwater or surface water ("blue" water), and any resulting wastewater streams ("grey" water) (Hoekstra et. al., 2009). In the food processing industry, direct water usage includes water used for cleaning of food and facilities, as an ingredient in products, and as a coolant for equipment and facilities. All the water used in the beginning of the food chain (e.g. crop production) is known as indirect water for the food-processing sector. The direct water footprint is low compared to the indirect water footprint, which constitutes most of the water used for food products. For example, the water footprint to produce 1 kg of chocolate is 24,000 liters (Hoekstra et. al., 2009) with most of the water used in the external water footprint for cocoa production. Therefore, food processors seeking to significantly decrease their water footprint tend to buy their cocoa from water efficient suppliers. Furthermore, crops harvested (bought from farms) used in food production are the largest water consumer in the supply chain. Food processors are working to decrease their direct water consumption by treating and reusing water.

Data/Knowledge Gaps

(a) Plant Genetics:

<u>Data</u>

There is currently an abundance of data available in terms of genome mapping for plants, and there are currently a number of genetically modified crops in the market that have increased favorable plant characteristics. Geneticists are able to identify key DNA regions of some of these positive traits discussed, but not all of them, and nor do they have a comprehensive understanding of the plant mechanisms that control these traits.

<u>Knowledge Gaps</u>

In terms of drought-tolerance, questions remain balancing the tradeoffs between plant health risk in normal scenarios and improved performance in drought scenarios. Furthermore, there are remaining knowledge gaps regarding scaling drought-tolerance results because of the abundance of differing variables in any given drought scenario (Tardieu, 2012). Regarding heat resistance genetics, there has been progress in understanding the complex heat shock traits and genetic mechanisms of high temperature tolerance responses (Singh & Grover, 2008), but more work needs to be done to better understand these as well as the epigenetic regulation of heat responses (Liu et. al., 2015). In terms of salt tolerance, there has been some work done regarding salt tolerance traits in plants (ion exclusion, osmotic tolerance, and tissue tolerance), but the effect of introduced genes by genetic engineering needs to be evaluated in the field to determine their effect on salinity tolerance (Roy et. al., 2014). Regarding higher yielding plant genetics in general, there is a basic understanding of optimizing plant architecture to produce high-yielding breeds of plants, but there needs to be an establishment of an ideal plant architecture for various crops for developing effective breeding strategies (Cai et. al., 2016). Subsequently, there is a need for better education and decision-making processes regarding the selection of cropping scenarios.

(b) Irrigation technology and practices:

Data

Non-traditional water has been applied all over the world with success stories in Europe and the Middle East. Treated wastewater is the only “new-water” type that has been extensively used and it has been the main focus of researchers. Irrigation technologies are present and a lot of them are on the market. However, farmers with small revenues are missing out because of the high costs of the innovation that could help them increase their yields. Similarly on a bigger scale, developing countries are overlooked in this situation because of financial reasons.

Knowledge Gaps

Researchers can truly evaluate their newly developed technology on the field by seeing its performance when farmers use it. Therefore, by improving usability and adoption of the technology through farmers, the researchers would know the drawbacks of their technology and they would have a better idea on the way to upgrade their product. Therefore, sensors, irrigation scheduling tools, and irrigation delivery systems should be enhanced to help food growers to become water sustainable.

There is a lack of solid information to date on the impact of applying non-traditional water on soil health and structure. Furthermore, reclaimed water irrigation has been hailed as the freshwater replacement by some researches indicating the benefits of this application. For example, treated effluent contains nutrients that can help grow crops and enrich the soil’s humus content from the presence of organic matter in the recycled water. On the other hand, some researchers have rebuffed the idea of replacing freshwater by showing the damages done using non-traditional water. For instance, using reclaimed water can lead to decreasing the crop size and quality. Therefore, more research is needed to evaluate the viability of using the different types of non-traditional water for agriculture. Safety and health are two major issues when using non-traditional water for irrigation. Research should revolve around the use of “new-water” by assessing the health risks of farmers for direct contact when irrigating. Also, research is needed to investigate the safety of consumers. Another major issue is the acceptance by overcoming the stigma of “wastewater”. Developing nations should be incorporated when new technologies are being developed because we are aiming for a global sustainable water use and each country has its different climate, environment, and challenges.

(c) Urban Agriculture:

Data

Available data regarding the potential of urban agriculture and its global are available through the FAO and the United Nations Development Program (UNDP). However, much of the information regarding food production and water use in urban agriculture is highly estimated.

Knowledge Gaps

Currently, in most countries there is no precise statistics on the acreage of land in urban agriculture and the corresponding quantification of food produced and water use. Thus, it is quite difficult to accurately quantify its impact on the food and water portfolios. Additionally, there are knowledge gaps regarding treatment and impacts of on-site water reuse options, such as greywater, air-conditioning condensate, and even blackwater, which is more relevant in developing countries.

(d) Food Processing:

Data

There are some general estimates on water needed for processing different kinds of foods. However, the best source to obtain water consumption data would be directly from the food manufacturers branch organizations.

