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Synthesis, part of a Special Feature on A Social-Ecological Analysis of Diversified Farming Systems: Benefits, Costs, Obstacles, and Enabling Policy Frameworks

Economic Factors Affecting Diversified Farming Systems

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ABSTRACT. In response to a shift toward specialization and mechanization during the 20th century, there has been momentum on the part of a vocal contingent of consumers, producers, researchers, and policy makers who call for a transition toward a new model of agriculture. This model employs fewer synthetic inputs, incorporates practices which enhance biodiversity and environmental services at local, regional, and global scales, and takes into account the social implications of production practices, market dynamics, and product mixes. Within this vision, diversified farming systems (DFS) have emerged as a model that incorporates functional biodiversity at multiple temporal and spatial scales to maintain ecosystem services critical to agricultural production. Our aim is to provide an economists' perspective on the factors which make diversified farming systems (DFS) economically attractive, or not-so-attractive, to farmers, and to discuss the potential for and roadblocks to widespread adoption. We focus on how a range of existing and emerging factors drive profitability and adoption of DFS. We believe that, in order for DFS to thrive, a number of structural changes are needed. These include: 1) public and private investment in the development of low-cost, practical technologies that reduce the costs of production in DFS, 2) support for and coordination of evolving markets for ecosystem services and products from DFS and 3) the elimination of subsidies and crop insurance programs that perpetuate the unsustainable production of staple crops. We suggest that subsidies and funding be directed, instead, toward points 1) and 2), as well as toward incentives for consumption of nutritious food.

Key Words: *agriculture; diversified farming systems; economics*

INTRODUCTION

The 20th century brought significant changes to the economics of global agriculture. In more developed countries such as the United States, the face of agriculture was once that of the small family farmer. Today, the agricultural landscape in developed —and to some extent developing—countries is dominated by agribusiness and large farming operations. While many of these operations are still family-owned and farm size, management, and production methods remain diverse, on the whole, farms are larger and more mechanized and specialized than ever before (Schmitt 1991, Chavas 2001, Sumner and Wolf 2002). This transition is a direct result of the increase in relative price of labor and changes in domestic and global agricultural policies (Ruttan and Binswanger 1978, Kislev and Peterson 1982), and was spurred by dramatic improvements in agricultural productivity, and a shift from more labor-intensive agriculture to more capital- and technology-intensive agricultural practices that employed new varieties, synthetic inputs, and irrigation (Griliches 1963, van Zanden 1991, Antle 1999, Chavas 2001, Paul et al. 2004, Dimitri et al. 2005, Hoppe et al. 2007, Chavas et al. 2010). While agricultural production in much of Asia, Africa, and Latin America is more heterogeneous and more labor-intensive in general, specialization, mechanization, and technological change have increased productivity of agricultural commodity crops such as soybeans and sugarcane in Brazil, wheat and rice in China and India, palm oil in Indonesia and Malaysia, and others (Feder et al. 1985, Jayasuriya and Shand 1986, Pingali 2007). Incorporating and disseminating technological advances that improve productivity and incomes in smallholder farming systems remains a challenge throughout the developing world (Barlow and Jayasuriya 1984).

In spite of—or perhaps in response to—this shift toward specialization and mechanization, there has been renewed momentum on the part of a vocal contingent of consumers, producers, researchers, and policy makers who draw attention to the social, environmental, and economic implications of this transition (Ikerd 1993, McCann et al. 1997, Timmer 1997, Webster 1997, Antle 1999, Seyfang 2006). They envision a new model of agriculture that employs fewer synthetic inputs, incorporates practices which enhance biodiversity and environmental services, and takes into account the social implications of production practices, market dynamics, and product mixes. Components of this movement are taking hold in the economic and cultural mainstream in the United States, Europe and other countries. Evidence of this shift includes the rise of organic, "fair trade", and other production and certification schemes, and the growth of consumer willingness-to-pay for these differentiated food products. The prevalence of local farmers' markets and slow and local food movements, and the emergence of Payments for Ecosystem Services (PES) and multifunctional agriculture (MFA) within agricultural landscapes are also supporting this change (Thompson 1998, Hinrichs 2000, Heal and Small 2002, Loureiro and Hine 2002, Weatherell et al. 2003, Loureiro and Lotade 2005, Antle and Stoorvogel 2006, Swinton et al. 2006, Heiman et al. 2009).

