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Nexus between Food, Energy and Ecosystem Services in the Mississippi River Basin: Policy Implications and Challenges

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One of the great challenges for the US Corn Belt is increasing the productivity of food and fuel production while reducing nutrient runoff, which is a key contributor to hypoxia in the Gulf of Mexico. The Mississippi–Atchafalya River Basin (MARB) drains about 41% of the conterminous United States and includes the Corn Belt, which is one of the most productive farming regions in the world. The hypoxic zone in the Gulf is the second largest in the world; in the summer of 2017 it was equal in size to the state of New Jersey, the largest extent ever recorded. Excess nutrient run-off generated by tillage and fertilizer-intensive agricultural and livestock production in the MARB is estimated to contribute about 80% of dissolved inorganic nitrogen (N) and more than 60% of delivered phosphorus (P) in the Gulf of Mexico (White et al., 2014). The U.S. Environmental Protection Agency (2007) estimates that a 45% reduction in both N and P loadings from the MARB relative to the 1980–1996 average annual level is needed to achieve desired reductions in the size of the hypoxic zone.

Ribaudo, Livingston, and Williamson (2012) show that, despite improvements, about 66% of corn acreage does not achieve the rate, timing, and method criteria that minimize environmental losses of nitrogen. Moreover, nutrients are typically applied at a uniform rate across spatially heterogeneous soil types and land quality, resulting in some areas having insufficient nutrients and others too much, where the excess is lost as run-off (Zilberman, Khanna, and Lipper, 1997). Determining the optimal mix of alternative nutrient management practices and the locations where they should be adopted is complicated by spatial heterogeneity in the agricultural landscape, asymmetric information about the costs of adoption, and uncertainty about the effect of climatic and biophysical factors in determining the environmental implications of adoption.

While much of the focus in the MARB has been on water quality, agricultural production in the region also impacts other ecosystem services, including greenhouse gas emissions and habitat for birds, pollinators, and natural enemies of agricultural pests. It is estimated that the application of conventional tillage practices after 1900 led to the loss of over half of the soil carbon stocks in agricultural soils in the US Corn Belt by mid-century (Matson et al., 1997; Parton et al., 2015). Tillage and rotation practices also affect biodiversity-related ecosystem services (McLaughlin and Mineau, 1995). Agricultural production is a source of greenhouse gas emissions from livestock production, direct energy and fertilizer use. Agriculture can also contribute to mitigating emissions from other sectors (particularly, the energy-intensive transportation and electricity-generating sectors). By providing bioenergy, agricultural production can enable the displacement of fossil fuels and offset carbon emissions by sequestering carbon in soil through plant growth. The choice of crops, rotation, and tillage practices and the soil and climatic conditions where they are adopted can influence the carbon intensity of the bioenergy generated, net carbon emissions, biodiversity, and habitat.

Bioenergy production in the region has primarily been in the form of corn ethanol, induced by the 2007 Renewable Fuel Standard (RFS). Acreage under corn has expanded as the share of corn diverted from food to biofuel production has grown to over 40%. Studies using satellite data show that grasslands in the vicinity of corn ethanol plants have declined due to the expansion of cropland acreage since 2007 (Wright et al., 2017).The direct carbon intensity of corn ethanol is lower than that of gasoline (Wang et al. 2012), However corn production is both fertilizer and tillage intensive and studies show that corn ethanol expansion has contributed to worsening the dead zone in the Gulf of Mexico (Donner et al., 2002; Hendricks et al., 2014). With land being used for both food and fuel production in the MARB, it is important to consider the optimal allocation of land among food and fuel crops as well as alternative management practices that can meet demands while protecting multiple ecosystem services in the region.

A number of practices and crops have been identified that can meet demands for food and fuel while controlling surface water runoff and erosion, reducing nutrient losses, and mitigating greenhouse gas emissions. These include conservation tillage; changes in nutrient application timing, rate, method, and form; and crop diversification (e.g., adding crop rotations, cover crops, and perennials) (Khanna and Zilberman, 1997; McIsaac et al., 2001; Friedrich, Derpsch, and Kassam, 2012). Precision farming technologies enable farmers to capture spatially referenced data about nutrient content and soil quality in the field and use computerized equipment that is precisely controlled by satellites to apply the right treatment in the right place at the right time. Emerging information-based technologies and "big" data can bring data from multiple sources to enable farmers to improve decision making and to manage multiple input applications according to in-field variations in production conditions. Other practices such as conservation tillage and cover crops can increase soil carbon sequestration and reduce run-off. The effects of these practices on input use, crop yields, and returns to land are site-specific (Khanna, Epouhe, and Hornbaker, 1999; Khanna, 2001; Khanna, Isik, and Zilberman, 2002).

