Agroecology and Sustainable Food Systems

ISSN: 2168-3565 (Print) 2168-3573 (Online) Journal homepage: http://www.tandfonline.com/loi/wjsa21

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To cite this article: Albie Miles , Marcia S. DeLonge & Liz Carlisle (2017) Triggering a positive research and policy feedback cycle to support a transition to agroecology and sustainable food systems, Agroecology and Sustainable Food Systems, 41:7, 855-879, DOI: 10.1080/21683565.2017.1331179

To link to this article: http://dx.doi.org/10.1080/21683565.2017.1331179

Published online: 17 Jul 2017.

AGROECOLOGY AND SUSTAINABLE FOOD SYSTEMS
2017, VOL. 41, NO. 7, 855–879
https://doi.org/10.1080/21683565.2017.1331179

Triggering a positive research and policy feedback cycle to support a transition to agroecology and sustainable food systems

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ABSTRACT

An ecologically sustainable and socially equitable food system, one that restores ecosystem services, enhances human welfare, and promotes community-based economic development, is urgently needed. Applied agroecological research and the development of regional and community food systems are key means through which pressing ecological and social externalities may be mitigated. However, progress in both of these areas has been limited, particularly in the USA, with constraints in each likely holding the other back. In this article, we first review and explore how public investment in agroecology research and development has been limited in the USA. We then discuss how agricultural research funds could be shifted to better support the development of more resilient and equitable food systems. Finally, we explore a broader set of structural obstacles to food system change and identify key policies that could work jointly to strengthen a positive feedback cycle of research, policy, education and practice. Such a feedback cycle could work to accelerate a transition to ecological farming and food system norms that enhance natural resources sustainability, equity and resilience.

KEYWORDS

Agriculture policy; agroecology; diversified farming systems; public investment; resilience; sustainable food systems; USDA research

Introduction

There is growing international awareness of the need for a transition to a more ecologically sustainable, resilient, and equitable food system (Alkon and Agyeman 2011; Hoy 2015; Reganold et al. 2011; Shannon et al. 2015; West et al. 2014). At the same time, increased attention has been directed toward agroecology as a discipline and practice that offers a strong analytical framework, toolkit, and interdisciplinary perspective to both study and facilitate the needed changes (Méndez et al. 2015; Gliessman 2015; Montenegro De Wit and Iles 2016). Given that agroecology and the benefits of biologically

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Part of the special issue "Agroecology: building an ecological knowledge-base for food system sustainability."

diversified farming systems are so promising and yet not new, questions have arisen as to why more ecologically based agriculture and sustainable food systems have not been widely adopted in the USA (Allen 2010; Fernandez et al. 2013). A complete answer to this question may be found only through comprehensive and multidisciplinary analyses of the social, cultural, economic, technological, scientific, epistemological, and political drivers of the development of the US agrifood system and its role in national and global political economies (Altieri 1995; Gonzalez De Molina 2013; Goodman and Watts 1997; Graddy-Lovelace and Diamond 2017; Howard 2016; McMichael 2011; 2013; Montenegro De Wit and Iles 2016; Perkins 1997; Bonanno et al. 1994; Vanloqueren and Baret 2009). A partial understanding, however, may be gleaned by evaluating the public context in which agroecology could be either reinforced or discouraged. Thus, in this article we explore how US public research funding and a range of federal and state policy conditions may be shaping the generation of agroecological knowledge and its application toward achieving greater sustainability, equity, and resilience.

The state of public research investments is a useful starting point in the consideration of obstacles and opportunities for agroecology, as analyses have shown that investments in agricultural research and development pay off with high returns, with respect to a range of social, economic, and productivity goals (Pardey, Alston, and Chan-Kang 2013). It follows that historically underfunded (i.e., low priority) areas of agricultural research have therefore not experienced equal opportunity to achieve high levels of agronomic, social, economic, or ecological performance (Carlisle and Miles 2013; DeLonge, Miles, and Carlisle 2016; Vanloqueren and Baret 2009). Such circumstances are typically avoided among research areas where initial investments are likely to be recovered through the development of marketable products and patents (e.g., biotechnology, agrichemical inputs), as the private sector has incentive to fill funding gaps. However, this is not likely to be the case for agroecology and sustainable food systems research, which tends to reduce reliance on purchased inputs and decentralize economic and political power, while increasing public benefits that cannot be easily privatized (Bacon et al. 2012; Clancy, Fuglie, and Heinsey 2016; Howard 2016; Sandhu et al. 2015).

Recent analyses of USDA funding have demonstrated that ecologically based agricultural research—including studies of organic, diversified, or agroecological farming—has been largely neglected (Carlisle and Miles 2013; DeLonge, Miles, and Carlisle 2016; Lipson 1997). Therefore, these assessments indicate that recent advances in sustainable agriculture, including the marked economic and environmental performance of diversified farming systems and the rapid growth of the organic food industry, are to be understood in the context of a profound lack of public and private investment in research and development (Carlisle and Miles 2013; Kremen and Miles 2012). Given these low levels of research funding, and growing evidence that ecologically based farming systems can outperform conventional agriculture across nearly all tested environmental, social, and economic performance metrics (Crowder and Reganold 2015; Ponisio and Ehrlich 2016; Ponisio et al. 2015; Reganold and Wachter 2016; Willer and Lernoud 2016), we argue that there is a profound gap between the potential of agroecology to resolve agrifood problems and the current levels of federal funding to support advances in this field (DeLonge, Miles, and Carlisle 2016). Furthermore, closing this gap may be a key lever for triggering a positive feedback cycle in which agroecological research facilitates greater adoption, which in turn can encourage additional research investment.

In this article, we broadly explore barriers and opportunities for agroecology, building upon past work on research investments. We first briefly review the degree to which public research funding sources are, or could be, supporting agroecology research. We then reflect on how research priorities could be shifted to advance agroecology and sustainable food systems. Finally, we propose a broader set of key policies, beyond shifting public funding, that could be implemented at local to federal scales to successfully scale agroecology and achieve a more ecologically sustainable and socially equitable society.

Defining agroecology and agroecological research

Agroecology has historically been defined as a form of applied agricultural ecology, concerned primarily with addressing environmental externalities of modern agriculture through the redesign and management of farming systems using traditional and ecological knowledge (Altieri 1995; Gliessman, Garcia, and Amador 1981). More recently, agroecology has been further defined as a transdisciplinary scientific field of study, a productive practice, and a social movement that aims to understand and transforms food systems toward greater ecological sustainability, social equity, and resiliency (Francis et al. 2003, Gliessman 2015, Méndez et al. 2015).

While the definition of agroecology is complex, the stages in the transition to agroecology and sustainable food systems can be conceptualized through a five-level framework developed by Gliessman (2016). This framework can be applied to categorize agricultural and agroecological research, and includes: improving system efficiency to reduce the use of conventional agro-chemical inputs and their ecological and social risks (Level 1); substituting more sustainable inputs and practices into farming systems (e.g., many practices included in certified organic agriculture, Level 2: input substitution); redesigning farming systems based on ecological knowledge to maximize ecosystem services (Level 3: farm-scale agroecology); reestablishing connections between producers and consumers to support a socioecological transformation of the food system (Level 4: "transformative" agroecology); and supporting a fundamental shift in global society where ethics, knowledge, culture and economy are rethought and directed toward ecological restoration, social justice and equity in the food system and within all forms of human activity (Level 5: global transformation to a sustainable society) (DeLonge, Miles, and Carlisle 2016; Gliessman 2016).

The current state of affairs for agroecology research

The USDA is the government agency with the direct and obvious responsibility to fund agroecological research, given their mission to "provide leadership on food, agriculture, natural resources, rural development, nutrition, and related issues based on public policy, the best available science, and effective management" (USDA 2017). Furthermore, the Department has budget capacity for this scope of work—vastly exceeding that of any other organization in the public sector (Table 1)—as well as discretion to prioritize its investments. Yet, recent examination of USDA's investments, based on the framework described above, found that less than 15% of total funding for extramural competitive research grants were allocated to projects that contained any kind of farm-scale agroecological component; meanwhile, less than 4% of USDA research funds were granted to projects that included the study of farm-scale ecologically based farming practices (biophysical science) in addition to a socioeconomic aspect (social science) that could enable increased adoption of more sustainable practices (DeLonge, Miles, and Carlisle 2016). This 2015 analysis, which was designed to be conservative so as not to underestimate investments,[1] evaluated 824 projects representing nearly $300 million of competitive grant funding from the USDA's National Institute of Food and Agriculture (NIFA). Based on these findings and the established environmental, social, and economic performance of more ecologically based farming systems, we concluded that the USDA is vastly underfunding farm-scale and transformative agroecological research[2]

Table 1. Overview of agency budgets: total budgets and budgets of research programs most relevant to agroecology. "Primary relevant subgroups" (Column 3) refers to the name of the subgroup as identified in the available budget. Data are from the most recent publicly available estimated or enacted (i.e., not proposed) budget.