Knowledge Gaps

Databases on water consumption for different types of food manufacturing are limited and generally proprietary. Therefore, a large data gap exists regarding the actual quantification of water-use in food manufacturing.

Potential Transformative Solutions Needing More Research (e.g. technologies, community building, policy and governance, etc.)

(a) Drought Tolerant Plant Genetics:

A European Union-funded project was launched in 2015 (DROPS) to discern genetic patterns associated with water-efficiency and drought-resistance in corn, durum wheat, bread wheat, and sorghum. This project employs a method of targeted analysis that focuses on characteristics (e.g. grain abortion rate, vegetative growth maintenance, root system architecture, and transpiration efficiency) that indicate how well cereal plants can produce grains in dry, hot conditions (European Commission, 2015). One finding from this research initiative was that most traits associated with drought tolerance have a “dual effect” of being positive in severe drought scenarios and negative in mild drought to normal rainfall periods (Tardieu, 2012). The results from this study need to be fully disseminated for the use of agriculturalists and planners. Then, there can be capacity building regarding best crop selection practices based on local conditions and available drought-tolerant crops.

(b) Irrigation Technology and Practices:

Non-traditional water application requires research to evaluate the potential for soil chemical changes that may lead to the alteration of the soil's physical structure. Furthermore, research is needed to understand the soil chemistry changes leading to the soil physics modifications. Consequently, this research will advance water sustainability if one of the "new-water" types is proven to be a potential replacement for freshwater with minimal (repairable) or without any damage to the soil health. In addition, research funding is needed for studies involving "new water" generators such as wastewater treatment plants or a new water system where grey-water is separated from wastewater and reused for urban agriculture. In order for society to accept "new water", new regulations for the use of non-traditional water for agriculture are needed. Farmers in developing nations should receive proper education on the negative effects of using untreated wastewater. Developed countries and water-rich nations should provide alternatives to water scarce countries to overcome the challenges and reduce water depletion.

Food security will be achieved when researchers and Extension specialists cooperate with producers to facilitate the implementation of new technology and knowledge for new discoveries that reduce water use and maximize yields around the world. For instance, low interest loans specified for cutting edge technologies can be provided to food growers in order to push forward the breakthroughs of researchers. Also, farmers that use "non-traditional" water (if they are proven to be a viable substitute for freshwater) could be rewarded using a variety of incentives, tax breaks, and/or low interest loans to encourage others to do the same, potentially leading to a decrease on the dependence of freshwater in the agriculture sector. Although ongoing research is focusing on maximizing yields, there is a need for defining and finding techniques to measure actual, attainable, and potential yields at different scales in time (short or long term) and space (field, farm, space, region, global) in order to close the yield gaps to achieve food security (FAO, 2015).

(c) Urban Agriculture:

Transformative solutions that could encourage the sustainable growth of urban agriculture are changes in city regulations, community education, and capacity-building regarding urban agricultural practices and their benefits. An example of such an initiative is the "Food for Cities" program established by the FAO in 2001, which is multidisciplinary and aimed at addressing challenges associated with urbanization by building more sustainable and resilient food systems (FAO, 2016).

(d) Food Processing:

Farmers should be motivated and funded by large food and beverage companies to incorporate sustainable water management practices. Large food processing companies should set a water footprint target and buy their supplies from farmers using responsible water practices. The government needs to take action by encouraging leading food processors to improve the sustainability of their water consumption. Setting water use standards for food products will induce businesses to shrink the water footprints of their goods to meet required standards.

Impact on Science and Society

The findings and potential solutions discussed above impact the ways in which the food production process consumes water resources. Plant geneticists are gaining a better understanding of the genetic regulation areas that control higher-yielding plant traits, but there is still work needed to gain a comprehensive and employable understanding of these traits. As plant genetic biotechnology progresses, agriculturalists are further enabled to choose more sustainable and water-efficient cropping scenarios. Regarding irrigation practices, recent research efforts are transforming convention to encourage consideration of non-traditional practices that are sustainable and water efficient. Regarding urban agriculture, impacts of its growth are increased water efficiency and the bolstering of food and nutrition security, especially for the urban poor. Lastly, the main impact of the research and solutions of water use in food processing is to initiate a dialogue between researchers, manufacturing corporations, and farmers regarding water use to encourage water efficiency in a mutualistic way in order to decrease the water footprint of food products.

Conclusion

In summary, water is a scarce commodity and the food production industry (from farm to market) uses more water than any other sector. Recent findings in drought-tolerance plant genetics, irrigation, urban agriculture, and food processing focus on sustainable water use technology in order to decrease the stress on freshwater resources globally. The research challenges will require funding from the food industry and regulatory agencies as well as incentives aimed at motivating stakeholders to minimize water consumption. On an international scale, agencies and institutes should fund water sustainability projects to reach water and food security in developing countries. Interdisciplinary research (plant breeding/genetics, irrigation engineering, agronomy, water management, soil science, food scientists, etc.) should be integrated with food manufacturers and producers in order to enhance communication on the latest discoveries and technologies.

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