
COMMENTARY

Leveraging agroecology for solutions in food, energy, and water

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Global agriculture is facing growing challenges at the nexus of interconnected food, energy and water systems, including but not limited to persistent food insecurity and diet-related diseases; growing demands for energy and consequences for climate change; and declining water resources, water pollution, floods and droughts. Further, soil degradation and biodiversity loss are both triggers for and consequences of these problems. In this commentary, we argue that expanding agroecological principles, tools, and technologies and enhancing biological diversity can address these challenges and achieve better socioeconomic outcomes. Agroecology is often described as multi- or transdisciplinary, and applies ecological principles to the design and management of agricultural systems through scientific research, practice and collective action. While agroecology has roots in the study of food systems, agricultural land use has many direct and indirect linkages to water and energy systems that could benefit from agroecological insights, including use of water resources and the development of bio-based energy products. Although opportunities from the science and the practice of agroecology transcend national boundaries, obstacles to widespread adoption vary. In this article, we therefore focus on the United States, where key barriers include a shortage of research funds, limited supporting infrastructure, and cultural obstacles. Nevertheless, simply scaling up current models of agricultural production and land use practices will not solve many of the issues specific to food related challenges nor would such an approach address related energy and water concerns. We conclude that a first critical step to discovering solutions at the food, energy, water nexus will be to move past yield as a sole measure of success in agricultural systems, and call for more holistic considerations of the co-benefits and tradeoffs of different agricultural management options, particularly as they relate to environmental and equity outcomes.

Keywords: sustainable agriculture; systems science; biological diversity

Introduction

New impetus for interdisciplinary research on food, energy, and water systems is emerging, driven by an increasing recognition that focus on gains in one specific area can inadvertently lead to losses in others, as well as by concerns about population growth, climate change, water resources, and deficiencies of the current food and agricultural system. As this research area develops, the scientific community can work to identify the most critical questions, tools, and approaches to cost-effectively uncover sustainable solutions. In this article, we propose that the field of agroecology is poised to effectively address these challenges, but we also highlight several obstacles that may need to be overcome to enable broader application of agroecological solutions.

A commonly used definition of agroecology is that it is “the science of applying ecological concepts and

principles to the design and management of sustainable food systems” (Gliessman, 2014), and many authors have stressed the importance of defining agroecology more broadly as jointly a science, practice and social movement (Sevilla Guzmán et al. 2013). While definitions of agroecology vary (Montenegro de Wit and Iles 2016), we have interpreted that a core feature is that it *entails a systems – based study of the agricultural system – from crop production to product use – and draws on the biophysical and social sciences to develop ecologically, economically, and socially sustainable agricultural practices*. It is noteworthy that agroecology is often defined in terms of food systems, but that the field includes tools and perspectives that are highly relevant to agricultural systems more broadly, which are tightly linked to water and energy systems.

Agroecology involves a multi-disciplinary, and often a transdisciplinary, approach that can lead to solutions that serve the public good by simultaneously fostering food system productivity and resilience, reducing energy consumption and supporting bioenergy production, as well as conserving water resources (Kremen and Miles, 2012; Ponisio et al., 2015; Gliessman, 2014; Schipanski

et al., 2016). Agroecology can be conceptualized as multi-disciplinary in its approach in addressing concurrent research disciplines; it should be noted further, however, that it is also transdisciplinary in that it incorporates but also elements of practice and collective action, which can enable the scaling of agricultural practices from individual farms to larger landscape-level change. As a result, there is growing recognition that an agroecological transformation is needed on a global scale (IPES–Food, 2016). Notably, more than four hundred scientists working in related fields, including experts from within and outside of the United States, have called for an increase in public funds to help support such a shift (Union of Concerned Scientists, 2017). While a move toward agroecological principles is needed globally, this commentary will focus primarily on opportunities, barriers, and motivations that are particularly germane within a U.S. policy context.