Agency/Org	Budget (bill. $)	Primary relevant subgroup(s)	Budget (bill. $)	Year of budget
USDA	$152	Research, Extension & Education	$2.9	FY15
NSF	$7.5	Research & Related Activities[3]	$6.0	FY16
DOE	$29.6	Office of Science	$5.3	FY16
		Biological & Environmental Research[4]	*($0.6)*	"
		ARPA-E	$0.3	"
NASA	$19.3	Science—Earth Science Research	$0.5	FY15
FFAR	$0.2	Total Net Assets	$0.2	2015
Philanthropic	$5.3	Funding related to Food & Agriculture[5]	$0.7	2015
NIH[6]	$31.3	Special type 1 diabetes research	$0.15	FY16

(Crowder and Reganold 2015; DeLonge, Miles, and Carlisle 2016; Reganold and Wachter 2016).

The lack of the NIFA's investment in agroecology likely reflects, and is entrenched by, the fact that funding programs with direct relevance to agroecology represent only a very small portion of USDA's total and research budgets (Tables 1 and 2). For example, the Agriculture and Food Research Initiative (AFRI) provides the largest amount of available competitive research funding, but is split among several programs with different areas of emphasis. Of these, the Bioenergy, Natural Resources, and Environment (BNRE) program is the one most clearly supportive of ecologically and

Table 2. Characteristics of select current or recent programs that could potentially support agroecology. Budgets for ongoing programs were from FY16 wherever possible. Anticipated funding for specific grant areas are from FY17 estimates when clearly available. If not available, data on actual awarded funding from the most recent available year was used.

Agency/Org	Research program ID	Available funding/funding granted (mill $)	Grants **(mill $/grant)**, max or range
USDA	AFRI (total budget)	$350.0[a] –	–
	AFRI-BNRE	***$15.0[b]***	**$0.5**
	AFRI-CCS	*$27.6* [b]	$0.2–$1.0
	AFRI-ANRS	*$8.4* [b]	–
	AFRI-Exploratory	*$2.0* [b]	–
	OREI	$17.6 [b]	$2.0
	ORG	$3.8 [b]	$0.5
	SCRI	$48.1 [b]	–
	SARE (total budget)	$24.7[a] –	–
	NE-SARE, R&E	***$1.3[c]***	$0.2
	W-SARE, R&E	***$1.7[c]***	$0.2
	NC-SARE, R&E	***$1.7[c]***	$0.2
	S-SARE, R&E	***$1.1[c]***	$0.2
	CIG	$26.6[d]	$2
NSF	INFEWS	$28.4[e]	$1.0–$3.0
	BREAD	$12.0[f]	$2.1
DOE	ARPA-E ROOTS	$35.0[g]	$1.0–7.0
FFAR	New Innovator	$2.4[h]	$0.3
	Seeding Solutions	Not yet known	$1[i]

a. NSAC (2016).

b. FY17 grants provided on program webpages available online, for example, https://nifa.usda.gov/sites/default/files/grant/FY16%20OREI%20RFA.pdf.

c. SARE (2016), estimated as 50% of 2014 and 2015 total "Research and Education" awards.

d. FY16 NRCS EQIP, reported at https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/financial/cig/?cid=nrcseprd1288325.

e. INFEWS 2016 awards from abstracts available via https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505241.

f. FY15 funding at www.nsf.gov/pubs/2015/nsf15538/nsf15538.htm.

g. 2017 funded grants https://arpae.energy.gov/sites/default/files/documents/files/ROOTS_Project_Descriptions_Final.pdf.

h. Funds of $4.8 million were matched at 50%, so this reflects FFAR's direct investment: http://foundationfar.org/2016/11/16/foundation-food-agriculture-research-grants-new-innovator-award-nine-early-career-scientists-pursuing-research-transformative-potential.

i. New program; total grant funding not yet posted. http://foundationfar.org/wp-content/uploads/2016/11/Seeding-Solutions_FFAR-Funding-Opportunity.pdf.

socioeconomically informed research projects, but it receives relatively limited funding. Other relevant programs that receive limited funding are the Organic Transitions Program (ORG), Organic Research and Extension Initiative (OREI), Specialty Crops Research Initiative (SCRI), and the Sustainable Agriculture Research and Education (SARE) program (Table 1). Funding for agroecology may be available in other parts of the USDA, although it is unlikely that the proportions or total amounts allocated for such research would be significantly greater than what is available from NIFA. Such sources could include other agencies within the Research, Education, and Economics (REE) mission area (the Agricultural Research Service, Economic Research Service, and National Agricultural Statistics Service), or the National Resource Conservation Service (e.g., the Conservation Innovation Grants (CIG) awarded through the Environmental Quality Incentives Program, Table 1).

While other funding sources outside of the USDA could also support agroecological research, an evaluation of current and recent programs in key agencies and organizations indicates that such opportunities are also sparse (Tables 1, 2). For example, government agencies with a scope of work in line with agroecological research include the National Science Foundation (charged to "advance the national health, prosperity, and welfare"), the Department of Energy (with respect to sustainable bioenergy production), and NASA's Earth Sciences Division (for agroecosystem analysis). Another potential resource is the Foundation for Food and Agriculture Research (FFAR), a relatively new nonprofit organization established by the 2014 Farm Bill, tasked with funding research through public–private partnerships. Philanthropic funding for sustainable agriculture research has also filled some of the pronounced funding gaps in recent years (GAFF, 2015), but has not made up for the significant overall decline in public investment in agriculture, or the underfunding of agroecology.

Research directions for advancing agroecology and sustainable food systems

There are two major problems with the current state of funding for agroecology and sustainable food systems. The first and most obvious problem, described above, is that this field of research and development is profoundly underfunded given its proven track-record of market growth and profitability (Crowder and Reganold 2015; Willer and Lernoud 2016) and its ability to reduce ecological externalities from agriculture (Bommarco, Kleijn, and Potts 2013; Kremen and Miles 2012), conserve biological diversity (Kremen 2015; Perfecto and Vandermeer 2008), reduce public health risks (Reganold and Wachter 2016), maintain near parity in productivity (Ponisio and Ehrlich 2016; Ponisio et al. 2015), and advance climate change adaptation and mitigation (Altieri et al. 2015), food system resiliency and food security over the long term (Hoy 2015, Schipanski et al. 2016). As discussed above, according to our recent analysis, less than 15% of USDA competitive research funding was allocated to projects that include any element of agroecology, and these awards are likely to represent the best opportunities for this type of research in the broader funding landscape. But the problem that emerges upon closer analysis is both subtler and more regrettable: even within this underfunded area, it is the most promising research—showing the greatest potential for transforming natural resource sustainability, human health and wellbeing—that receives the least financial support (DeLonge, Miles, and Carlisle 2016). A closer look at the research priorities reflected in actual federal investments according to DeLonge, Miles, and Carlisle (2016) affords a chance to critique the current funding structure, while also envisioning a new research agenda for the future that aims to transform the food system toward ecological sustainability, resiliency, community participation, and social equity (Altieri 1989; Carlisle and Miles 2013; Levidow, Pimbert, and Vanloqueren 2014).