Perennial grasses or energy crops, like miscanthus and switchgrass, are a promising feedstock for meeting the advanced biofuel component of the RFS. They have high yield per unit of land and large root systems that result in reduced soil erosion and run-off and significant amounts of soil carbon sequestration (Khanna et al., 2011; Housh, Khanna, and Cai, 2015; Vanloocke et al., 2017). Their yield and potential to sequester carbon in the soil differ across location and across different types of perennial energy crops. They also have the potential to substantially reduce the carbon intensity of transportation fuel. Dwivedi et al. (2015) estimate carbon savings of 130%–156% from miscanthus-based ethanol and of 97%–135% from switchgrass compared to gasoline, depending on location and soil quality, which influence crop yields and soil carbon sequestration levels. However, producing energy-crop-based biofuels is significantly more expensive than gasoline and unlikely to occur in the absence of significant policy incentives.

In general, the costs and ecosystem benefits of adopting conservation practices are site-specific due to the heterogeneity in growing conditions, soil quality, topography, and distance from water bodies. The optimal mix of practices therefore needs to vary spatially to maximize environmental benefits at least cost. Requiring all areas to reduce nitrate run-off or greenhouse gas emissions uniformly in the MARB would not be the most efficient strategy because not all areas contribute equally to the environmental outcome or have the same cost of abatement. Spatially varying the extent and mix of conservation practices adopted within and across watersheds can significantly lower the costs of soil carbon sequestration and reducing nutrient and sediment run-off (Rabotyagov et al. 2014a). Similarly, cost-effective locations for energy crop production vary across the region due to spatial differences in crop yields, soil carbon sequestration potential, and costs of converting land to these crops (Khanna et al., 2011; Chen, Huang, and Khanna, 2012).

However, even the lowest-cost strategy for achieving the hypoxia goal is estimated to cost approximately $2.7 billion per year in terms of lost profitability and will require implementing improved practices on about 18% of MARB cropland (Rabotyagov et al. 2014a). Housh, Khanna, and Cai (2015) estimate that converting 11% of cropland from corn and soybeans to perennial energy crop miscanthus in the Sangamon watershed in Illinois could reduce nitrate run-off by 9% at a cost of $95–$130 million dollars annually; this cost includes the loss in returns to farmers from converting land from its most profitable use and the costs of establishing cellulosic refineries to convert miscanthus to biofuel. Other studies show that fairly large-scale conversion of land would be needed to achieve relatively modest reduction in nitrate loadings; converting 40% of the corn acreage currently devoted to ethanol production in the MARB to miscanthus or switchgrass could reduce nitrate run-off by 5%–15% (VanLoocke et al., 2017). However, it is important to recognize that some of these practices also provide other environmental co-benefits, such as greenhouse gas mitigation. Housh et al. (2015) show that while converting 11% of cropland from corn (and corn ethanol) to miscanthus (and miscanthus-based ethanol) in the Sangamon watershed would reduce nitrate run-off by 9%, it would also reduce carbon emissions (through soil carbon sequestration and gasoline displacement) by over 35% relative to a baseline level with only corn ethanol. Using land to produce energy crops that displace coal would result in even larger greenhouse gas reductions. Khanna et al. (2011) find that converting less than 2% of Illinois cropland to bioenergy crops could provide bioelectricity to reduce carbon emissions from coal-fired power plants in Illinois by 11%.

Adopting alternative practices and perennial crops in some regions can occur voluntarily because it increases farm profitability (Khanna and Zilberman, 1997) or provides diversification benefits that reduce the riskiness of crop production (Miao and Khanna, 2017). Even without any government subsidy, an average of over 36% of U.S. acres are under conservation tillage (Conservation Technology Information Center, 2012). However, policy incentives are likely needed to induce a large-scale switch toward environmentally sustainable crops and crop production practices that can increase risks or impose irreversible sunk costs with uncertain returns (Song, Zhao, and Swinton, 2011; Skevas et al, 2016). Conservation programs seek to directly incentivize the adoption of environmentally friendly farm management practices (best management practices) by providing financial incentives. Other farm policies and energy policies can also influence incentives for adoption.

Evidence on the performance and cost-effectiveness of existing policies in achieving environmental outcomes is mixed. Conservation programs, such as the Environmental Quality Incentives Program (EQIP), provide incentives payments that are typically uniform across the landscape and are based on adopted practices rather than environmental performance outcomes; they are thus not well targeted to achieve specific environmental outcomes. These efforts are likely to be inefficient and costly because they do not recognize the differences in environmental impacts of the same set of practices due to differences in location, topography, weather, and soil conditions (Khanna and Farnsworth, 2006). A recent report from the U.S. Government Accountability Office (2017) notes the inefficiency of EQIP due to lack of information to target EQIP funds to optimize environmental benefits and to ensure that it funds the most cost-effective applications.