Agroecology and biological diversity for more resilient food, energy, and water systems

Industrial agricultural landscapes planted as large-scale monoculture systems, with either food or energy crops, have been linked to broad environmental and societal consequences. Such biologically simplified farming systems have been connected to water-related issues such as pollution and toxic algal blooms (Porter et al., 2015; Smith et al., 2015), and depletion of groundwater (Richey et al. 2015). At the same time, many of these systems are also prone to soil erosion and degradation (Montgomery, 2007; Veenstra and Burras, 2015), loss of pollinator species (Kremen et al., 2002), and the decline of rural communities (Francis et al., 2014), all of which could contribute to additional problems, such as a loss of system resiliency. One recent study supported this hypothesis regarding resilience, finding that higher-income countries that are more heavily reliant on large-scale monocultures had a greater yield deficit following extreme weather as compared to lower-income countries that likely include more diverse crops and management (Lesk et al. 2016). Thus, these industrial-scale landscapes of food and energy crops may be putting pressure on natural resources and socio-economic systems in the interest of achieving potentially high productivity, but with unintentional losses resulting from low resilience. Increasingly, many of the agricultural practices used on these landscapes are also exacerbating current and future challenges by contributing substantially to greenhouse gas emissions and climate change risks, such as floods and droughts. Recent estimates indicate that agriculture is responsible for about 9% of U. S. (Environmental Protection Agency, 2015) and 11% of global emissions (Tubiello et al., 2015), respectively.

Despite growing evidence of weaknesses, biologically simplified agricultural landscapes have continued to expand in recent years, leading to overall declines in biodiversity in both croplands and grasslands (United States Department of Agriculture, 2005; Newbold et al., 2016). This expansion has been in part due to policies that incentivize such systems and reduce financial risk (Union of Concerned Scientists, 2016a). A good example of this in the United States that also demonstrates the tight linkages

between food, energy, and water systems is the continued conversion of perennial grasslands into corn and soybean production for bioenergy. This trend intensified following the passage of the Renewable Fuel Standard in the mid-2000s and associated higher commodity prices (Wright and Wimberly, 2013; Lark et al., 2015). Importantly, in this case, policies that were intended to strengthen agricultural markets for rural communities have had mixed outcomes, associated with the High Plains Aquifer causing stress on local groundwater supplies (Scanlon et al. 2012). Even prior to this policy, however, increased U.S. Federal crop insurance subsidies (resulting from the 1994 Crop Insurance Reform Act) had reduced the financial risk of cultivating environmentally sensitive lands; these subsidies have been linked to disproportionately large unintended consequences such as nutrient loss and soil erosion (United States Department of Agriculture, 2006).

As a juxtaposition to the current model of bioenergy production, alternative crop systems developed through an agroecological approach that is both regionally and environmentally appropriate, offer great potential for the bioeconomy overall. An example of this is the cultivation of pennycress in the Upper Midwest, a multi-functional oilseed crop that is cold-tolerant and requires minimal inputs, which could be grown using double or relay cropping to protect soil and water resources over winter; currently, the dominant corn-soybean crop rotations of this region do not include any soil or water protection outside of their summer annual growing cycle (Jordan et al. 2016).

In general, biologically diversified farms managed using insights from agroecology can remain productive and resilient while also conserving water and energy resources, and enhancing other ecosystem services. For example, the strategic incorporation of perennials (including perennial food, energy, or non-crop plants) into small areas of fields has been found to significantly reduce water pollution and create other positive environmental outcomes (Liebman and Schulte, 2015; Liebman et al., 2013; Helmers et al., 2012) while still allowing the most productive areas of fields to be used for more intensive, lower diversity production (“precision conservation”; Berry et al., 2003; Brandes et al., 2016). Systems managed in this way may become even more pivotal as climate change stresses water systems, as demonstrated by the recent persistent drought in California (Morris and Bucini, 2016). Further, in an example focused on pest management, the proximity of more diverse vegetation (including forest and hedge rows) was shown to increase the population of natural enemies as compared to pests in intensive vegetable production (Letourneau et al., 2015). And, according to a global meta-analysis, enhancing diversity by incorporating multiple crops in rotation significantly increased total soil carbon and nitrogen as well as microbial carbon and nitrogen (McDaniel et al. 2014).

Importantly, in addition to the many environmental benefits, research indicates that biological diversity and ecological practices can also have a positive effect on yields. In other studies, diverse crop rotations have further been found to limit yield variability in years with abnormal weather (Gaudin et al., 2015), and increase average

yields (Smith et al. 2008; Ponisio et al. 2015), while reducing reliance on purchased inputs. Incorporating conservation agriculture practices more generally (no tillage, crop residue management, crop rotation) has also increased crop yields in several dry environments (Pittelkow et al., 2015).