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While closely related to the concepts of sustainable, multifunctional and organic agriculture, diversified farming systems (DFS) have emerged as a separate agricultural model (Chambers and Conway 1991). Diversified farming systems share much in common with sustainable, multifunctional, organic and local farming systems, but are unique because they emphasize incorporating functional biodiversity at multiple temporal and spatial scales to maintain ecosystem services critical to agricultural production. These ecosystem services include but are not limited to pollination services, water quality and availability, and soil conservation (see Kremen, Iles, and Bacon 2012). Our aim is to provide an economists' perspective on how a range of existing and emerging factors drive profitability of DFS at the farm level and how these relate to the adoption and emergence of diversified farming systems at larger scales. We begin with an overview of the factors that impact the profitability of agricultural systems, follow with a discussion of the economic factors that support and run counter to diversified farming systems, and conclude with our thoughts on how technological innovation and market trends must continue to evolve if DFS are to become economically sustainable and widespread.

FACTORS THAT IMPACT THE PROFITABILITY OF AGRICULTURAL SYSTEMS: AN OVERVIEW

How profitable is it to farm? The answer depends upon the choices a farmer makes about what crops to grow and where, what technologies to use, and many other short- and long-term management decisions. Economists assume that farmers make choices so as to improve their utility, or well-being. In particular, farmers tend to pursue activities that increase their income, reduce their financial and physical risk, reduce labor requirements, and are convenient or enjoyable. A variety of constraints play into farmers' decisions, including constraints with respect to available production technologies, biophysical or geophysical constraints, labor and input market constraints, financial and credit constraints, social norms, intertemporal tradeoffs, policy constraints, and constraints to knowledge or skills (Stoorvogel et al. 2004).

The literature on technology adoption at the farm level tells us that many factors—in particular, variables that vary across farms and are sources of heterogeneity—influence farmers' choices about what crops to grow, whether to use a new technology, and how to manage their land. Just as individual consumers have different preferences about products they consume, farmer characteristics, asset endowments, risk preferences, and intertemporal considerations affect their choices. Farmer attitudes, resource availability, and education and knowledge are especially important; farmers may be risk-averse toward making changes in cropping decisions or adopting new agricultural practices, or might have very conservative attitudes toward technology or lower or higher levels of concern for the natural environment (McCann 1997, Hanson et al. 2004, Musshoff and Hirschauer 2008, Serra et al. 2008). A farmer's income or resource base and ability to obtain credit will also influence his/her choice of crops, farming systems, and willingness to invest in new crops, systems, or technologies (McCann 1997, Knowler and Bradshaw 2007). A risk-averse farmer or one who is credit or income-constrained (which often is the norm rather than the exception, particularly in developing countries) may be less likely to adopt new technologies, even if they are likely to reduce his susceptibility to risk or increase productivity or income over the long-run (Nerlove et al. 1996, Hanson et al. 2004). Lack of knowledge and information about the costs and benefits of adopting new technologies or conservation practices *or* lack of knowledge about how to implement such technologies or practices will also affect a farmer's propensity to adopt them (Chavas et al. 2010, Chavas and Kim 2010). Even if farmers have full information and can implement new technologies efficiently and at low cost, differences in intertemporal preferences or credit constraints may mean that farmers are unwilling to sacrifice current profits or income for long-term improvements in soil fertility, risk-reductions, or improved yields (Shively 2001, Sunding and Zilberman 2001, Coxhead and Shively 2002).

Biological and geophysical factors and input and output market conditions are important variables that also impact farmer decision-making and adoption of land use practices or technologies. Biological and geophysical factors that influence production can include water availability, soil fertility, and risks of floods, droughts, frost, or pest or weed infestations, and the importance of each of these factors varies with the types of crops planted (Loomis et al. 1971, Leemans and Born 1994). Input market conditions can shape farmer production decisions in a number of ways; dynamics of local and seasonal labor availability may mean that it is not profitable to grow a crop with a very narrow harvesting window in a month where the overall demand for agricultural labor is high in the region (Fisher 1951, Binswanger and Rosenzweig 1986). Input price volatility and economies of scale with respect to inputs or technologies can also contribute to farmers planting different mixes of crops, or planting more land in one crop than another (Zilberman et al. 2012). Similarly, output market conditions including prices, price variability, transportation costs, and supply chain transactions costs are important determinants of how profitable it is for farmers to grow a crop. Many of these variables are influenced by location; Rogers (2003) notes that communities closer to urban centers are likely to adopt new technologies more quickly. Consumer attitudes and willingness to pay (i.e., the maximum amount a consumer would be willing to pay for a good or attribute) for differentiated crops or particular attributes, such as organic or local production or pesticide-free varieties, also affect the agricultural systems that emerge in response to the demands of a changing market.

