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Closing the knowledge gap: How the USDA could tap the potential of biologically diversified farming systems

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Abstract

Modern agriculture has proven highly productive, yet has simultaneously generated environmental and social impacts of global concern. Pressing environmental issues call into question the ability of the current model of industrial agriculture to sustain adequate yields without undermining the natural resource base upon which it depends. Meanwhile, global food needs are projected to double by 2050, raising questions over the need to further intensify agricultural production. Current research demonstrates that biologically diversified farming systems can meet global food needs sustainably and efficiently, as they outperform chemically managed monocultures across a wide range of globally important ecosystem services while producing sufficient yields and reducing resource waste throughout the food system. Research and development related to diversified systems, however, commands less than two percent of public agricultural research funding. We argue that this "knowledge gap" is at the crux of the "yield gap" that is often raised as the impediment to transitioning a greater share of global agriculture to diversified, agroecological production. If United States Department of Agriculture (USDA) research, education, and extension were to shift significantly toward agroecology and biologically diversified farming systems, the potential to address global resource challenges would be

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enormous. Here we present a broad framework for how the USDA could use existing infrastructure to address the challenges of food and farming in the twenty-first century and beyond.

Keywords
agricultural policy, agricultural research, agroecology, diversified farming systems, land grant university system, sustainability, U.S. Department of Agriculture

Modern agriculture has proven highly productive, yet has simultaneously generated environmental and social impacts of global concern. Pressing environmental issues call into question the ability of the current model of industrial agriculture to sustain adequate yields without undermining the natural resource base upon which it depends. Meanwhile, global food needs are projected to double by 2050, raising questions over the need to further intensify agricultural production. Current research demonstrates that biologically diversified farming systems can meet global food needs sustainably and efficiently, as they outperform chemically managed monocultures across a wide range of globally important ecosystem services while producing sufficient yields and reducing resource waste throughout the food system. Research and development related to diversified systems, however, commands less than two percent of public agricultural research funding. We argue that this "knowledge gap" is at the crux of the "yield gap" that is often raised as the impediment to transitioning a greater share of global agriculture to diversified, agroecological production. If United States Department of Agriculture (USDA) research, education, and extension were to shift significantly toward agroecology and biologically diversified farming systems, the potential to address global resource challenges would be enormous. Here we present a broad framework for how the USDA could use existing infrastructure to address the challenges of food and farming in the twenty-first century and beyond.

The Problem with Business-as-Usual Agriculture

While achieving impressive levels of crop productivity over the past six decades, modern agricultural systems have accomplished this feat with significant ecological and social costs (Hazell & Wood, 2008; Millennium Ecosystem Assessment [MEA], 2005; Committee on Twenty-First Century Systems Agriculture, Board on Agriculture and Natural Resources, Division on Earth and Life Studies, and National Research Council [NRC], 2010; President's Council of Advisors on Science and Technology [PCAST], 2012; Tilman, Cassman, Matson, Naylor, & Polasky, 2002). With the industrialization of agriculture, biologically diversified farming systems have been gradually replaced with biologically simplified monocultures that are highly dependent on fossil energy and industrial inputs (Dodson, Sipe, Rickson, & Sloan, 2010; Tscharntke, Klein, Kruess, Steffan-Dewenter, & Thies, 2005). The industrialization of agriculture and the loss of biodiversity in and around agroecosystems has significantly reduced the provisioning of globally important ecosystem services to and from agriculture, including crop pollination, natural pest control, soil and water quality maintenance, efficient nutrient cycling, carbon sequestration, and biodiversity conservation (Zhang, Ricketts, Kremen, Carney, & Swinton, 2007). Further, the suite of practices and agrochemical inputs that substitute for ecosystem services in much of modern agriculture contribute to significant environmental, social, and economic impacts, including soil and water quality degradation, eutrophication of surface and groundwater, loss of wild biodiversity, increased greenhouse gas emissions, marine hypoxic zones, and occupational and dietary exposure to agricultural chemicals (Diaz & Rosenberg, 2008; Gomiero, Pimentel, & Paoletti, 2011; Hayes et al., 2010; Marks et al., 2010; PCAST, 2012). In short, the "maximal production" approach to agricultural research and development has indeed delivered benefits, but these are being outpaced by its costs. To sustain yields — and the resources they depend on — we need to shift to a "net gain" approach. A fundamentally new model for agricultural research, education, and extension is needed to meet growing demand for food, fiber, and fuel in a manner that is ecologically sustainable, socially equitable, and economically viable over the long term (Gliessman, 2004; Koohafkan, Altieri, &

Holt-Giménez, 2011; NRC, 2010; Pretty et al., 2010).