Research priorities emerging from actual spending

The distribution of 2014 research projects funded by USDA NIFA corresponding to the five levels of agricultural sustainability (Gliessman 2015) is graphically represented in Figure 1 (DeLonge, Miles, and Carlisle 2016). The largest share of funding—the base of this upside-down pyramid—went to projects focused on mitigating individual problems associated with an agriculture system heavily focused on conventional grain monoculture. These "Level 1" research projects aim to improve efficiencies in conventional farming practices at the farm scale: for example, controlling particular pests with more precise pesticide use, mitigating nutrient loss through more efficient fertilizer use, and using less water through efficient application. The next layer of this hierarchy, representing fewer research projects and associated funding, is "Level 2" research into substitution. Examples of Level 2 research include studies of biological pesticides that can be substituted for conventional pesticides, organic matter inputs that can replace synthetic fertilizer, and conservation tillage that can replace heavy till systems. Finally, at the top of the pyramid and receiving a much smaller portion of research funding we find "Level 3" whole-systems research that aims to strategically design agroecological farming systems that tackle problems at the roots, and "Level 4" social–ecological research that works to better connect producers to consumers through policy, business, or social supports. This "Level 4" research is needed to facilitate the successful adoption of more sustainable and equitable farm-scale practices at a wider scale. Systems research that addresses farm-scale challenges while also approaching socioeconomic factors on a larger

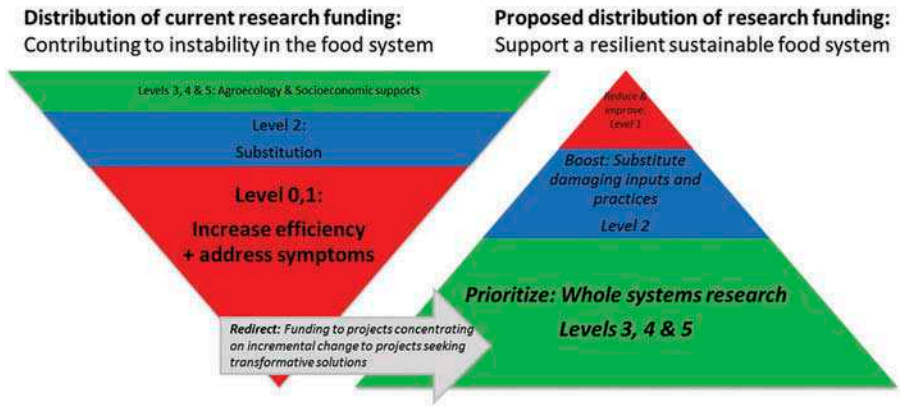

Figure 1. Observed distribution of current research funding for food and agriculture systems and proposed changes to support a more resilient food system informed by agroecology. Relative sizes of segments of the left-hand upside-down pyramid are based on the analysis of USDA NIFA funding reported in DeLonge, Miles, and Carlisle (2016) and correspond to the five "levels" of sustainability framework introduced by Gliessman (2015). We propose that the proportion of funding going to research that can only incrementally improve food and agriculture systems is too high, and contributes to low levels of resilience and instability. We argue that a more resilient system could be encouraged by shifting investments more toward whole-systems agroecologically informed research that builds resilience and addresses the root causes of problems.

national or global scale is here referred to as "Level 5." This type of research that may be needed to achieve global-scale sustainability was outside of the scope of our study and is particularly rare. Based on this analysis of USDA extramural funding, the most straightforward example of US public funding for agricultural research, we propose that the current structure of funding at the USDA and elsewhere is one of several key factors holding agricultural research back from tackling more ambitious sustainability and equity goals (McIntyre 2009; Levidow, Pimbert, and Vanloqueren 2014; Sanderson Bellamy and Ioris 2017).

A proposed hierarchy of agricultural research priorities

From an agroecological perspective, with the explicit goals of sustaining agricultural yields, optimizing the use and conservation of local natural resources, minimizing environmental and social externalities, and ensuring equitable access to healthy food, the existing hierarchy of agricultural research priorities that emerges from current spending is inverted (Gliessman 2015; Méndez et al. 2015). It is whole-systems agroecological research on alternative farming systems design and management (Level 3) that provides the necessary empirical foundation for mitigating, rather than simply reducing, the impacts of damaging agricultural practices (Kremen and Miles 2012). Both are needed, but the prioritization that they receive through

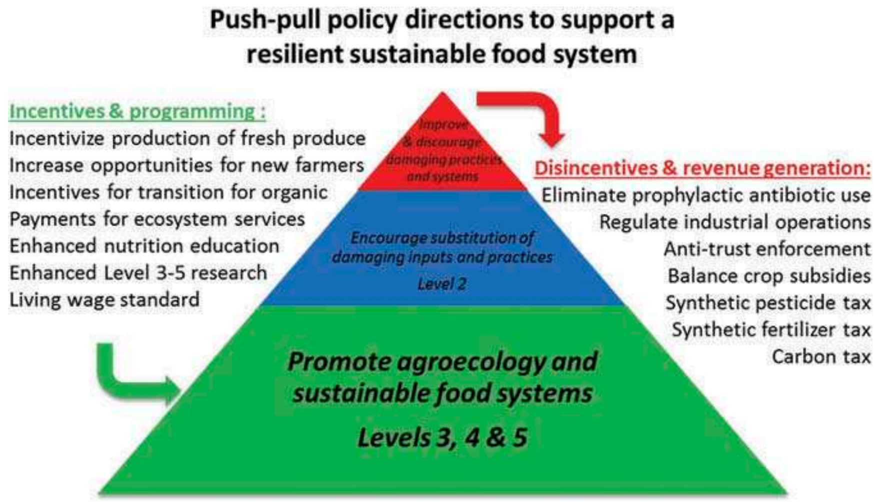

Figure 2. Policy incentives and disincentives to enhance the potential benefits achieved through a more ecologically informed agricultural research agenda (see Figure 1). Several policy initiatives could be instrumental in both pushing and/or pulling the food and agricultural system toward greater resiliency at a national and even international scale. Below we have indicated a few examples of each, although this list is not meant to be comprehensive.

public research funding must be fundamentally changed. Hence, we call for a research agenda for advancing agroecology and sustainable food systems (Figure 2) that places a strategic priority on such whole-systems research, so as to invest a critical mass of resources to catalyze transformative food system change (Gliessman 2016; Reganold et al. 2011), rather than continuing to dedicate the lion's share of funding to incremental approaches insufficient to meet the immense challenges of food insecurity, environmental degradation, biodiversity conservation, and climate change adaptation and mitigation (Tscharntke et al. 2012, Altieri et al. 2015). Ultimately, we cannot make progress on mitigating the social and environmental impacts of industrial agriculture, or phasing out dangerous inputs and practices, without significant investments in whole-systems research supporting a national, and even international, transition to ecologically based agriculture and equitable food systems (Gliessman 2016).

A. Prioritize: whole-systems research ("Levels 3–5")

This highest priority, foundational category should include farm-scale agroecological studies (Level 3) as well as research that combines ecological farming practices with economic, policy, and other social science investigations of tradeoffs, unintended consequences, and factors that affect adoption rates (Levels 4 and 5) (Geertsema et al. 2016). Social–ecological systems research in this category should address the full supply chain, including questions of needed infrastructure and institutions for food production, processing, distribution, and access, as well as knowledge sharing and ongoing on-farm agroecological research. Research partners involved in such projects should work collaboratively across disciplines and with community partners, toward viably scaling up a sustainable and restorative agrifood system (Carlisle and Miles 2013; Francis et al. 2003; Méndez et al. 2015). At the farm scale—and within larger social–ecological systems projects—high-priority research should focus on ecological farming practices that consider optimal farm and landscape configurations that lead to ecosystem-scale functioning, such as long-term crop rotations, spatially diversified farms, agroforestry, crop-livestock integration, and ecologically managed grazing lands (Bonaudo et al. 2014; Liebman and Schulte 2015; Moraine, Duru, and Therond 2016). Such projects should devote explicit attention toward how ecologically based practices and planned biodiversity can enable resilience, climate change adaptation and mitigation, and the combined impact of *multiple* beneficial practices within one system (Bommarco, Kleijn, and Potts 2013; Hoy 2015; Landis 2017). Successful research in this foundational category will require long-term funding and facilities, such as the USDA Long-Term Agroecosystem Research sites and the network of Climate Hubs. Expanding existing shorter-term but systems-level research, such as research projects funded through programs like AFRI, SARE, and OREI, may help to fill these research gaps (Table 2).

B. Boost: replacement of industrial inputs and damaging practices ("Level 2")

Building on this whole-systems foundation, the second priority in this research agenda would be to (a) phase out the most toxic agrochemicals and replace them with biological substitutes or biocontrols, and (b) move away from damaging practices to more environmentally regenerative practices, regardless of scale. Whole-systems research will greatly expand understanding of such alternatives by helping researchers understand interactions among farm- and landscape-scale interventions (Gurr et al. 2016; Rusch et al. 2016a, 2016b). Examples of current programs that support this type of important research as part of their portfolios are SARE, OREI, and ORG (Table 2).

C. Maintain and enhance: existing research to improve the efficiency of industrial agriculture and to understand and mitigate unintended consequences

The third priority in this research agenda would focus on new tools to minimize loss and waste of food, byproducts, and various inputs throughout the supply chain. Such research could be enhanced by aiming to address root causes of problems (rather than merely treating symptoms), building on the foundation created by whole-systems research in our top priority area. Research on environmental and human health impacts of industrial agriculture must continue, so long as this approach to agriculture continues—but it should be tailored toward improving or replacing practices and processes with alternatives that better promote human and environmental health.