Finally, policies and regulations can impact the profitability and evolution of different agricultural systems by facilitating or hindering trade in particular types of agricultural products, by influencing farmer decisions about what crops to grow or how much land to farm using policies such as price supports or set-aside programs, or by making different types of production or land-use relatively more or less "expensive" via regulations, taxes and subsidies, or standards (Hardie et al. 2004, Goetz and Zilberman 2007). In addition, many policies that do not specifically target agriculture, such as labor and immigration or water policies, have a significant effect on the costs of agricultural production. For example, laws such as those that regulate pesticide usage and application or limit water use can make it more costly to produce using synthetic pesticides or inefficient irrigation systems (Lichtenberg et al. 1988, Lichtenberg 2002). While in the short-run such regulations may have a negative impact on farmer welfare, they also serve to stimulate innovation and adoption of new technologies in order to comply with regulations and reduce the costs of production (Lichtenberg 2002).

How can we describe trends in adoption and diffusion of agricultural technologies at landscape, regional, or global scales? Early studies on adoption noticed that the number of adopters, or the cropped area of using the new technology, were S-shaped (or followed a logistic curve) as a function of time. They explained this pattern by imitation behavior among farmers; adoption is slow until enough farmers begin using the technology, and then rates of adoption speed up rapidly before they plateau (Rogers 2003). The more profitable the new technology, the faster the rate of adoption and the higher the level of adoption after the diffusion process has played out (Griliches 1957). Farmers are heterogeneous, however, which impacts how and when they make decisions. In light of this heterogeneity, David (1975) and Feder et al. (1985) introduced the threshold model of adoption which characterized adoption within a community as a dynamic process whereby farmers make decisions according to explicit economic decision rules. Differences in when and how farmers adopt new technologies, then, arise due to heterogeneity among farmers and differences in other factors, such as their location and land quality. Larger farmers, for example, are often early adopters of mechanized technologies that exhibit increasing returns to scale.

There is an interplay between farmer heterogeneity and the biological and geophysical factors that influence adoption that we mentioned earlier in this section; farmers in areas with soils with lower water-holding capacity will reap greater benefits from adopting irrigation technologies, and pest control strategies are adopted first in regions with high pest pressures. Over time, technologies and practices diffuse as producers gain knowledge and experience, or "learning by doing," and as more and more farmers begin to use the technology, or "learning by using." More and more farmers will adopt a technology as the fixed costs of adoption decline with time, and for some technologies, the gains from adoption *increase* with time as the network of producers using the technology increases in size (i.e., technologies that exhibit network externalities, such as cell phones) (Sunding and Zilberman 2001). These basic principles that guide producer adoption choices provide a background for analyzing the factors that will affect whether farmers adopt diversified farming systems.

ECONOMIC FACTORS THAT SUPPORT DIVERSIFICATION

Within the context of farmer decision making, there are a number of ways that diversified farming systems can help farmers maximize their utility, including through their roles in mitigating different types of risks, providing complementary inputs and optimizing production in the face of different biophysical or input and output market constraints, and through providing income or nonpecuniary benefits from ecosystem services or other benefits of using DFS practices. In this section, we focus on how these factors might make diversification an economically optimal choice for the farmer.

Farmers are typically risk-averse (where risk implies, for example, that the farmer knows that the price of their outputs will vary with some known probability). They face many different types of risk including price risk (e.g., the risk that the price that they receive for their output will be higher or lower than average in a given year), yield risk (e.g., the risk that a pest infestation or drought will cause yields to be lower than average), input supply risk (e.g., the risk of a water shortage or a labor shortage at a critical point in the production process) and other types of risks (e.g., the risk of a family member getting sick or a tractor breaking down) (Mcnamara and Weiss 2005). Many of these types of risk (e.g., price risk, yield risk) contribute directly to profit risk, which is ultimately most important to the producer. Farmers and their families can respond to risks in many ways, and can respond ex ante (before the event) in precautionary ways, or ex post (after the event) to try and minimize their losses. Strategies for coping with risk include finding off-farm employment (Mcnamara and Weiss 2005, Ito and Kurosaki 2009), saving or using credit markets, informal borrowing (e.g., loans between family members), adopting risk-reducing technologies such as seed varieties with properties such as drought or herbicide resistance that emerged during the green revolution (Feder et al. 1985), engaging in contracts such as those that ensure that the farmer will have a buyer for his product at the end of the season at a set price (Goodhue and Hoffmann 2006), and diversification of production.

Diversification of crops that the farmer produces may be an effective tool to help farmers deal with several types of risk including price and yield risk, risk in input markets (e.g., in labor markets), and other output market risks (i.e., the risk that you might not be able to find a buyer for your product). In the case of price risk, because the markets for different crops are characterized by different degrees of risk (in the simplest treatment of price risk, each price for each crop is characterized by a different mean and variance), the farmer can use what he knows about the means and variances of the prices for each crop to choose a mix of crops that have a low correlation of profitability (Coyle 1992). If the price risks for two crops are poorly-correlated, the farmer can use diversification and choose an optimal portfolio of crops to help insure against drops in profit or utility that occur if the price for one crop is lower than average in a given year (Bromley and Chavas 1989). Farmers' cropping choices, degree of diversification, and allocation of land amongst different crops will be direct reflections of their weighing these diverse risks (Dorjee et al. 2007).