Conservation programs to induce environmentally friendly practices on enrolled land also run the risk of leakage or slippage as landowners expand production using conventional practices on other acres not enrolled in the program (Wu, 2000). Indirect land-use changes induced by an increase in crop prices due to diversion of corn to corn ethanol has the potential to lead to expansion of crop acreage and loss of carbon stored in soils and vegetation on grasslands and forestlands; this can erode the direct benefits in terms of greenhouse gas savings due to displacement of gasoline by biofuels (Fargione et al., 2008; Searchinger et al., 2008). Another concern with conservation programs is the lack of permanence of their environmental benefits (such as soil carbon sequestration). For example, land exiting the Conservation Research Program in response to high crop prices and converted to conventional crop production is estimated to lead to a large loss of stored carbon (Gelfand et al., 2011).

Farm programs such as subsidized crop insurance, designed to reduce the riskiness of agricultural income, can also affect input use and crop choices that have environmental consequences. Crop insurance can affect the use of inputs such as fertilizer and pesticides; the direction of these effects could be positive or negative. By reducing the need for risk-reducing inputs, crop insurance can reduce the amount of fertilizer and pesticide applications; however, by shifting acreage away from uninsured land uses like hay and pasture to insured crops like corn, crop insurance can also increase chemical use (Weber, Key, and O'Donoghue, 2016). Miao and Khanna (2017) show that the availability of subsidized crop insurance for conventional crops raises the returns to land needed to convert it to energy crop production.

Additionally, renewable energy policies can affect crop choices in ways that are synergistic or conflicting with an environmental outcome. Producing ethanol from corn may mitigate greenhouse gas emissions by displacing gasoline but could increase acreage under corn and nutrient run-off. Excessive removal of corn stover for cellulosic biofuel production can lower soil carbon stocks but lead to overall mitigation of carbon emissions by displacing gasoline. Its impact on nitrate run-off could be positive or negative since sediment run-off could increase but nitrate leaching could decrease. Other choices could lead to complementary benefits, such as cellulosic biofuels and reduced nutrient run-off (Dwivedi et al., 2015; Housh et al., 2015; Vanloocke et al., 2017).

However, farm and energy policies are fairly blunt instruments for achieving conservation and can sometimes involve trade-offs between ecosystem impacts, as in the case of corn ethanol policy. Similarly, the cellulosic biofuel component of the RFS considers all cellulosic feedstocks that lead to biofuel that is 60% less carbon intensive than gasoline as being compliant with the standard. It does not distinguish among feedstocks such as corn stover, which may worsen water quality, and energy crops that improve water quality. It also does not incentivize the production of feedstocks that may achieve higher greenhouse gas savings than the 60% threshold if they are more costly to produce.

Implications and Challenges for Conservation Policy

Studies show that the least-cost approach to achieving environmental targets beyond those achieved voluntarily or due to existing energy and farm policies would be performance-based incentives, such as a nitrate tax to reduce nitrate run-off or a carbon tax to reduce greenhouse gas emissions (Housh et al., 2015; Housh, Khanna, and Cai, 2015). These policies are better targeted to the sources of pollution, provide incentives related to environmental outcomes, and induce the most cost-effective options for pollution abatement. To prevent leakage, the coverage of these policies needs to be at an appropriate geographical scale. Alternatively, developing markets for trading pollution credits between point and non-point pollution sources could also incentivize the adoption of conservation practices. Several challenges arise in implementing this least-cost approach.

First, the non-point nature of these environmental impacts makes it particularly challenging to observe, monitor, and ascribe responsibility for nitrate run-off or soil carbon sequestration to fields/farmers. Targeting of policy incentives to the source of run-off is difficult to implement due to the absence of information and data needed to identify the sources of pollution and to measure their contribution to the pollution generated. These difficulties also arise due to the diffuse nature of the discharges, the heterogeneity in the links between input use and polluting discharges, the large land area over which discharges are transported before affecting water bodies, the effect of climatic and biophysical factors in determining the magnitude of the pollution, and difficulties in monitoring and measuring discharges. Moreover, the extent to which discharges from one land parcel impact a water body depend not only on management decisions on that parcel but also on those on upstream and downstream parcels. Efficiently designed policy incentives need to be spatially differentiated and targeted to specific land parcels rather than uniform across the landscape. Given the nature of nonpoint pollution, efficient policy design also requires that these incentives should be related to environmental performance outcomes and the marginal costs to farmers of reducing those impacts.