D. Redirect: existing research on incremental average yield increases, to building resilient farming systems

Instead of continuing research on incremental yield increases (with a focus on "average" years), crop and animal breeding programs and other productivity research should be resituated within whole-systems analysis that emphasizes resilience, diversity, and long-term rotations, and considers a broader portfolio of benefits, risks, and externalities of crop choices and practices. As a first step, research is needed to create suitable metrics that properly value co-benefits from sustainable and regenerative agricultural systems.

Broad policy directions to trigger momentum in agroecology and sustainable food systems

Competitive research funding is an essential source of farm-scale and collaborative socioecologic innovations that have the power to spur change in farming practices and agricultural education, with vast ripple effects (Soulard and Meynard 2016). However, accelerating the pace and impact of past and new research will rely on prompt attention to several much broader disincentives as well as a lack of incentives, which together work to hamper progress at all of the "levels" of transition described above. A diverse set of policies to address these needs could be put into place and enforced to promote and accelerate a large-scale shift toward ecologically based agriculture and socially equitable food systems, locally, nationally, and globally.

We propose that a "push-pull" system that combines and balances incentives and disincentives could be effective in achieving sustainable food system goals (Figure 2). For example, disincentives for problematic systems could include policies that reduce fossil energy and damaging agriculture inputs and practices. At the same time, incentives for more sustainable practices could take the form of programs that encourage agroecology, starting with but not limited to increased investment in research, education, and extension. Collectively, such policy structures could dis-incentivize non-sustainable inputs and land-use practices and incentivize the implementation of diversified farming systems that regenerate ecosystem services that mitigate ecological and social externalities from agriculture. Several examples of candidate policies have been discussed in the literature (Carlisle and Miles 2013; Reganold et al. 2011; Shannon et al. 2015). Here we list select examples that are particularly relevant to the transition to sustainable food systems and that could potentially be implemented on scales ranging from local to state to national:

A. Disincentives: a "Push" away from unsustainable practices

(1) *A price on carbon*: Modern agriculture and food systems generate an estimated 20–35% of global greenhouse gas emissions, a significant amount of which is carbon dioxide, along with nitrous oxide and methane (West et al. 2014). Intensive use of chemical fertilizer, biofuels, and confined grain-fed animal agriculture require significant amounts of fossil energy while generating emissions and other externalities along the production chain (Lechenet et al. 2014; Park et al. 2012; Tubiello et al. 2014). A tax on carbon, tradable permit system, or hybrid model (Steckel et al. 2017) would dis-incentivize carbon-intensive food and farming systems and make regional production more competitive in the face of agricultural globalization. A price on carbon could generate significant revenues to incentivize sustainable farming practices that reduce emissions and sequester carbon while building soil quality, farming system resiliency, and regenerating a suite of ecosystem services (Altieri et al. 2015; Bommarco, Kleijn, and Potts 2013; Jiggins 2014; Lin 2011; Power 2010; Reganold and Wachter 2016).

(2) *A pesticide mill tax*: Monoculture farming systems are susceptible to pests, weeds, and pathogens, which frequently create pesticide dependency for farmers (Tscharntke et al. 2005). To enhance biological control in agriculture, farming systems must be re-designed to function on a new set of complimentary ecological interactions that support natural pest regulation and other ecosystem services (Bommarco, Kleijn, and Potts 2013; Gurr et al. 2016; Iverson et al. 2014) while reducing the use of synthetic pesticides that pose significant risks to environmental quality and human health (Kim, Kabir, and Jahan 2017; Liebman et al. 2016). One solution to this challenge could be to impose a pesticide mill tax and utilize direct revenues to support agroecology and biological pest control programs (Gurr et al. 2016; Liebman et al. 2016; Van Bruggen et al. 2016; see *B. Incentives*). California, for example, now assesses a fee on all pesticide sales at the point of first sale into the state. Revenues currently support the state's pesticide regulatory program, the California Department of Pesticide Regulation (CDPR 2016a, 2016b). Gradually increasing pesticide mill taxes can provide a disincentive for unnecessary pesticide applications

while generating revenues for other programs supporting input use efficiency and ecologically based pest management strategies (e.g., Integrated Pest Management and biological control) (Lechenet et al. 2014).

(3) *A fertilizer mill tax*: As overuse of synthetic chemical fertilizer poses a range of environmental quality, soil quality and human health risks, and gradual reduction of such fertilizers will be necessary in the transition to a more ecologically based and sustainable form of agriculture (Steffen et al. 2015; Zhang et al. 2015). To facilitate this shift, a fertilizer mill tax could be modeled after California's pollution tax, which generates billions of dollars each year to fight climate change. This tax could provide the necessary incentives for efficient synthetic fertilizer applications and generate financial resources for new programs (see *B. Incentives)* supporting reduced reliance on fertilizers, nutrient budgeting, organic matter recycling and ecologically based farming practices known to improve soil quality, sequester carbon, and reduce energy use and other environmental externalities such as the eutrophication of aquatic ecosystems and ground water and the growth of global hypoxic zones (Buckley and Carney 2013; Diaz and Rosenburg 2008; Farrell and Jones 2009; Gibbons et al. 2014; Reganold and Wachter 2016).

(4) *Regulate Concentrated Animal Feeding Operations (CAFOs) and end the prophylactic use of antibiotics*: CAFOs raise most food animals, employing high-density confinement, artificial growth hormones, and antibiotics to boost profitability and control a wide range of diseases to which these animals are susceptible (Moses and Tomaselli 2017). Effluent from CAFOs in water and air containing steroid growth promoters pose an unknown risk to public health while causing chronic nutrient and fecal microbial pollution (Blackwell et al. 2015; Mallin et al. 2015). The prophylactic use of antibiotics in animal agriculture is driving the development of genetic resistance to antibiotics and threatens to play a major role in an emerging international public health crisis (Landers et al. 2012; Shannon et al. 2015; Tarpley 2014; WHO 2015). A ban of prophylactic (i.e., low dose) use of antibiotics in animal agriculture would dis-incentivize problematic practices and accelerate a transition to preventative and integrated pest management and improved animal welfare (Sossidou et al. 2015; Vaarst 2015). Meanwhile, revenues generated through the taxation strategies described above could be used to support research and incentivize integrated and ecologically managed grazing systems (Bonaudo et al. 2014; Moraine, Duru, and Therond 2016).

(5) *Create stricter regulations and antitrust enforcement to prevent unfair pricing and consolidation*: The US agrifood system is characterized by

high levels of consolidation in agricultural inputs, commodities processing and shipping, packaged foods and beverages, meatpacking, distribution, and retail (Howard 2016). Potential negative impacts of high levels of industry consolidation can include higher prices to consumers, disproportionate influence over public policy-making affecting labor, nutrition and environmental standards, lack of private investment in research and development, maintenance of high barriers to entry, and thus potentially reduced competition and innovation (Gilens and Page 2014; Howard 2016; Nestle 2013; Shannon et al. 2015; Smith, Chouinard, and Wandschneider 2011; Smith and Tasnádi 2014). Enforcing existing antitrust laws could help curb existing levels of consolidation, prevent unfair pricing, lower barriers to entry and stimulate innovation, create jobs, spur community-based economic development, and enhance quality of life and natural resource conservation throughout the US agrifood system (Boys and Hughes 2016; Mundler and Laughrea 2016; Johnson, Aussenberg, and Cowan 2012).

(6) *Rebalance price support programs to further incentivize agroecology*: In the USA, commodity crops for animal feed and biofuels receive substantial subsidies that encourage production, while the same cannot be said for most food products that are needed as part of a healthy diet (Muller et al. 2009). Rebalancing price support programs, in part by decreasing subsidies for commodity crops and increasing price supports for specialty crop production, could dis-incentivize problematic industrial systems and increase access to healthy, nutritious, and sustainably produced foods (Reganold et al. 2011; Shannon et al. 2015).

B. Incentives: a “Pull” to advance sustainable food systems

(1) *Increase opportunities for new farmers using agroecological methods of production*: New farmers require access to land, capital, training, and infrastructure resources for the development of new, innovative agriculture, and food-processing enterprises. Agriculture remains a capital-intensive occupation and the number of young people entering agriculture as a profession continues to decline. Enhancing opportunities through tax breaks and support for accessing land for young farmers and ranchers to enter the workforce and overcome initial hurdles to become economically viable operators will be vital to enabling agroecologically based food systems (Shannon et al. 2015). The USDA Beginning Farmer and Rancher Development Program (BFRDP) is a critical federal program enabling a wide range of

organizations and institutions to support new generations of producers in their region. Significantly scaling the level of support to this and related programs, while prioritizing training in agroecology and organic farming systems, will be key to launching food and farming enterprises aligned with agroecological principles and practices.