The types of risk and constraints the farmer faces are not just macroeconomic; they often take the form of limited availability of inputs, such as fertilizer, water, labor, or capital. Using diversification, farmers can respond to input-related risks by choosing to farm a combination of crops with different characteristics (i.e., crops that are more or less drought-resistant, or crops that are harvested in different seasons to mitigate labor risks). One of the most important types of input constraints and risks the farmer may face is labor or capital constraints and risks associated with harvesting. The labor and capital requirements for many agricultural crops vary seasonally and are often far higher at the time of harvest than at any other point in time during production. In the case where farmers are labor constrained and rely mainly on family labor, or require timely availability of costly, hired labor, farmers may diversify and grow several different crops for which the labor requirements peak at different points throughout the year so as to not leave fruit rotting on the tree or vegetables withering on the stalk (Musser and Patrick 2002).

Biological constraints or risks to production are also important drivers of diversification, and can contribute to both input and output risk. Limited water or nutrient availability may cause farmers to plant a mix of crops that minimize surface water runoff or that take advantage of the nitrogen fixing abilities of particular crops in order to restore the soil nutrient balance through practices such as crop rotation (e.g., corn and soybean rotations). Crop rotation also plays a major role in pest and disease control (see e.g., Kremen and Miles in this issue or El-Nazer and McCarl 1986). Although these biological factors favor crop rotation in many cases and contribute to the allocation of production of different crops over the landscape, land shares in different crops will still respond to prices and to new cultivation, irrigation, or harvesting technologies. In a similar way to crop rotation, integrated crop-with-livestock systems can harness biological synergies by meeting feed input needs for livestock (through crop silage) at the same time as the livestock provide necessary nutrients to crop agriculture (through manure). Pest pressures may also spur diversification by encouraging farmers to plant different varieties of crops, to intercrop on the landscape to encourage resilience to pests, or enhance biodiversity of agricultural systems as farmers adopt techniques such as integrated pest management (IPM) to deal with pest problems (Feder et al. 1985, Mahmoud and Shively 2004).

Yet another economic incentive for farmers to adopt DFS is the potential to market products grown in DFS as specialty goods that appeal to a growing contingent of consumers concerned about the impacts of their food choices on their health and on the health of the environment. With modern agribusiness has emerged a transition from the idea of producing commodities to producing differentiated products with particular attributes, such as being "local," "organic," "pesticide-free," or "sustainable," that are desirable to consumers (Boehlje 1999). This transition began in developed countries, and is now underway in the developing world (Rearden and Timmer 2012). While DFS may not always be strictly local or organic, the synergies between DFS production methods and many of these existing, marketable labels that consumers are familiar with imply that DFS producers might capture price premiums associated with these attributes in the marketplace (Raynolds 2004, Oberholtzer et al. 2005). Through different marketing channels such as community-supported agriculture (CSA), consumers can commit in advance to buy bundles of products, rather than a particular type of fruit or vegetable, as part of a weekly or bimonthly share of diverse and seasonal produce (Brown and Miller 2008). This particular model helps producers deal with potential output market risk.

Policies and regulations can be important drivers of adoption of different types of farming systems. For the past 25 years, scientists have warned of climate change and of the need for conservation in order to maintain the quantity and quality of natural resource stocks as global populations rise (Stern 2007). Though the implications of climate change at local, regional, and global scales are still uncertain, climate change will certainly have implications for the changing face of global agriculture (Rosenzweig and Parry 1994, Howden et al. 2007). Inherent in human-driven climate change is the role of fossil-fuel intensive practices and technologies. Agriculture that relies heavily upon mechanization, fossil-fuel inputs and clearing of new land is now acknowledged to be "costly" both from a greenhouse gas perspective as well as due to its consumption and degradation of land, water, and biodiversity resources (Robertson et al. 2000, Tomich et al. 2011). The role of modern agriculture and agricultural policies in contributing to nutrition deficits and obesity epidemics worldwide is also becoming an important concern, particularly for more developed countries (Cash et al. 2005, Alston et al. 2006) Thus, there is an important role for policies and regulations to drive a suite of initiatives that aim to internalize the environmental and health externalities associated with industrial agriculture.