A Promising Solution: Biologically Diversified Farming Systems

A large body of scientific research demonstrates that biologically diversified farming systems outperform chemically managed monocultures across a wide range of globally important ecological and social services (Bacon, Getz, Kraus, Montenegro, & Holland, 2012; Gomiero et al., 2011; Kremen & Miles, 2012). Biologically diversified farming systems are agricultural systems that integrate a suite of agronomic practices and/or landscape management strategies that incorporate functional biodiversity at multiple spatial or temporal scales to enhance the ecosystem services that provide key inputs to agriculture (Kremen, Iles, & Bacon, 2012). Thus, from the diversified farming systems perspective, economic and ecological sustainability go hand in hand.

Compared to monocultures managed with agrichemicals, biologically diversified farming systems support significantly greater biodiversity, soil quality, carbon sequestration, soil water-holding capacity, energy use efficiency, and resistance and resilience to climate change. When contrasted with conventional agriculture, biologically diversified farming systems also tend to enhance the biological control of weeds, diseases, and arthropod pests, while increasing pollination services from native insects. Importantly, the available evidence also indicates that the degree to which these later ecosystem services are provided by farming system diversification alone may be insufficient to consistently control pests and diseases or provide pollination services at the levels required by growers. However, the above findings illustrate the potential of biologically diversified farming systems to reduce or ameliorate many pressing global environmental impacts caused by modern agriculture, while enhancing key ecosystem services and producing similar yields (Davis, Hill, Chase, Johanns, & Liebman, 2012; Kremen & Miles, 2012). Given the very high rates of return on investment for government expenditures on agricultural research and extension (Alston, 2009), we recommend significant increases in USDA research, extension, and educational support for agroecological research and development, so as to realize the full ecological and economic potential of biologically diversified farming systems.

Promising — But Woefully Underresourced

Despite the well documented performance of biologically diversified farming systems, funding to advance such farming systems remains only a small fraction of agricultural research and development budgets, both nationally and globally (International Assessment of Agricultural Knowledge, Science and Technology for Development [IAASTD], 2008; Lipson, 1998; Sooby, 2001; Vanloqueren & Baret, 2009). Current USDA data, for example, demonstrate that certified organic farming systems research accounts for only 1.68% of total Research, Extension and Education (REE) funding (Organic Farming Research Foundation, 2012). Moreover, while organic farming systems frequently utilize biological diversification as a key soil fertility and pest management strategy, both the lack of research and extension support and the selective pressure of organic markets have pushed much of U.S. organic agriculture toward monoculture systems supported by a process of input substitution (Guthman, 2004). Because monocultures of organic crops do not necessarily meet the targets of ecological and social sustainability, we have undertaken an analysis of the USDA Current Research Information Systems (CRIS) database to identify and quantify the total REE support for agroecological research that facilitates the development of biologically diversified farming systems that provide multiple ecosystem services and meet specific targets of ecological and social sustainability. Our findings indicate that, to date, such support makes up an even smaller fraction of total REE funding than that allocated to organic farming systems research.

The most prominent criticism of the biologically diversified approach to agriculture is that there is insufficient data to support its capacity to produce equivalent yields and "feed the world" (Phalan, Onial, Balmford, & Green, 2011). As a recent meta-analysis (Ponisio, M'Gonigle, Mace, Palomino, de Valpine, & Kremen, 2013) suggests, however, such "insufficient data" is not an ontological problem fundamental to agroecological production (which results in yields comparable to conventional systems when both are subject to equivalent "best management practices"). Rather, "insufficient data" for the yield potential of diversified farming systems on a global scale is an epistemological problem, arising from the paucity of well designed studies that could help identify and improve the productivity of such systems. Given the substantial evidence that such systems can achieve significant efficiencies and even overyield conventional monocultures in some instances by exploiting biological complementarities (Davis et al., 2012; Kremen & Miles, 2012; Li, Li, Sun, Zhou, Bao, Zhang, & Zhang, 2007; Vandermeer, 2011; Zhu et al., 2000), we see this as yet another argument for increased funding for agroecological research and development. Conducting this much-needed research will provide the empirical basis for the design and management of biologically diversified farming systems that sponsor a wide range of ecosystem services, reduce or eliminate yield gaps where they exist, and sustain agricultural productivity and environmental quality over the long term (Tscharntke et al., 2012).