Second, agricultural production can impact multiple environmental services at the same time, improving some while worsening others, necessitating the consideration of trade-offs and synergies among environmental outcomes. When multiple environmental services arise jointly from the same acre of land, a single policy instrument may achieve more than one objective. Multiple policy instruments designed in isolation of consideration of multiple jointly determined ecosystem impacts of an activity could result in farmers obtaining multiple environmental credits/payments for the same activity. This has led to concerns about the possibility for credit stacking or “double dipping” by farmers who could receive compensation for providing many environmental services from the same activity on a parcel of land. However, determining “additionality” or credits generated for providing an ecosystem service beyond the level required for compliance in one environmental market is complicated and requires understanding of the complementarities and substitutability in the provision of these various environmental services.

Third, determining the optimal level of the nitrate tax or carbon tax needed to induce the adoption of practices needed to achieve desired environmental outcomes in the aggregate requires deeper understanding of the behavioral factors that influence technology adoption decisions by farmers. Conservation practices often impose upfront costs of equipment, machinery, and establishment and can increase or decrease the riskiness of crop yields. These factors can be major deterrents to converting land from annual crops to perennials. Perennials impose high establishment costs that have to be borne upfront if farmers are unable to obtain credit. Furthermore, perennial energy crops have a lifespan of 10–15 years and require a long-term commitment of land to the crop. They require 1–3 years for establishment, during which a farmer would incur fixed cost of establishing these crops and forgo returns that could have been earned under alternative use of that land (such as growing conventional crops). Without the access to subsidized crop insurance that is typically available for conventional crops, perennial crop production also involves risks that may differ from those associated with conventional annual crops. These may be higher than the risks of growing conventional crops in some areas and lower in other areas (see Miao and Khanna, 2014, 2017; Skevas et al., 2016).

The decision to convert land from existing uses to a perennial energy crop will therefore depend on location and farmers' risk and time preferences, the riskiness of alternative crops, and correlation among those risks as well as the presence of credit constraints and crop insurance. Studies suggest that farmers tend to be more risk averse than non-farm business owners and that their discount rates can be as high as 40% (Khanna et al., 2017; Miao and Khanna, 2017; Khanna, Louviere, and Yang, 2017). High degree of risk aversion and high discount rate, together with a constraint on credit, can raise the returns that farmers need or the penalties that need to be imposed to induce them to switch to a conservation practice. Policies that reduce upfront costs of adoption, such as establishment cost share subsidies, and those that reduce the risks associated with adoption may be more effective than per unit subsidies/taxes for pollution reduction/generation.

Directions for Future Research to Inform Conservation Policy

The use of land for food and fuel production in the MARB has multiple and heterogeneous impacts on ecosystem services. The optimal allocation of this land among alternative crops and cropping practices to meet growing demands while protecting the environment cost-effectively requires spatially targeted policy incentives. The non-point nature of agricultural pollution as well as informational asymmetries between policy-makers and farmers make it challenging to identify the sources of environmental impacts since they can be related to production technologies or natural conditions. The presence of private information among farmers that is not available or verifiable by regulators can lead to moral hazard and adverse selection, which limit the ability of regulators to design targeted site-specific policies. Emerging advances in information and computing technologies coupled with ability to capture, store, and analyze massive volumes of data from millions of acres of cropland have the capacity to provide site-specific information about production decisions, environmental conditions, crop varieties, and yields. This "big" data coupled with modeling tools can enable analysts to quantify the environmental impacts of agricultural production activities. Future research is needed to determine how this capability can be used to guide science-based agro-environmental policy that has been constrained by the lack of data on farm management decisions.

Integrated biophysical and economic models offer the capability for quantifying the impact of land use choices on multiple ecosystem services at a fine spatial resolution, particularly when combined with the increasing availability of publically available remote sensing data on soil quality, land use, crop yields, and weather information. These integrated approaches can be used to determine whether a single or multiple policies are needed to optimally address multiple jointly determined externalities and how to design these policies to avoid redundancies, conflicting incentives, and unintended consequences. Models can also be used to determine additionally of environmental impact relative to a counter-factual baseline and site-specific contributions. However, using model-based outcomes for environmental regulation can be challenging for technical and practical reasons. A few studies have illustrated approaches for translating complex model outcomes to approximate biophysical relationships between observable decisions and unobservable environmental outcomes and using them to develop pragmatic approaches to implement performance-based policies (Yang, Khanna, and Farnsworth, 2005; Rabotyagov et al., 2014b). More research is needed to examine the performance of such approaches and to extend them to address multiple jointly produced ecosystem impacts of agricultural production decisions.

Lastly, behavioral economic approaches can be used to provide information on the role of economic and non-economic considerations that affect technology adoption decisions. These can indicate the extent to which the standard prescription for pricing externalities will be effective and the role that nudges, information provision, technical assistance, and risk mitigation can play in achieving desired outcomes cost-effectively. Further research is needed to understand how the effect of risk and loss aversion, time preferences, social and peer pressure, inattention, and search costs on conservation and land management choices can guide the design of conservation policies.

For More Information

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