These policies may include establishing and expanding existing public (nonmarket) payments for ecosystem services, or creating regulations that give rise to private markets that support biodiversity in agricultural landscapes. Above and beyond PES, there are three categories of policies that are likely to emerge in the next decade which may lend support to DFS: carbon tax or trading systems that penalize carbon-intensive agricultural or transportation practices; pollution control regulations that address pesticides, herbicides, animal waste, or agricultural runoff; and taxes or subsidies for producers and/or consumers that are designed to make consuming cheap calories (such as those from high-fructose corn syrup; see Cash et al. 2005) more expensive or consuming nutrient-rich foods cheaper in order to affect consumption patterns that contribute to global obesity epidemics and malnutrition.

Public and private payments for ecosystem services are a final important set of economic drivers that may support diversified farming systems. In the context of agriculture, payments for ecosystem services are usually payments to landowners for leaving high-value conservation land uncultivated or payments that arise from an understanding that a working agricultural landscape, while not an undisturbed ecosystem, can perform a diverse array of services that go above and beyond producing food (Randall 2002, Sandhu et al. 2008). These services include but are not limited to soil conservation and carbon sequestration through no-till agriculture or planting of hedgerows (Antle and Diagana 2003, Knowler and Bradshaw 2007), water conservation or quality improvement, and maintenance or conservation of biodiversity through practices such as active promotion of pollinators, intercropping to promote both plant and animal biodiversity, and establishing planting of native plant species (Babcock et al. 1996, DiFalco 2012). Above and beyond the multifunctionality or ecosystem service benefits provided by these practices, they can also generate indirect benefits for farmer well-being through nonpecuniary externalities such as improved health through reduced exposure to pesticides (Huang et al. 2003).

Public (nonmarket) payments for ecosystem services include examples of federal programs such as the Conservation Reserve Program (CRP) and EQIP (Environmental Quality Incentives Program) in the U.S., payments provided as part of Rural Farming Contracts in France, the 1999 Basic Law of Food Agriculture and Rural Areas in Japan (Smith 2006), the Grain-for-Green program in China (Uchida et al. 2009), and Costa Rica's PES programs for carbon sequestration via forestry, afforestation, forest conservation, and agroforestry (Montagnini and Nair 2004). Beyond PES schemes, other public incentives to adopt environmentally sustainable production methods can help farmers to offset the fixed costs of adopting a new technology; in 2006, the Northern Constitutional Finance Fund of Brazil (a federal credit institution) established the "Sustainable Amazon" credit line to fund sustainable agriculture and investment in sustainable infrastructure in the Amazon region of the country, and gave out more than 1 billion USD in loans during 2010 (Banco da Amazônia 2011). Subsidized credit and PES schemes acknowledge that there are positive externalities—including the ecosystem services being provided by agricultural landscapes or multifunctional landscapes—that are not being priced appropriately in a market context. In other words, these services have a net benefit to society, but there is no corresponding market income for the individual farmers providing such services, which constitutes a "market failure." Because society derives some benefit when the government steps in and establishes policies that encourage farmers to adopt management practices which generate ecosystem services, these types of public payments can be welfare-improving for farmers and society as a whole if done correctly (Just and Antle 1990, Randall 2002, Smith 2006, Swinton 2006).

Private payments for ecosystem services occur in a market context, and can arise from direct willingness to pay for ecosystem services (e.g., when a bottling company that relies on a high level of water quality in order to produce a quality product pays farmers to implement land management practices which reduce sedimentation in local waterways or reduce nitrate leaching into the groundwater), or via demand for mitigation or compensation activities mandated by regulation. In the United States, laws such Section 404 of the Clean Water Act of 1972 and Section 9 of the Endangered Species Act of 1973 require compensatory action if the statutes in the sections are not met. For example, in the case of the Endangered Species Act, the construction of a new office building in an area that is considered to be prime habitat for an endangered species requires the purchase of an offset of an equivalent unit of habitat within a designated compensation area (Sohn and Cohen 1996, Fox and Nino-Murcia 2005, Bowman 2011). Agricultural landscapes do not always naturally provide habitat for endangered species, but in some cases, plantings of native vegetation or committing to particular cropping mixes can turn an agricultural landscape into a multifunctional landscape that can serve as a species "bank" accompanied by credits to be sold in private markets. Biodiversity offset markets are emerging as a result of legislation in the United States, Brazil, Europe, and Canada (Burgin 2008).

To the extent that DFS by definition maintain ecosystem services critical to agricultural production, public and private PES schemes could provide economic benefits to DFS if there is private or public willingness to pay for ecosystem services being maintained through diversified farming methods. If DFS use fewer pesticides than conventional systems or incorporate other practices that improve surface or groundwater quality, there may be future willingness to pay on the part of municipal or state governments or water boards for improved water quality from DFS due to the associated human health benefits or reduced costs of water treatment. Similarly, if DFS maintain pollination services or other ecosystem services as part of a working agricultural landscape (i.e., support higher levels of bird biodiversity or provide soil conservation benefits), DFS may be able to obtain payments through PES programs.