(2) *Assist farmers in the transition to new ecologically based farming practices*: Farmers face many obstacles as they transition to new agronomic practices. This is the case, for example, for farmers transitioning to organic certification, which involves a 3-year transition period before growers are eligible to label products as organic and receive price premiums (USDA NOP 2017). As the transition period is one of heightened economic risk for growers, incentive programs could help defray certification costs and provide research, technical services, risk management, and other support to ensure economic viability (Gliessman and Rosemeyer 2009; Greene 2014; Klonsky and Greene 2005). Critical to the process of successful transitioning to ecologically based production is the availability of adequate and well-informed extension services and social networks capable of providing the knowledge-intensive and site-specific technical information necessary for restoring ecosystem services and managing soil fertility and pests under new agronomic and market conditions (Chase, Johanns, and Delate 2016; Delbridge and King 2016; Morgan and Murdoch 2000; Warner 2007).

(3) *Link crop insurance to risk-reducing soil, air, and water conservation practices*: Crop insurance programs meant to protect farmers and reduce risk should take key soil data into consideration and encourage practices that build farm resilience and thereby minimize risk in the long term. Under guidelines established by the USDA Risk Management Agency (RMA), farmers must undertake all the "generally recognized practices" to support production and harvesting of crops and reaching target yields, which may exclude some NRCS conservation practices. Linking crop insurance to published NRCS conservation practices is a common sense way to ensure growers against losses while incentivizing producers to adopt resilience-boosting practices, reduce risk, and to achieve greater conservation outcomes (NSAC 2016; NRCS 2016). Furthermore, currently available soil data could be integrated into crop insurance rates as a first step to improving these insurance programs with respect to productivity, profitability, and environmental outcomes (Woodard and Verteramo-Chiu 2017).

(4) *Compensate for ecosystem services*: Establishing a system for payments for ecosystem services (PES) to compensate farmers and ranchers for enhancing and sustaining services such as clean water and climate

regulation could economically incentivize the most sustainable farming practices (Farley and Costanza 2010; Power 2010). For example, PES models could offer economic incentives in the form of tax breaks, or direct payments for the adoption of ecological farming practices. Such systems could be funded in part using revenues from some of policy disincentives proposed above, and would increase the profitability of ecologically based agriculture (Swinton et al. 2007).

(5) *Encourage resiliency and equity planning*: Tools such as regional food system resiliency and equity plans, using agroecology and ecologically based agriculture as centerpieces, could increase the likelihood of the most sustainable, equitable outcomes (Jiggins 2014; Schipanski et al. 2016). Research has shown that climate change mitigation and agricultural resiliency can be effectively achieved through agroecology, conventional breeding, biological diversification, and organic farming practices (Altieri et al. 2015; Gilbert 2014; Harvey et al. 2014; Hodbod et al. 2016; Hoy 2015; Kremen and Miles 2012; Reganold and Wachter 2016).

(6) *Strengthen living wage standards and safety net programs*: Living wage standards and safety net programs (e.g., Supplemental Nutrition Assistance Program) can increase household purchasing power, food security, and nutrition, thereby promoting equitable access to safe, affordable, healthy, culturally appropriate, and sustainably produced foods (Collins and Klerman 2017).

(7) *Expand interdisciplinary and applied agroecology education at the post-secondary level*: Beyond the structural changes outlined above, transitioning to a sustainable food system (Levels 3 and 4) and society (Level 5) will require developing fundamentally new approaches to higher education and learning, where scholars and practitioners are trained to think across disciplinary boundaries and apply this knowledge toward addressing real-world problems through work in agriculture, natural resource management, research, public policy, education, and public health (Francis et al. 2017; Miles et al. in press; Moore 2005; Wals et al. 2014). The integration of the natural sciences (e.g., ecology, environmental science), social sciences (e.g., political ecology, rural sociology), and the humanities (e.g., environmental and food ethics) will be essential to developing learner's understanding of the agrifood sector as a complex socioecological system (Gliessman 2016; Méndez et al. 2015) influenced by a diversity of human values (Galt, Clark, and Parr 2012; Kaiser and Algers 2016; Lieblein et al. 2012; Pojman, Pojman, and McShane 2016; Thompson 2016). With its systematic integration of applied ecology, critical social sciences, and explicit normative goals, the widespread adoption of agroecology programming in higher education will be essential to the acquisition of the skills, knowledge, and

human values required for advancing greater agrifood and natural resource sustainability, equity, and resilience (Parr et al. in preparation).

Long-term and systems-oriented agroecological research, particularly farm- and landscape-scale research that seeks to redesign systems to be more sustainable and to address problems at their roots, is at the crux of solutions that will serve as a foundation for more sustainable and equitable food systems. Unfortunately, this type of research, which serves the public good and is likely to rely mostly on public investment, has been profoundly underfunded. This lack of funding has been best documented for the case of USDA competitive grants, and it appears that there are limited sources for funding from other agencies and organizations, even in cases where their missions could be interpreted to include agroecological research.

In light of the observed structure of funding for agricultural research (based on previous analysis of USDA competitive research funding), we propose that agricultural research funds within and external to the USDA could be strategically shifted to better support a more resilient and equitable food system. Specifically, we suggest that whole-systems agroecological and socioeconomic research (Levels 3–5) could be enhanced to provide a stronger foundation for sustainable food and agriculture systems. On this foundation, research oriented around substitution of improved practices or inputs (Level 2) could also be boosted. Research that focuses on more incremental improvement to productivity, yields, and increased efficiency (Level 1) may require less public investment, as innovative systems tackle these challenges at their roots and as private investment is more likely capable of filling these research gaps.

We argue that a significantly realigned research and development agenda toward agroecology can be instrumental in uncovering and building momentum toward more sustainable and scalable solutions. However, a favorable set of complementary policy incentives and disincentives would be needed to support and accelerate the implementation of those solutions. These policies could be implemented at multiple scales, to benefit farmers, natural systems, and the public at large.

Notes

1. To achieve this goal, we looked for presence of any *component* of Level 1–4 research in each of the projects we evaluated, rather than requiring that a project be entirely focused on any specific level.
2. Level 5 research was outside the scope of the analysis of USDA research funding.
3. This funding goes toward a wide range of competitive grants (about 12,000 new grants per year). More details are available online at https://www.nsf.gov/about/glance.jsp.

4. "Biological & Environmental Research" is a *subarea of Office of Science, and is the subarea most likely to include relevant research.*
5. This funding estimate is from a landscape assessment conducted by Global Alliance for the Future of Food (2015). Not all funding was allocated toward research.
6. While the National Institute of Health (NIH) does not fund agroecological research, it does fund medical research that addresses problems related to today's food system. Therefore, one relevant research area from the NIH is shown for comparison. Available online at https://www.nih.gov/about-nih/what-we-do/budget.

Funding

We would like to thank TomKat Foundation and The Grantham Foundation for the Protection of the Environment for funding that supported M. DeLonge while contributing to this article.

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References

Alkon, A. H., and J. Agyeman. 2011. *Cultivating food justice: Race, class, and sustainability*. Cambridge, MA: MIT Press.

Allen, P. 2010. Realizing justice in local food systems. *Cambridge Journal of Regions, Economy and Society* 3(2):295–308.3. doi:10.1093/cjres/rsq015.

Altieri, M. A. 1989. Agroecology: A new research and development paradigm for world agriculture. *Agriculture, Ecosystems & Environment* 27(1–4):37–46. doi:10.1016/0167-8809(89)90070-4.

Altieri, M. A. 1995. *Agroecology: The science of sustainable agriculture*, 2nd ed. London, UK: Intermediate Technology Publications Ltd (ITP).

Altieri, M. A., C. I. Nicholls, A. Henao, and M. A. Lana. 2015. Agroecology and the design of climate change-resilient farming systems. *Agronomy for Sustainable Development* 35 (3):869–90. doi:10.1007/s13593-015-0285-2.

Bacon, C., C. Getz, S. Kraus, M. Montenegro, and K. Holland. 2012. The social dimensions of sustainability and change in diversified farming systems. *Ecology and Society* 17:4. doi:10.5751/ES-05226-170441.

Blackwell, B. R., K. J. Wooten, M. D. Buser, B. J. Johnson, G. P. Cobb, and P. N. Smith. 2015. Occurrence and characterization of steroid growth promoters associated with particulate matter originating from beef cattle feedyards. *Environmental Science & Technology* 49 (14):8796–803. doi:10.1021/acs.est.5b01881.

Bommarco, R., D. Kleijn, and S. G. Potts. 2013. Ecological intensification: Harnessing ecosystem services for food security. *Trends in Ecology & Evolution* 28(4):230–38. doi:10.1016/j.tree.2012.10.012.

