Achieving Water Security in Agriculture: The Human Factor

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ABSTRACT

It is widely recognized that achieving water security will take substantive investments in hydrology, engineering, soil science, agronomy, and a wide variety of physical and natural sciences and technologies. Less understood is the human aspect, the social science of beliefs, values, human perceptions and decision-making, social relationships, and social organization that intentionally and unintentionally construct, destroy, and reconstruct the water and land resources to which society is intimately linked. Addressing the complex issues of water security will require humans to acknowledge the threats to security and a willingness to give priority to assuring water quality, water availability, and water access to meet the needs of a growing world population and their economic engines. Soil–water–vegetation–climate–human relationships are central to maintaining and repairing the hydrological cycle necessary for fresh, safe, and abundant water supply. The current and future condition of our earth ecosystem is substantively dependent on individual and social decisions and policies associated with water. There is a need for (i) more coupled human-natural science to understand these relationships, (ii) greater public participation in connecting scientific facts and social values, and (iii) a willingness to innovate and adapt water and land use decisions and policies as scientific understanding and values evolve.

The patterns of civilization–human and social decisions and actions–overlay the natural patterns of soil, water, vegetation, and climate (USDA Climate and Man Yearbook, 1941). Achieving water security in agriculture will require close attention to the scales of geography, time, and the social structures of human behavior and institutions (Jackson et al., 2010). These relationships are complex, dynamic, and often unpredictable requiring monitoring and sensing of change and flexible, adaptive responses. Values, beliefs, perceptions of risks, peer and hierarchical power relationships, political and economic conditions, public policies and enforcement infrastructure, as well as shifting long-term weather patterns are factors that influence capacities to balance competing demands among many sectors for adequate, clean, and safe water supplies.

WATER AND HUMANS

Water headlines 1 wk in January 2014, well illustrate the coupled human–natural ecosystem relationships that underlie water security and the difficult challenges ahead. The first reports that dust from drought and land use in Southwest United States is carried on strong winds into the atmosphere where it lands on mountain snowpack. The darker snowpack melts faster as it absorbs instead of reflects the sun radiant energy, leading to earlier snow melt and heavy spring runoff which erodes hillsides, floods streams, and exceeds reservoir capacity to handle the fast flows (Campoy, 2014). A second article quotes the governor of California as the state enters its third year of drought, “we are in an unprecedented, very serious situation, and people should pause and reflect on how dependent we are on the rain, on nature, and on one another,” (Carlton and Lazo, 2014). The drought includes parts of 11 mostly western states, with restrictions on urban and rural water use including growers in California’s fertile central valley and projections that more than one-third of their agricultural land areas would be fallowed. A third, front page article, details an investigation of a West Virginia chemical spill into the Elk River 2.41 km upstream from the capital city, Charleston, which contaminated the water supply of nearly 300,000 people for a week (Maher et al., 2014).

Water security concerns encompass (i) water disasters such as flooding and drought, (ii) water quality affected by agricultural nutrient pollution (hypoxia conditions in bays and gulfs) and chemical contamination, and (iii) water quantity characterized by competing sectors needing water access: agricultural irrigation, recreation, manufacturing, and potable water for rural and urban populations. The management of water resources in agriculture, rural, and urbanizing environments is complicated with solutions to one problem often leading to unintended consequences to other human and natural systems. Several particularly persistent negative outcomes that are threats to water...
security include unsustainable use of water, widespread impairment of water quality, failure to meet specific water quality goals, continued use of farming practices known to contribute excess nutrients and other pollutants, and economic stress for agricultural producers (Gold et al., 2013).

Chapin (2009, p. 41) proposes that achieving water security requires attention to the underlying ecosystem. “Maintaining the essential role of intact ecosystems in the hydrological cycle is the single most effective way to sustain the supply and quality of fresh water for use by society” (Fig. 1). However, social and biophysical interdependencies are not well understood because they are complex at three types of scale (time, space, and human institutions), with problem definition socially constructed making relationships difficult to model because of the many social, economic, and political factors (Batie, 2008; Jackson et al., 2010). This complicates decisions about when, where, and how to manage the hydrologic cycle as they are socially negotiated among stakeholders with highly divergent viewpoints and understandings of the problem with no one view “right” (Batie, 2008; Morton, 2011). Thus, issues of water security and resource degradation must be problematized if society is to effectively re-examine and evaluate the balance among social, economic, agricultural, and ecological conditions and act for the wellbeing of the many segments of society in need of water resources.