ECONOMIC FACTORS THAT RUN COUNTER TO DIVERSIFICATION

Just as there are economic reasons for a farmer to diversify production in response to risk, biophysical or input constraints, or market conditions, there are many reasons it may be economically efficient for a farmer to specialize in the production of a particular crop. Throughout history, agro-climatic conditions have contributed to both diversification and specialization of agricultural production. Studies suggest that most regions employed diversified farming systems that concentrated on the production of a few key staples (e.g., rice, wheat, or barley) together with complementary fruit and vegetable crops and livestock production (for its flexibility, and for fertilizer production) (Timmer 1997, Diamond 1998). However, even in regions with a more diverse crop portfolio, such as the Mediterranean, there was some degree of specialization within subregions (e.g., Greece and olive oil; France and wine) due to trade. Today, technological innovation has made some factors that previously limited agricultural production (such as climatic or biological constraints to production) less relevant. Together with trade, these trends have magnified regional specialization. For example, in the Central Valley of California, water projects have effectively transformed vast deserts into a 3-season greenhouse for the rest of the country. In turn, California's carefully-constructed comparative advantage in fruit and vegetable production has meant that growers in other states struggle to compete in these markets if consumers value an array of product choice on the shelves over quality or location attributes (Timmer 1997). Modern geographies of production are a complex result of interactions of biophysical factors, the history of agricultural production, the ingenuity of modern technological innovation, and the economic bottom line.

Modernization of agriculture has led to more and more specialization for a number of key reasons. The introduction of synthetic fertilizers and chemicals decoupled the need for livestock waste as a complementary input to agricultural production. Economies of scale in the production, harvesting and processing of agricultural products have also contributed to this trend toward specialization and mechanization. Staple commodities were mechanized first because they were lower-value and therefore exhibited the largest gains for farmers of reductions in harvesting costs due to mechanization (Raup 1969, Rosset 1991, D'Souza and Ikerd 1996, Paul et al. 2004). The ability to store commodities also means that they can be sold and stored strategically according to current and expected market conditions. Among crops that are produced as monocultures, breeding of crops for a few key traits has also contributed to reduced genetic diversity and increased specialization (Heal et al. 2004). Increased opportunity costs of time for farmers and laborers (higher wages in industries other than agriculture) have led to increases in farm size to reduce labor costs (Kislev and Peterson 1991).

The consumer's desire to have an array of cheap produce available, no matter the season, and decreased long-distance transportation costs due to improved infrastructure have also had important implications for regional specialization. Even in markets where some consumers are demanding food that is produced more locally, sustainably, organically, and diversely, the high costs of certification and marketing (Hardesty and Leff 2010) and risks associated with pests commonly controlled by synthetic pesticides, in the case of organics or pesticide-free varieties, can make these varieties more expensive than conventional varieties, and make consumer demand (and therefore farmer revenues) unpredictable (Lohr and Salomonsson 2000, Regmi and Gehlhar 2005). Farmers marketing locally-grown food also face the challenges of transporting small volumes of goods to local markets (Pretty et al. 2005). Finally, variation in regional agricultural suitability and length of growing seasons mean that diverse, local production systems may not provide the same consistent product variety that consumers have become accustomed to. When large volumes of conventional produce varieties can be shipped cheaply and provide a consistent (if possibly inferior-tasting) product year-round, so long as consumers choose low prices over quality, specialization will thrive.

In addition to these economic factors that have driven specialized rather than diversified production, agricultural commodity programs have sustained the specialization of production of a few global agricultural commodities such as corn, rice and wheat, in some regions (Pingali and Rosegrant 1995). In the United States, such programs arose during the Great Depression as increasing yields of these globally-traded commodities (with mostly inelastic demand, or demand that varies little with an increase or decrease in price) contributed to falling prices and, in turn, reduced farm incomes. Although these programs are not directly responsible for increased specialization in the countries where they were implemented, they required production of program crops to receive program payments, and thereby disincentivized diversification. Furthermore, overproduction of commodity crops in countries where they were subsidized led to depressed global food prices, and adversely affected terms-of-trade for developing countries and—in-turn—likely affected their investment in domestic agricultural production as they began to import more food (Mellor 1988, Anderson 1992). In the last decade, commodity prices have increased and the initial logic behind commodity programs has become less relevant; farms are larger and incomes are higher than ever before in the developed countries (Gardner 1992). Even as commodity programs are slowly being eliminated, however, the emergence of crop insurance programs for commodity crops serves as an effective subsidy-in-disguise with questionable social welfare implications (Sproul 2010) and little-to-no benefit for DFS; O'Donoghue et al. (2009) showed that U.S. farmers responded to the 1994 Federal Crop Insurance Reform Act with increased specialization.