Bonaudo, T., A. B. Bendahan, R. Sabatier, J. Ryschawy, S. Bellon, F. Leger, and M. Tichit. 2014. Agroecological principles for the redesign of integrated crop–livestock systems. *European Journal of Agronomy* 57:43–51. doi:10.1016/j.eja.2013.09.010.

Bonanno, A., Busch. L., Friedland, W., Gouveia, L., and Mingoine, E., eds. 1994. From Columbus to ConAgra: The Globalization of Agriculture and Food. Lawrence: Univ. Press Kansas

Boys, K. A., and D. W. Hughes. 2016. A regional economics–based research agenda for local food systems. *Journal of Agriculture, Food Systems, and Community Development* 3(4):145–50.

Buckley, C., and P. Carney. 2013. The potential to reduce the risk of diffuse pollution from agriculture while improving economic performance at farm level. *Environmental Science & Policy* 25:118–26. doi:10.1016/j.envsci.2012.10.002.

California Department of Pesticide Regulation (CDPR). 2016a. http://www.cdpr.ca.gov/

California Department of Pesticide Regulation (CDPR). 2016b. Mill Assessment: http://www.cdpr.ca.gov/docs/mill/masesmnu.htm

Carlisle, L., and A. Miles. 2013. Closing the knowledge gap: How the USDA could tap the potential of biologically diversified farming systems. *Journal of Agriculture, Food Systems, and Community Development* 3:219–25. doi:10.5304/jafscd.2013.034.025.

Chase, C., A. Johanns, and K. Delate. 2016. Making the transition from conventional to organic. *Ag Decision Maker Newsletter* 13(5):3.

Clancy, M., K. Fuglie, and P. Heinsey. 2016. U.S. Agricultural R&D in an Era of Falling Public Funding. Amber Waves, USDA. https://www.ers.usda.gov/amber-waves/2016/november/us-agricultural-rd-in-an-era-of-falling-public-funding/

Collins, A. M., and J. A. Klerman. 2017. Improving nutrition by increasing supplemental nutrition assistance program benefits. *American Journal of Preventive Medicine* 52(2): S179–S185. doi:10.1016/j.amepre.2016.08.032.

Crowder, D. W., and J. P. Reganold. 2015. Financial competitiveness of organic agriculture on a global scale. *Proceedings of the National Academy of Sciences* 112(24):7611–16. doi:10.1073/pnas.1423674112.

Delbridge, T. A., and R. P. King. 2016. Transitioning to organic crop production: A dynamic programming approach. *Journal of Agricultural and Resource Economics* 41(3):481–98.

DeLonge, M. S., A. Miles, and L. Carlisle. 2016. Investing in the transition to sustainable agriculture. *Environmental Science & Policy* 55:266–73. doi:10.1016/j.envsci.2015.09.013.

Diaz, R. J., and R. Rosenberg. 2008. Spreading dead zones and consequences for marine ecosystems. *Science* 321(5891):926–29. doi:10.1126/science.1156401.

Farley, J., and R. Costanza. 2010. Payments for ecosystem services: From local to global. *Ecological Economics* 69(11):2060–68. doi:10.1016/j.ecolecon.2010.06.010.

Farrell, M., and D. L. Jones. 2009. Critical evaluation of municipal solid waste composting and potential compost markets. *Bioresource Technology* 100(19):4301–10. doi:10.1016/j.biortech.2009.04.029.

Fernandez, M., K. Goodall, M. Olson, and V. E. Méndez. 2013. Agroecology and alternative agri-food movements in the United States: Toward a sustainable agri-food system. *Agroecology and Sustainable Food Systems* 37(1):115–26.

Francis, C. A., E. S. Jensen, G. Lieblein, and T. A. Breland. 2017. Agroecologist education for sustainable development of farming and food systems. *Agronomy Journal* 109(1):23–32. doi:10.2134/agronj2016.05.0267.

Francis, C. A., G. Lieblein, S. Gliessman, T. A. Breland, N. Creamer, R. Harwood, and M. Wiedenhoeft. 2003. Agroecology: The ecology of food systems. *Journal of Sustainable Agriculture* 22(3):99–118. doi:10.1300/J064v22n03_10.

GAFF (Global Alliance for the Future of Food) 2015. Global sustainable food and agriculture: A Philanthropic landscape assessment. 108p. Available at: http://www.futureoffood.org/wpcontent/uploads/2015/06/Final_FoF_Report_Jun25.pdf

Galt, R. E., S. F. Clark, and D. M. Parr. 2012. Engaging values in sustainable agriculture and food systems education: Toward an explicitly values-based pedagogical approach. *Journal of Agriculture, Food Systems, and Community Development* 2(3):43–54. doi:10.5304/jafscd.2012.023.006.

Geertsema, W., W. A. Rossing, D. A. Landis, F. J. Bianchi, P. C. Rijn, J. H. Schaminée, and W. Werf. 2016. Actionable knowledge for ecological intensification of agriculture. *Frontiers in Ecology and the Environment* 14(4):209–16. doi:10.1002/fee.1258.

Gibbons, J. M., J. C. Williamson, A. P. Williams, P. J. Withers, N. Hockley, I. M. Harris, and J. R. Healey. 2014. Sustainable nutrient management at field, farm and regional level: Soil testing, nutrient budgets and the trade-off between lime application and greenhouse gas emissions. *Agriculture, Ecosystems & Environment* 188:48–56. doi:10.1016/j.agee.2014.02.016.

Gilbert, N. 2014. Cross-bred crops get fit faster: Genetic engineering lags behind conventional breeding in efforts to create drought-resistant maize. *Nature* 513(7518):292–93. doi:10.1038/513292a.

Gilens, M., and B. I. Page. 2014. Testing theories of American politics: Elites, interest groups, and average citizens. *Perspectives on Politics* 12(03):564–81. doi:10.1017/S1537592714001595.

Gliessman, S. R. 2015. *Agroecology: The ecology of sustainable food systems*, Third ed. Boca Raton, FL: CRC Press.

Gliessman, S. R. 2016. Transforming food systems with agroecology. *Agroecology and Sustainable Food Systems* 40(3):187–89. doi:10.1080/21683565.2015.1130765.

Gliessman, S. R., R. E. Garcia, and M. A. Amador. 1981. The ecological basis for the application of traditional agricultural technology in the management of tropical agro-ecosystems. *Agro-Ecosystems* 7(3):173–85. doi:10.1016/0304-3746(81)90001-9.

Gliessman, S. R., and M. Rosemeyer, Eds. 2009. *The conversion to sustainable agriculture: Principles, processes, and practices*. Boca Raton, FL: CRC Press.

Gonzalez De Molina, M. 2013. Agroecology and politics. How to get sustainability? About the necessity for a political agroecology. *Agroecology and Sustainable Food Systems* 37(1):45–59.

Goodman, D., and M. Watts. 1997. *Globalising food: Agrarian questions and global restructuring*. London and New York: Routledge.

Graddy-Lovelace, G., and A. Diamond. 2017. From supply management to agricultural subsidies—and back again? The US Farm Bill & agrarian (in) viability. *Journal of Rural Studies* 50:70–83. doi:10.1016/j.jrurstud.2016.12.007.

Greene, C. 2014. Support for the organic sector expands in the 2014 Farm Act. *Amber Waves*, 1G. USDA ERS. http://www.ers.usda.gov/amber-waves/2014-july/support-for-the-organic-sector-expands-in-the-2014-farm-act.aspx#.Vzpg3SMrJpl

Gurr, G. M., S. D. Wratten, D. A. Landis, and M. You. 2016. Habitat management to suppress pest populations: Progress and prospects. *Annual Review of Entomology* (62):91–109. doi:10.1146/annurev-ento-031616-035050.

Harvey, C. A., M. Chacón, C. I. Donatti, E. Garen, L. Hannah, A. Andrade, L. Bede, D. Brown, A. Calle, J. Chara, and C. Clement. 2014. Climate-smart landscapes: Opportunities and challenges for integrating adaptation and mitigation in tropical agriculture. *Conservation Letters* 7(2):77–90. doi:10.1111/conl.12066.

Hodbod, J., O. Barreteau, C. Allen, and D. Magda. 2016. Managing adaptively for multi-functionality in agricultural systems. *Journal of Environmental Management* 183:379–88. doi:10.1016/j.jenvman.2016.05.064.

Howard, P. H. 2016. *Concentration and power in the food system: Who controls what we eat? (Vol. 3)*. London, UK: Bloomsbury Publishing.

Hoy, C. W. 2015. Agroecosystem health, agroecosystem resilience, and food security. *Journal of Environmental Studies and Sciences* 5(4):623–35. doi:10.1007/s13412-015-0322-0.