Agriculture is a critical sector of society affecting the availability of safe and affordable water resources, a safe food supply, global food security, sustainable bioenergy, and the management of ground water and nutrients levels in surface waters. Agriculture uses account for more than 60% of groundwater demand (Hutson et al., 2000), releases excessive N and P into proximate water bodies, much of it from sediment and water runoff which are primary sources of anoxic conditions (Alexander et al., 2008), and has expanded production into highly erodible lands as well as floodplains and former wetland areas by extensive systems of drainage. Agriculture is a human–natural system (agroecosystem) which has re-made nature by the way it manages biogeochemical cycles and ecological processes. These human actions, purposeful and unintended, have consequences that affect the degradation, protection, and restoration of agroecosystems. The management of soil resources underlie the availability of water for plant and animal production and water infiltration and percolation that replenishes ground water and determines the quality and availability of water resources. Thus, key challenges for agriculture are how to better manage the soil–water interaction to reduce water runoff and soil loss to erosion; improve nutrient cycling; increase water infiltration and storage and availability of moisture; increase resilience under variable and extreme precipitation conditions (i.e., drought, saturated soils); utilize soil chemical and biological filtering to remove pollutants and pathogenic bacteria; and ensure storage capacity to buffer seasonal fluctuations in river flows.

Science has provided ample evidence that it is technologically possible to engineer water structures, create new soil conservation strategies to manage soil moisture and control pollution, and bio-engineer agricultural production to use less water. Although some progress has been made in addressing water resource concerns, external non-stationary drivers such as land use; increasing climate variability; shifts in markets, policies, and regulations (Gold et al., 2013) as well as individual and group social relationships; beliefs; perceptions of risks; and capacities/willingness to act can quickly lead to polarized situations, conflicts of interest, increased levels of uncertainty, and no definitive solutions. This suggests that technologies alone are likely insufficient to achieve water security in agriculture, and the social factors associated with agroecosystems are part of the solution.

**SOCIAL ASPECTS OF AGROECOSYSTEMS**

Human society is held together by shared normative understandings, public discourse, and moral persuasion which guide the construction of the form and function of social, political, and economic structures (Morton, 2011). Social definitions of the problem of water security in agriculture and sense of urgency or crisis will drive willingness and capacity to act. The ways in which governments, markets, and civil society intersect, communicate, and process science and local knowledge can affect public attitudes, beliefs, and normative expectations about water and land use functions. Adaptive responses to changing conditions, whether increasingly variable weather patterns, new opportunities for expanding markets, short-term economic spikes, social and legal pressures to reduce pollution impacts on the environment, or public policies to incentivize change in practices can take several forms ranging from resistance to change (maintain the status quo), to modifications in current practices, to total transformation of the landscape when current uses seem no longer sustainable.

The empirical evidence of patterns which explain agricultural adoption of conservation best management practices (BMP) that would address water security issues is weak. Prokopy et al. (2008) meta analysis of 55 articles representing 25 yr of literatures on adoption of BMP found no factors were consistently significant. A number of social variables had significance in several studies: access to information, social networks, environmental awareness, and positive attitudes toward the environment. They concluded that social and economic factors influencing adoption of conservation BMP were complex. Further, they suggest, like Coughenour (2003) that adoption of individual BMPs is likely different than a systems approach to conservation involving interactions among multiple BMPs.

![Fig. 1. Agroecosystem wetlands in support of the hydrological cycle.](image)
The U.S. agriculture is a nested system of fields, farm enterprises, local watersheds, ecosystems, policy and market systems, and systems of innovation (Anderson-Wilk, 2009). Flora’s (2004) agroecosystem management framework articulates four different levels of social factors (internalization, social pressure, economic, and force) and the positive and negative sanctions that represent human risk perceptions and cost-benefit assessments associated with individual and public decision making. Figure 2, an adaptation of this framework, places assessments associated with individual and public decision makings, personal values, beliefs, identities, experiences, perceptions, and actions as the foundation which shapes social relationships and cultural norms as individuals interact and attempt to manage collectively held resources. Economic exchanges and market conditions; public policies and regulations; and institutional willingness/capacity to enforce rules are socially constructed by organizations, government, and special interest sectors reflecting dynamic and shifting power relations. There is a great deal of complexity and unpredictability to these relationships which are influenced by geography, social-biophysical interactions, and time scales.

**Personal Perspectives, Social Pressures, and Collective Action**

In agriculture, farmers are key players directly influencing how water and soil resources are managed at the field and farm levels. In turn their decisions and actions affect their own productivity, the surrounding social and biophysical landscape, and the water conditions downstream of their watershed. One of the most significant challenges to water quality is nonpoint-source pollution from off-field/off-farm loss of soil and agricultural nutrients to proximate water bodies leading to hypoxic conditions in bays and gulfs (Morton, 2011). Farmer conceptions of their roles in agriculture as producers of crops, conservers of soil and water, and/or protectors of biodiversity can influence the adoption of different technologies, some focused on yields and management efficiencies and others on protection of the ecological system within which they farm and make their livelihoods (McGuire et al., 2013). The social relations among farmers and their scientific and technical crop advisors are critical sources of information, peer pressure, and normative practices in the art of farming. This is particularly apparent in surveys of farmers and their beliefs about climate change, perceptions of risk, and adaptation or mitigation responses to flooding, saturated soils, and loss of soil (Arbuckle et al., 2013). Structural equation models reveal that farmer beliefs are influenced by agricultural and environmental interests with trust in agricultural interests as sources of climate information associated with non-belief and uncertainty about climate change, and trust in environmentally oriented groups related to belief that climate change is occurring and attributable to human activities (Arbuckle et al., 2013).