How, then, do these factors continue to affect the proliferation of diversified farming systems? Because DFS often employ intercropping or multicropping systems in order to take advantage of complementarities between crops, prevent soil erosion, and foster biodiversity, they are also less-easily mechanized and therefore are more labor-intensive than planting monocultures. In the same way, the use of chemical pesticides and fertilizers and GMOs is often cheaper than manual weeding or biological pest control or IPM technologies (Dobbs et al. 1988). In more developed countries where the costs of labor are high, in developing countries where labor markets are incomplete (i.e., where transactions costs of matching willing workers with employers are high) (Binswanger and Deininger 1997), and wherever local and regional labor shortages are a key limiting factor for agricultural production (as is becoming the case in the United States; see Devadoss and Luckstead 2008), farmers will require developments in precision agricultural technologies that allow for more efficient intercropping and planting on smaller scales if they are to adopt DFS systems. Although labor surpluses exist in developing countries and DFS may provide new opportunities for rural employment, there is a tradeoff between keeping labor costs low to make labor-intensive agricultural production economically viable, and retaining agricultural workers through higher incomes in order to compete with urban migration (Binswanger and Deininger 1997, Hu 2002). Because precision farming uses information technology to vary application of inputs by location, input use efficiency improves and is highly adaptable to bio-ecological conditions. The technology is expensive and faces many challenges in the development of new harvesting technologies and production management, but (in particular) the application of precision farming to harvesting technologies will be necessary if multicropping or intercropping is to become widespread in regions where mechanized monocultures prevail. In general, pest and input management techniques, harvesting technologies, and flexible physical capital that can be employed in diverse agricultural systems may help balance the increased labor requirements relative to other systems where labor costs are the most important factor limiting the profitability of DFS. Thus, though the productivity and sustainability of DFS may be high, the high labor costs and requirements associated with such systems are a major barrier to adoption.

The potential for DFS to cash in on public or private payments for ecosystem service schemes represents both a potentially significant economic benefit to such systems, as well as a great challenge. In spite of growth in emerging markets for PES in developed and developing countries, the degree to which PES will provide financial support for DFS is unclear. Valuation of the economic benefits associated with the ecosystem services provided via DFS production methods is still in its early stages, and even if ecosystem services are identified, questions remain: to whom are the services valuable...and how much are they willing to pay for them? Critically, even if demand for these ecosystem services exists on the part of consumers, governments, or private firms, the mechanisms and markets to make these exchanges work are still missing in many cases. Below, we discuss several key sticking points associated with linking PES to DFS, including: lack of research on and valuation of environmental services provided in DFS, transaction costs, heterogeneity in benefit provision and the costs of provision of benefits, landowner coordination problems associated with engaging in PES markets, and lukewarm political and financial support for publicly-funded PES programs.

Because DFS by definition focus on providing crucial ES for agricultural production (and therefore reducing costs associated with synthetic pesticides or fertilizers, waste treatment, or pollination services), identifying and quantifying WTP for ES beyond those critical to agricultural production at the single farm/single landowner level may be a key component in making these systems economically sustainable. Identifying the exact direct, indirect, or existence benefit provided by DFS methods is a first step, and combining rigorous evaluation of ES with evaluations of willingness to pay for these services is crucial (see Glebe 2007 for a discussion on the environmental benefits of agriculture in the European context). For example, in the case of pollination services, neighboring farmers may receive a direct benefit from increased production due to improved pollination from a landowner who maintains a healthy native bee community as part of a DFS (Brosi et al. 2008, Lonsdorf et al. 2009). Understanding the production functions associated with environmental services (e.g., how much one landowner maintaining a healthy native bee community contributes to other landowners' production) is absolutely critical to understanding how PES schemes will support DFS.

Knowing who benefits from what services is a starting point for rigorous economic research on the value of or WTP for environmental services from DFS, but even if we knew who benefited from DFS and how much, creating and adapting existing markets to correctly link provision of environmental services in DFS to existing WTP for such services is a challenge (Daily and Matson 2008). Tepid political and financial support for expansion of publicly-funded PES programs has limited the supply of such services, and privately-funded PES programs have been limited in large part to payments for watershed protection (Los Negros program in Bolivia, Pirampiro in Ecuador), payments for improvements in water quality (Nestlé-sponsored Vittel in France), and payments for carbon sequestration (Wunder et al. 2008). Finally, the transactions costs for farmers to enter into existing PES schemes as well as for private or public entities to develop new PES schemes are often quite high (Bulte et al. 2008, Engel et al. 2008).