Iverson, A. L., L. E. Marín, K. K. Ennis, D. J. Gonthier, B. T. Connor-Barrie, J. L. Remfert, B. J. Cardinale, and I. Perfecto. 2014. Review: Do polycultures promote win-wins or trade-offs in agricultural ecosystem services? A meta-analysis. *Journal of Applied Ecology* 51(6):1593–602. doi:10.1111/1365-2664.12334.

Jiggins, J. 2014. Agroecology: Adaptation and mitigation potential and policies for climate change. In *Global environmental change* (Volume 1), ed. B. Freedman 733–43. Dordrecht: Springer Netherlands.

Johnson, R., R. A. Aussenberg, and T. Cowan, 2012. The role of local food systems in US farm policy. In *CRS Report for Congress R* (Vol. 42155).

Kaiser, M., and A. Algers. 2016. Food ethics: A wide field in need of dialogue. *Food Ethics* 1 (1):1–7. doi:10.1007/s41055-016-0007-8.

Kim, K. H., E. Kabir, and S. A. Jahan. 2017. Exposure to pesticides and the associated human health effects. *Science of the Total Environment* 575:525–35. doi:10.1016/j.scitotenv.2016.09.009.

Klonsky, K., and C. Greene. 2005. *Widespread adoption of organic agriculture in the US: Are market-driven policies enough?* Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Providence, Rhode Island, July 24–27, 2005 http://ageconsearch.umn.edu/record/19382/files/sp05kl05.pdf

Kremen, C. 2015. Reframing the land-sparing/land-sharing debate for biodiversity conservation. *Annals of the New York Academy of Sciences* 1355(1):52–76. doi:10.1111/nyas.2015.1355.issue-1.

Kremen, C., and A. Miles. 2012. Ecosystem services in biologically diversified versus conventional farming systems: Benefits, externalities, and trade-offs. *Ecology and Society* 17:4. doi:10.5751/ES-05035-170440.

Landers, T. F., B. Cohen, T. E. Wittum, and E. L. Larson. 2012. A review of antibiotic use in food animals: Perspective, policy, and potential. *Public Health Reports* 127(1):4–22.

Landis, D. A. 2017. Designing agricultural landscapes for biodiversity-based ecosystem services. *Basic and Applied Ecology* 18:1–12. doi:10.1016/j.baae.2016.07.005.

Lechenet, M., V. Bretagnolle, C. Bockstaller, F. Boissinot, M. S. Petit, S. Petit, and N. M. Munier-Jolain. 2014. Reconciling pesticide reduction with economic and environmental sustainability in arable farming. *Plos One* 9(6):e97922. doi:10.1371/journal.pone.0097922.

Levidow, L., M. Pimbert, and G. Vanloqueren. 2014. Agroecological research: Conforming—or transforming the dominant agro-food regime? *Agroecology and Sustainable Food Systems* 38(10):1127–55. doi:10.1080/21683565.2014.951459.

Lieblein, G., T. A. Breland, C. Francis, and E. Østergaard. 2012. Agroecology education: Action-oriented learning and research. *The Journal of Agricultural Education and Extension* 18(1):27–40. doi:10.1080/1389224X.2012.638781.

Liebman, M., B. Baraibar, Y. Buckley, D. Childs, S. Christensen, R. Cousens, H. Eizenburg, S. Heijting, D. Loddo, A. Merotto, and M. Renton. 2016. Ecologically sustainable weed management: How do we get from proof-of-concept to adoption? *Ecological Applications* 26(5):1352–69. doi:10.1002/15-0995.

Liebman, M., and L. A. Schulte. 2015. Enhancing agroecosystem performance and resilience through increased diversification of landscapes and cropping systems. *Elementa* 3: 000041. doi:10.12952/journal.elementa.000041.

Lin, B. B. 2011. Resilience in agriculture through crop diversification: Adaptive management for environmental change. *BioScience* 61(3):183–93. doi:10.1525/bio.2011.61.3.4.

Lipson, M. 1997. *Searching for the" O-word": Analyzing the USDA current research information system for pertinence to organic farming*. Santa Cruz, CA: Organic Farming Research Foundation.

Mallin, M. A., M. R. McIver, A. R. Robuck, and A. K. Dickens. 2015. Industrial swine and poultry production causes chronic nutrient and fecal microbial stream pollution. *Water, Air, & Soil Pollution* 226(12):407. doi:10.1007/s11270-015-2669-y.

McIntyre, B.D., 2009. International assessment of agricultural knowledge, science and technology for development (IAASTD): global report. http://www.fao.org/fileadmin/templates/est/Investment/Agriculture_at_a_Crossroads_Global_Report_IAASTD.pdf

McMichael, P. 2011. *Development and social change: A global perspective: A global perspective*. Thousand Oaks, CA: Sage Publications.

McMichael, P. 2013. Food regimes and agrarian questions. In *Agrarian change and peasant studies series*, 3. Action Publishing, Rugby, UK.

Méndez, V. E., C. M. Bacon, R. Cohen, and S. R. Gliessman, Eds. 2015. *Agroecology: A transdisciplinary, participatory and action-oriented approach*. Boca Raton, FL: CRC Press.

Miles, A., K. Enos, K. Maunakea Forth, and G. Maunakea Forth. in press. After the plantations: restoring ancestral abundance through food system change in Hawaiʻi. In *Nourish* ed C. Gupta,. San Francisco, CA: Extracurricular Press.

Montenegro De Wit, M., and A. Iles. 2016. Toward thick legitimacy: Creating a web of legitimacy for agroecology. *Elementa* 4:115.

Moore, J. 2005. Is higher education ready for transformative learning? A question explored in the study of sustainability. *Journal of Transformative Education* 3(1):76–91. doi:10.1177/1541344604270862.

Moraine, M., M. Duru, and O. Therond. 2016. A social-ecological framework for analyzing and designing integrated crop–livestock systems from farm to territory levels. *Renewable Agriculture and Food Systems* 1:1–14.

Morgan, K., and J. Murdoch. 2000. Organic vs. conventional agriculture: Knowledge, power and innovation in the food chain. *Geoforum* 31(2):159–73. doi:10.1016/S0016-7185(99)00029-9.

Moses, A., and P. Tomaselli. 2017. Industrial animal agriculture in the United States: Concentrated Animal Feeding Operations (CAFOs). In *International farm animal, wildlife and food safety law*, eds G. Steier and K. K. Patel, 185–214. New York, NY: Springer International Publishing.

Muller, M., A. Tagtow, S. L. Roberts, and E. MacDougall. 2009. Aligning food systems policies to advance public health. *Journal of Hunger & Environmental Nutrition* 4(3–4):225–40. doi:10.1080/19320240903321193.

Mundler, P., and S. Laughrea. 2016. The contributions of short food supply chains to territorial development: A study of three Quebec territories. *Journal of Rural Studies* 45:218–29. doi:10.1016/j.jrurstud.2016.04.001.

National Sustainable Agriculture Coalition (NSAC). 2016. Unified support for conservation as good farming practice needed At USDA. http://sustainableagriculture.net/blog/gfp-updated-at-rma/

Natural Resources Conservation Service (NRCS) (2016). Conservation Practices. https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/cp/ncps/?cid=nrcs143_026849

Nestle, M. 2013. *Food politics: How the food industry influences nutrition and health*, 3. Berkeley, CA: University of California Press.

Pardey, P. G., J. M. Alston, and C. Chan-Kang. 2013. Public food and agricultural research in the United States. The rise and decline of public investments, and policies for renewal. Available at http://foodandagpolicy.org/content/public-food-and-agricultural-research-united-statesthe-rise-and-decline-public-investments-a

Park, S., P. Croteau, K. A. Boering, D. M. Etheridge, D. Ferretti, P. J. Fraser, K. R. Kim, P. B. Krummel, R. L. Langenfeld, T. D. Van Ommen, and L. P. Steele. 2012. Trends and seasonal cycles in the isotopic composition of nitrous oxide since 1940. *Nature Geoscience* 5(4):261–65. doi:10.1038/ngeo1421.

Parr, D. M., A. Miles, R. E. Galt, C. J. Bernau, and D. Wong. in preparation. Creating institutional spaces for critical agroecology education: epistemological foundations and engaged communities of practice toward agri-food system transformation. *Agriculture and Human Values*.

Perfecto, I., and J. Vandermeer. 2008. Biodiversity conservation in tropical agroecosystems. *Annals of the New York Academy of Sciences* 1134(1):173–200. doi:10.1196/nyas.2008.1134.issue-1.

Perkins, J. H. 1997. *Geopolitics and the green revolution: Wheat, genes, and the cold war*. UK: Oxford University Press: Oxford, England.