**Markets, Public Policies, and Economic Contexts**

The U.S. Farm Bill legislation and the subsidies provided to specific commodities and specified conservation practices affect market prices and indirectly costs of land and agricultural inputs. Commodity prices, cost of inputs, access to and affordability of water for irrigation, access to markets, and farmer perceptions of BMP profitability can affect crop selection, rate and method of N applications, decisions to cultivate grasslands and highly erodable lands, and adoption (or not) of a wide range of farming technologies. Use of synthetic fertilizers and herbicide inputs have favored the specialization of grain crops and led to huge gains in yield and labor productivity (Bechdel et al., 2010; MacDonald, 2011) as well as farm profitability. However, the side effects have been damage to local and downstream water bodies as excessive N, P, and other agricultural chemicals are lost off field rather than taken up by vegetation (Ribaudo, 2011).

A growing bioeconomy has diversified demand and increased markets for a variety of agricultural feedstocks. However, neither market prices nor public subsidy incentives of biofuel–ethanol and cellulosic production take into account impacts on soil and water resources when marginal lands are cultivated due to high commodity prices or harvest practices withdraw too much C from crop residues and deplete soil capacity to sustain the hydrological cycle and the systems it supports. Failure to employ sustainable agricultural practices negates bioeconomy claims of producing renewable products. Technologies which use high quantities of biomass must rebalance the human–natural system relationships and move beyond sectorial economic benefit to the creation of fourth generation biotechnologies that concurrently address environmental issues such as soil and water conditions that can lead to decreased water security.

**THE HUMAN FACTOR**

Water issues connect agriculture to people and their communities and the larger landscape. Agricultural intensification, commodity price volatility, degraded water resources, hybridization of rural economies, and rural–urban competition for water resources are challenges already here. As new and old systems of agriculture re-engineer themselves to meet local and global demands for bio-based products, food security and leisure, water will be a critical, limiting resource. A narrow focus on technological innovations to achieve agricultural productivity only places society and the ecosystem it depends on at risk. Increasing extreme and unpredictable weather patterns, farmer uncertainty about sustainable production practices (Morton et al., 2013), and competing social needs for water are problems society is being forced to address. Risk analysis (known hazards) in combination with resilience analysis (unknown hazards) (Park et al., 2012) suggest that agriculture’s future
would be better framed as a multi-functional/eco-economy. This means that agroecosystem management must balance public good with private benefits, stress place-based development and accountability, and integrate eco-understanding with social and economic goals (Slee, 2012). Soil performance and its multi-functional capacity to improve nutrient cycling and increase water infiltration and storage capacity under variable and changing climate is a critical issue. The concept of an eco-economy rebalances the values placed on relationships among human management of agriculture, ecosystem services such as the hydrological cycle, and society.

Concerns for access and availability as well as quality of water resources are forcing meaningful dialog among competing and conflicting urban and rural interests, and among research, education, industry, technical and regulatory entities. Leadership at local, state, and national levels is needed to create core groups of people with skills and a common vision. This vision must encompass (i) recognition that water security is a systems problem, healthy agroecosystems are necessary to sustain a well-functioning hydrological cycle; (ii) strategies to incorporate soil performance/health improvement into crop production planning and business plans; and (iii) the building of social, political, and economic infrastructures necessary to enable widespread adoption of soil–water management that can improve the green and blue waters of agriculture.

Solutions to maintaining and repairing the hydrological cycle necessary for fresh, safe, and abundant water supply are dependent on investments of time and energy, infrastructure, natural and economic resources. These investments should focus on (i) more coupled human-natural science to understand these relationships, (ii) greater public participation in connecting scientific facts with social values, and (iii) increasing the willingness to adapt water and land use decisions and policies as scientific understanding and values change.

ACKNOWLEDGMENTS

Support for this work comes from USDA-NIFA Integrated Water Program award no. 2008-51130-19526 Heartland Regional Water Coordination Initiative and USDA-NIFA Climate Change, Mitigation, and Adaptation in Corn-based Cropping Systems Coordinated Agricultural Project (CAP) award no. 2011-68002-30190.

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