Finally, in many cases, the level and costs of provision of environmental services (ES) at the local or regional scale are heterogeneous (Antle et al. 2003, Engel et al. 2008), as well as in some cases dependent upon the coordinated actions of a large group of landowners (e.g., water quality, regional biodiversity) (Parkhurst and Shogren 2007, Drechsler et al. 2010). In most cases, heterogeneity in the marginal cost of provision of benefits makes PES a more economically-efficient and lower-cost mechanism for providing environmental services than less flexible policy alternatives, such as command-and-control regulation (Engel et al. 2008, Wünscher et al. 2008). Heterogeneity in the marginal benefit of provision of ES, in contrast, makes designing efficient and effective PES schemes more complicated. Consider the case where habitat for an endangered species the ES to be provided. In this case, benefits only exist above and beyond the conservation of a critical (and sometimes contiguous) area of habitat, and the marginal benefit of conserving a unit of habitat will depend upon the location of the property, as well as upon the total amount of existing suitable habitat. In cases such as this, targeting PES schemes for optimal ES provision is complex and costly (Babcock et al. 1997, Wu et al. 2001, Claassen et al. 2008), and there is a tradeoff between making programs more context-specific and efficient, and costs of implementation (Jack et al. 2008). Designing and expanding such programs will require public and private funding for research, program implementation, enforcement and monitoring, as well as funding for outreach and extension that minimize the costs to farmers of engaging with PES mechanisms.

Providing ES via landowner coordination is a special case where the marginal benefit of providing an environmental service is not constant. Almost all existing PES programs pay landowners to engage in behaviors or management practices on their property, and pay landowners independent of what other landowners in the region are doing. The provision of many environmental services, however, occurs at scales larger than that of the property boundary. Goldman et al. (2007) discuss three examples of types of benefits for which landowner coordination and landscape-level coordination for provision of benefits are critical: pollination services, hydrologic services, and carbon sequestration. Despite a number of papers that make the theoretical case for programs such as “cooperation bonus” programs that take this into account (Parkhurst et al. 2002, Shogren et al. 2003, Parkhurst and Shogren 2007), they are largely absent in practice. This is, in part, due to high transactions costs which increase with the number of landowners (Jack et al. 2008).

CONCLUSIONS

The expansion and adoption of DFS is limited by a number of factors, including still-limited demand for products produced via DFS, supply-side constraints such as high costs of tilling or harvest in multiple crop systems, and policies such as subsidies and crop insurance which discourage diversification. The supply-side constraints to adopting DFS such as high costs of tilling or harvest in multiple crop systems, pest damage or disease in crops where current alternative pest management strategies are costly or have little impact (Zilberman et al. 1991, National Research Council 2000), and limited supply channels and capacity for storage of diversified products. One key innovation that will be necessary to improve the productivity of DFS is the introduction and adoption of technologies that reduce the costs of harvesting in diversified systems, and the adoption of precision agriculture that helps farmers manage and optimize input allocation in multiple crop systems. These technologies are costly, however, and the development of innovative low-cost, practical strategies that reduce the costs of production in DFS in the developing world will be necessary if they are to become widespread.

Importantly, public investment in research and development for such technologies, in expanding the markets for ecosystem services and products from DFS systems, and in educating and spreading awareness about the benefits of DFS is justified and necessary; DFS provide important public goods, and public funding will be necessary if they are to become a profitable choice for farmers and a central part of global agriculture in the future. Finally, regional or global market-based incentives that incorporate the social costs of industrial agricultural models could help tip the balance toward diversified production models. Beyond carbon regulation, more stringent regulation of agricultural runoff, agricultural water use, pesticide safety, and water quality will have significant impacts on the face of agricultural production in the developing and developed world; to the extent that DFS rely less on fertilizer and pesticide application and inefficient water use and work to control soil erosion and runoff, these systems may be better positioned than other forms of agriculture to comply with evolving regulations, and at lower cost.

In summary, we envision several paths to overcoming the sticking points to the expansion of DFS. First, in order for consumers to be willing to pay for products produced in DFS, there is a need for education and public awareness campaigns that lay out the ecological benefits of DFS and the establishment of new market channels for consumers to gain access to products produced in DFS. Public incentives also need to align to provide support for DFS; this will require establishment and expansion of PES programs that pay farmers for the production of environmental benefits produced via DFS, as well as the substantial redirection of funds currently allocated toward subsidies and crop insurance toward PES programs, incentives for improved nutrition, and funding for research and development of technologies that can be applied in diversified systems.

Responses to this article can be read online at:
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