The accumulating evidence indicates that practices rooted in agroecology and biological diversity could reduce risks related to food security, energy and water resources, climate change and associated weather extremes, and other challenges, especially in the long-term. Whether such practices would ultimately reduce risk and/or bring rewards to farmers, however, depends on incentives, policy systems, and farmer risk-taking behaviors.

Obstacles for agroecology as a leading edge for sustainable solutions

Despite the promise of ecological design in agricultural systems, several hurdles may be preventing its wider acceptance as a framework to address food, energy and water system issues, particularly in the United States. For one thing, in our technology-focused era the fact that agroecology does not emphasize industrial technologies may cause it to be undervalued by producers and consumer alike, even though agroecological solutions often result from sophisticated syntheses of social, economic and environmental components that address underlying problems as parsimoniously as possible (Altieri, 1989; Montenegro de Wit and Iles 2016). But, importantly, there are also numerous infrastructural challenges, development, and adoption that are hindering broader adoption rates that could help foster an appreciation for the elegant multiple-optimization solutions available in agroecology.

In research communities, there has long been recognition that public infrastructure for the science and development of agroecology has been woefully underfunded (Carlisle and Miles, 2013; Lipson, 1997). Recently, an analysis of competitive funding from the U.S. Department of Agriculture confirmed a dearth of funding for projects that incorporated key agroecological practices (e.g., crop rotations, agroforestry, integrated crop-livestock systems), particularly in combination with socioeconomic elements that could realistically help agroecology gain traction at a larger scale (DeLonge et al., 2015). In addition to shortages of research funding in critical areas, training at educational institutions for the next generation of agricultural researchers is often lacking the social sciences (behavioral science, sociology, economic, etc.) that can encourage “systems thinking” and facilitate landscape level change, both of which are essential to agroecology. In cases where systems approaches are actually included in curricula, it is often noted that the programs could be further improved to overcome institutional and cultural barriers hindering student success (Graybill et al., 2006; Romolini et al., 2013; Basche et al., 2014). Finally, although there is a growing number of degree programs in agroecology and food systems in the U.S. (United States Department of Agriculture, 2015), such programs are still the minority relative to agronomy, crop and soil science programs; the

lack of existing scholar communities in this area is also likely a factor dampening the pace of transition.

Outside of academic institutions, agricultural producers must overcome significant social, political and economic obstacles in order to diversify their farming or ranching operations. Even for basic environmental best management practices (such as reduced tillage and nutrient management), which often represent non-systemic change, important determinants of farmer adoption have included both financial capacity and connections to knowledge sharing networks (Prokopy et al. 2008; Baumgart-Getz et al. 2012). The literature on cover crops, another basic best management practice, suggests that early adopters require significant trial and error and that it is the operations with a track record of higher levels of crop and livestock diversity that are more likely to adopt the practice (Dunn et al. 2016; Arbuckle and Roesch-McNally 2015; Singer et al. 2007). Further, surveys and interviews with Nebraska farmers and ranchers indicated that many hoped to adopt more sustainable practices to reduce drought risks but were limited by the need to maximize production to maintain cash flow (Knutson et al. 2011). Given the documented real and perceived challenges for farmers who are considering making relatively small changes to management practices, it would be reasonable to expect an even slower uptake of more holistic ecologically-based farming practices, especially without strong support and incentives.

Encouraging the broader adoption of agroecology would undoubtedly require developing more support for farmers wishing to transition their practices and for consumers who would prefer to purchase products from ecologically managed farms. This required support could include policy interventions such as increased support for peer-to-peer farmer networks for information transfer and market support, or supply chains that value the multifunctional benefits achieved by agroecology (Union of Concerned Scientists 2016b; Blesh and Wolf 2014).

Limits of yield-based solutions in the food system, and implications for water and energy

Despite the obstacles, there is a need for new models of agriculture that can remain productive and profitable in the face of rapidly depleting and increasingly stressed fresh water and energy resources. The need to transform food systems specifically is clear when considering that existing food systems are already falling short of addressing current needs related to food security, food access, and nutrition, even before projected population increases. These shortcomings indicate that scaling up current production systems is likely to pose additional problems for energy and water, without necessarily solving problems in the food system.