A Twenty-First Century Model for USDA Research, Education, and Extension

In order to tap the full potential of biologically diversified agriculture, we suggest that the USDA redirect and strengthen research, extension, and education at three major levels.

1. Beginning at the highest level, we propose shifting the strategic vision of research, extension, and education toward the objective of **ecological and social sustainability in food and agriculture.** We imagine a USDA in which all programming would be directed and evaluated according to this overarching goal.
2. Accordingly, **new targets and metrics** for assessing the ecological, social, and economic performance of farming systems would guide the allocation of funds among program areas and competitive grants, as well as evaluations of program success. We encourage the USDA to develop these targets themselves — through an ongoing process — but key criteria should certainly include the following characteristics of sustainable farming systems. Such systems (1) maintain or enhance the natural resource base upon which they depend, (2) rely on a minimum of off-farm and artificial inputs, (3) manage pests and pollination services through internal biological mechanisms, (4) are resistant and resilient to environmental and human-induced disturbances, (5) contribute minimally to environmental externalities while sustaining high levels of productivity over the long term, and (6) promote socially equitable and nonexploitative relations.
3. Significant progress in meeting such targets can be achieved through a new set of strategic research emphases. **Multidisciplinary teams,** conducting **long-term agroecological studies,** would provide key data for directing food and agriculture toward greater ecological and social sustainability. Such research would assess **whole systems,** across social, economic, and ecological dimensions. **Full life-cycle analysis** would provide a comprehensive "net gain" accounting of the constraints, costs, and benefits of **biologically diversified farming systems.** Research would focus on **regionally adapted varieties and farming systems,** would frequently be conducted on-farm in partnership with producers, and would be integrated with **interdisciplinary education and training at land-grant universities.**

In our research to date, we have identified several pilot research and development projects in USDA's CRIS database that could serve as models for such an approach:

- Shennan et al.'s "Collaborative Research and Extension Network for Sustainable Organic Production Systems in Coastal California";
- Myers et al.'s "Northern Organic Vegetable Improvement Cooperative";
- Grossman et al.'s "Evaluating the Potential of Winter Cover Crops for Carbon Sequestration in Degraded Soils Transitioning to Organic Production";

- Hatfield et al.'s "Reducing Tillage Intensity in Organic Crop Systems: Ecological and Economic Impacts of Targeted Sheep Grazing on Cover Crops, Weeds, and Soil"; and
- Barbercheck et al.'s "Improving Weed and Insect Management in Organic Reduced-Tillage Cropping Systems."

We are encouraged that the USDA is adopting multidisciplinary, Long-Term Ecological Research (LTER) methodologies and believe developing such research sites is a pragmatic investment for the USDA. As part of this process, we encourage the USDA to expand upon the sound models for medium-term studies of diversified farming systems that have already been developed within the REE system. A recent study conducted at Iowa State University's Marsden Farm (Davis et al., 2012) is one such model, as is the research conducted by John Teasdale at the USDA experiment station in Beltsville, Maryland. We would also encourage both in-house USDA facilities and land-grant universities to engage with long-term research models developed outside the public agricultural research system by organizations such as the Land Institute and the Rodale Institute. Model international case studies of socio-ecological research include Farshad & Zinck's (2000) "Assessing agriculture sustainability using the six-pillar model: Iran as a case study," and Khan, Midega, Pittchar, Pickett, & Bruce's (2011) "Push-pull technology: A conservation agriculture approach for integrated management of insect pests, weeds and soil health in Africa." The National Science Foundation's Coupled Human-Natural Systems program provides another promising model for such interdisciplinary research.

While such agroecological research and development projects account for a very small percentage of total REE grants to date, much greater social and ecological benefits could be realized if a stable base of financial and infrastructural support was provided to expand this scope of critically important work.

As one of the most successful public agricultural research systems in the world, the USDA is uniquely positioned to generate and disseminate agroecological knowledge at a meaningful scale. By shifting its strategic focus and supporting cutting-edge, multidisciplinary research on biologically diversified farming systems, USDA research, extension, and education can position the United States to take a responsible leadership role in a truly sustainable approach to meeting global food needs.

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