Pojman, L. P., P. Pojman, and K. McShane. 2016. *Food ethics*. Boston, MA: Cengage Learning.

Ponisio, L. C., and P. R. Ehrlich. 2016. Diversification, yield and a new agricultural revolution: Problems and prospects. *Sustainability* 8(11):1118. doi:10.3390/su8111118.

Ponisio, L. C., L. K. M'Gonigle, K. C. Mace, J. Palomino, P. De Valpine, and C. Kremen 2015. Diversification practices reduce organic to conventional yield gap. In *Proceedings of the Royal Society of London: Biological Sciences* (Vol. 282, No. 1799, p. 20141396). The Royal Society.

Power, A. G. 2010. Ecosystem services and agriculture: Tradeoffs and synergies. *Philosophical Transactions of the Royal Society of London B: Biological Sciences* 365(1554):2959–71. doi:10.1098/rstb.2010.0143.

Reganold, J. P., D. Jackson-Smith, S. S. Batie, R. R. Harwood, J. L. Kornegay, D. Bucks, and P. Willis. 2011. Transforming US agriculture. *Science* 332(6030):P670–671. doi:10.1126/science.1202462.

Reganold, J. P., and J. M. Wachter. 2016. Organic agriculture in the twenty-first century. *Nature Plants* 2:15221. doi:10.1038/nplants.2015.221.

Rusch, A., R. Bommarco, and B. Ekbom. 2016a. Conservation biological control in agricultural landscapes. *Advances in Botanical Research* 81:333–60.

Rusch, A., R. Chaplin-Kramer, M. M. Gardiner, V. Hawro, J. Holland, D. Landis, C. Theis, T. Tscharntke, W. W. Weisser, C. Winquist, and M. Woltz. 2016. b. Agricultural landscape simplification reduces natural pest control: A quantitative synthesis. *Agriculture, Ecosystems & Environment* 221:198–204. doi:10.1016/j.agee.2016.01.039.

Sanderson Bellamy, A., and A. A. Ioris. 2017. Addressing the knowledge gaps in agroecology and identifying guiding principles for transforming conventional agri-food systems. *Sustainability* 9(3):330. doi:10.3390/su9030330.

Sandhu, H., S. Wratten, R. Costanza, J. Pretty, J. R. Porter, and J. Reganold. 2015. Significance and value of non-traded ecosystem services on farmland. *PeerJ* 3:e762. doi:10.7717/peerj.762.

Schipanski, M. E., G. K. MacDonald, S. Rosenzweig, M. J. Chappell, E. M. Bennett, R. B. Kerr, J. Blesh, T. Crews, L. Drinkwater, J. G. Lundgren, and C. Schnarr. 2016. Realizing resilient food systems. *BioScience* (biw052). doi:10.1093/biosci/biw052.

Shannon, K. L., B. F. Kim, S. E. McKenzie, and R. S. Lawrence. 2015. Food system policy, public health, and human rights in the United States. *Annual Review of Public Health* 36:151–73. doi:10.1146/annurev-publhealth-031914-122621.

Smith, T. G., H. H. Chouinard, and P. R. Wandschneider. 2011. Waiting for the invisible hand: Novel products and the role of information in the modern market for food. *Food Policy* 36(2):239–49. doi:10.1016/j.foodpol.2010.11.021.

Smith, T. G., and A. Tasnádi. 2014. The economics of information, deep capture, and the obesity debate. *American Journal of Agricultural Economics* (aat113). doi:10.1093/ajae/aat113.

Sossidou, E. N., A. Dal Bosco, C. Castellini, and M. A. Grashorn. 2015. Effects of pasture management on poultry welfare and meat quality in organic poultry production systems. *World's Poultry Science Journal* 71(02):375–84. doi:10.1017/S0043933915000379.

Soulard, C. T., and J. M. Meynard. 2016. The contribution of agronomic research to innovation: The experience of INRA-SAD in France. In *Agricultural adaptation to climate change*, eds R. Bryant, M. A. Sarr, K. De'lusca, 117–30. Switzerland: Springer International Publishing.

Steckel, J. C., M. Jakob, C. Flachsland, U. Kornek, K. Lessmann, and O. Edenhofer. 2017. From climate finance toward sustainable development finance. *Wiley Interdisciplinary Reviews: Climate Change* 8(1):e437.

Steffen, W., K. Richardson, J. Rockström, S. E. Cornell, I. Fetzer, E. M. Bennett, and C. Folke. 2015. Planetary boundaries: Guiding human development on a changing planet. *Science* 347(6223):1259855. doi:10.1126/science.1259855.

Sustainable Agriculture Research & Education (SARE). 2016. 2015/2016 SARE Report from the field. 20p, available at www.sare.org

Swinton, S. M., F. Lupi, G. P. Robertson, and S. K. Hamilton. 2007. Ecosystem services and agriculture: Cultivating agricultural ecosystems for diverse benefits. *Ecological Economics* 64(2):245–52. doi:10.1016/j.ecolecon.2007.09.020.

Tarpley, R. J. 2014. Antibiotics: Discontinue low-dose use. *Science* 343(6167):136–37. doi:10.1126/science.343.6167.136-b.

Thompson, P. B. 2016. The emergence of food ethics. *Food Ethics* 1(1):61–74. doi:10.1007/s41055-016-0005-x.

Tscharntke, T., Y. Clough, T. C. Wanger, L. Jackson, I. Motzke, I. Perfecto, J. Vandermeer, and A. Whitbread. 2012. Global food security, biodiversity conservation and the future of agricultural intensification. *Biological conservation*, 151(1),53–59.

Tscharntke, T., A. M. Klein, A. Kruess, I. Steffan-Dewenter, and C. Thies. 2005. Landscape perspectives on agricultural intensification and biodiversity–ecosystem service management. *Ecology Letters* 8(8):857–74. doi:10.1111/j.1461-0248.2005.00782.x.

Tubiello, F. N., M. Salvatore, R. D. Cóndor Golec, A. Ferrara, S. Rossi, R. Biancalani, S. Federici, H. Jacobs, and A. Flammini. 2014. Agriculture, forestry and other land use emissions by sources and removals by sinks. ESS Working Paper No. 2, Mar 2014. *Statistics Division, Food and Agriculture Organization, Rome*, Italy. http://www.fao.org/docrep/019/i3671e/i3671e.pdf

USDA 2017. https://www.usda.gov/wps/portal/usda/usdahome?navtype=MA&navid=ABOUT_USDA

USDA National Organic Program (NOP). 2017. https://www.ams.usda.gov/programs-offices/national-organic-program

Vaarst, M. 2015. The role of animals in eco-functional intensification of organic agriculture. *Sustainable Agriculture Research* 4(3):103. doi:10.5539/sar.v4n3p103.

Van Bruggen, A. H. C., and M. R. Finckh. 2016. Plant diseases and management approaches in organic farming systems. *Annual Review of Phytopathology* 54:25–54. doi:10.1146/annurev-phyto-080615-100123.

Vanloqueren, G., and P. V. Baret. 2009. How agricultural research systems shape a technological regime that develops genetic engineering but locks out agroecological innovations. *Research Policy* 38(6):971–83. doi:10.1016/j.respol.2009.02.008.

Wals, A. E., M. Brody, J. Dillon, and R. B. Stevenson. 2014. Convergence between science and environmental education. *Science* 344(6184):583–84. doi:10.1126/science.1250515.

Warner, K. 2007. *Agroecology in action: Extending alternative agriculture through social networks*. Cambridge, MA: MIT Press.

West, P. C., J. S. Gerber, P. M. Engstrom, N. D. Mueller, K. A. Brauman, K. M. Carlson, and S. Siebert. 2014. Leverage points for improving global food security and the environment. *Science* 345(6194):325–28.

Willer, H., and J. Lernoud. 2016. *The world of organic agriculture, statistics and emerging trends 2016. FIBL, IFOAM First Edition Handbook*. 978–3. Bonn, Germany. ISBN 978-3-03736-306-5

Woodard, J. D., and L. J. Verteramo-Chiu. 2017. Efficiency impacts of utilizing soil data in the pricing of the federal crop insurance program. *American Journal of Agricultural Economics* 99(3):757–72. doi:10.1093/ajae/aaw099.

World Health Organization (WHO). 2015. Antibiotic resistance. http://www.who.int/mediacentre/factsheets/antibiotic-resistance/en/

Zhang, X., E. A. Davidson, D. L. Mauzerall, T. D. Searchinger, P. Dumas, and Y. Shen. 2015. Managing nitrogen for sustainable development. *Nature* 528(7580):51–59.