The right to food, which underlies the need for a productive agricultural system, has been defined as “physical and economic access at all times to sufficient, adequate and culturally acceptable food that is produced and consumed sustainably, preserving access to food for future generations” (United Nations, 2014). In spite of the popular claims that the extant system “feeds the world”,

the right to food is not a reality for many people today – even for those in areas with high agronomic productivity. Therefore, although maintaining affordable food prices and sufficient productivity is essential, a sole focus of maximizing output (e.g., crop yield) will not achieve the goal of creating a food system that maximizes overall well-being and equitable outcomes for all (Haynes-Maslow and Salvador, 2015). For example, today in the United States despite impressive agricultural yields from modern farming systems, food insecurity persists for approximately 14% of the U.S. population (United States Department of Agriculture, 2014). Further, chronic health concerns related to the food system are pervasive and include poor mental and physical health outcomes for children (Cook et al., 2004), higher incidences of cardiovascular risks in adults, including hypertension and hyperlipidemia (Seligman et al., 2010) and racially inequitable incidences of diabetes, where there are higher rates in communities of color (Union of Concerned Scientists, 2016c).

Even if there are linkages between food availability, accessibility and health outcomes, is there reason to believe that a shift in agricultural policy would help? Interestingly, existing research evaluating the degree to which current policies actually influence health is mixed. One recent study demonstrated a strong tie between subsidized foods and health outcomes in the U.S., finding that 56% of calories consumed by participants came from major subsidized food commodities and that people who consumed more foods processed with these commodities (such as corn and soy) had significantly higher incidences of cardiometabolic risks (Siegel et al. 2016). However, some economists and public health experts refute the notion that subsidizing commodity crops actually contributes to the “obesity epidemic” and poor health outcomes (Alston et al. 2008, Hawkes et al. 2012). More research is needed to better understand not only the current impacts of policies on health, but the potential positive role of innovative policies.

Efforts to develop and implement new food and agricultural policies that systematically address challenges are likely constrained by existing metrics of agricultural productivity, which have failed to capture critical environmental and societal impacts and often lead to an incomplete understanding of production costs and related tradeoffs (Davis et al. 2012). Specifically, analyses that more comprehensively evaluate the impacts of agricultural production on energy, water, land, health, or other resources are generally lacking, but those that do exist reveal the importance of such research. For example, Cassidy et al. (2013) proposed expanding the definition of yield from crop production per hectare of land to people actually fed, and found that growing food for direct human consumption versus biofuel or animal feed could increase food availability by 70%, enough to accommodate projected population growth. Similarly, Peters et al. (2016) evaluated the relationship between diets and land use by calculating the ability of existing U.S. agricultural land to meet the food needs of the U.S. population under several diet scenarios: current consumption patterns, diets with recommended fruit and vegetable

consumption and varied meat intake, and vegetarian and vegan diets. They found that several scenarios could satisfy the caloric needs of all Americans within the current land base (all of which require some reduction of meat consumption), but also highlighted that meeting dietary needs without clearing land may require using more existing farm land to grow grains, fruits, vegetables and pulse crops for direct human consumption (Peters et al., 2016). While these research efforts focused in food systems are good examples of the work needed to expand our understanding of productivity, the mostly commonly used metrics have not yet appropriately included how nutritious, accessible, or affordable food is, nor have they adequately considered the implications for other societal resources, including water and energy systems.

Beyond yield: an urgent call for long-term, systems science

While the need to produce abundant food to support a growing population has long been recognized as an agricultural and policy priority, it is becoming clear that this agricultural objective may be too narrow to guide needed research for transformative solutions, even when looking at food systems alone. Further, as we have discussed, the need to improve agricultural systems reaches past food, most notably to energy and water. For example, bioenergy products have the potential to contribute to energy demands. However, if they require additional land and water resources, the development of these products have implications for both food and water systems. In turn, conserving ground water resources, protecting waterways from pollution, and even mitigating the effects of droughts and floods, are all connected to agricultural land use and management. Although they are interwoven, quantifying societal co-benefits or tradeoffs in food, energy and water systems remains a challenge, and new perspectives, methods, and metrics are needed.

Amidst the obstacles, the field of agroecology stands as a strong source for innovations that can support the needs of a growing population while directly confronting the many outcomes beyond yields that must be addressed to achieve long-term sustainability. These outcomes include efficient use and protection of water as well as the sustainable development of energy resources, and also extend to food access and affordability, quality and healthfulness, and waste (Neff et al., 2015). There is no better time to seek creative solutions to systemic challenges. We must progress beyond yield to include the need for healthy food, sustainable food and energy products, conservation of water and energy resources, and a clean, equitable environment for the public good.

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Author contributions

Both co-authors contributed equally to research, writing and revision.

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