COMMUNITY ESSAY

Seeking a dialogue: a targeted technology for sustainable agricultural systems in the American Corn Belt

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This Community Essay aims to start a dialogue on the role of targeted environmental technologies in “sustainable agriculture.” Using the new water-quality technology of denitrification bioreactors as a specific example, we focus on the question: are edge-of-field technologies such as bioreactors simply band-aid approaches to sustainable agriculture? Or can they be part of a comprehensive paradigm shift? Denitrification bioreactors are a novel approach for reducing the amount of nitrate in on-farm agricultural drainage, a pollutant that has caused water-quality concerns at both local and national scales. We first address whether or not denitrification bioreactors might qualify singularly as a “sustainable technology” within the conceptual continuum of weak to strong sustainability. Then we introduce a broader perspective on the potential role that targeted technologies might play in multifunctional agricultural landscapes. We suggest that denitrification bioreactors are one technology that can, in a small way, mediate a shift in agrarian paradigms. A transition toward sustainability is a long and gradual process requiring the incorporation of a wide range of approaches including targeted technologies and multifunctional landscapes. While the issues presented here are hardly exhaustive, it is our hope that this commentary spurs broader dialogue within the sustainable agriculture community about the role of technology in the future of agriculture. We are seeking to encourage broader philosophical reflection on work being done in the name of a sustainable agriculture.

Introduction

The current Corn Belt landscape of the United States developed over several generations due to a multitude of factors including technological advances, demographic trends, regional shifts in production goals, economic and policy stimuli, and cultural heritage (Hurt, 2002). Today’s resulting Midwestern landscape is characterized as being a highly complex, socially constructed mosaic of intensive land uses constrained by ecological, technological, and economic capacity (Nassauer et al. 2002). It is clear that the current intensive model of agriculture, while highly productive in terms of economically important crop commodities, is also known to have pervasive impacts on patterns and processes essential to ecosystem function and therefore agricultural productivity and environmental quality (Tilman et al. 2002; Robertson & Swinton, 2005; Dale & Polasky, 2007). Further, many consequences of ecosystem impairment are subsequently passed on to society as costly negative externalities that are increasingly being experienced at multiple spatial and temporal scales (Tegtmeier & Duffy, 2004).

This state of affairs will likely push twenty-first century American agricultural policy toward the promotion of multifunctional landscapes (Ruhl et al. 2007), that is, economically viable landscapes that jointly produce increased quantities of ecosystem goods (e.g., food, fiber, and fuel) and broader arrays of environmental services that control negative externalities, enhance productive capacity, and provide numerous ecosystem benefits (Boody et al. 2005; Jordan & Warner, 2010). Generating, enhancing, and/or maintaining ecosystem services across landscapes is integral to any sustainable agriculture paradigm and will increasingly be viewed as a primary component of operationalized sustainability (Selman, 2008; Taylor-Lovell & Johnston, 2009). Nevertheless, farmers are significantly challenged to find a balance that fulfills their shorter-term production goals and longer-term stewardship interests (Chouinard et al. 2008). In short, the future of agriculture is a very complex socioecological issue with much at stake for farmers, consumers, and the environment.

Arguments and concerns about a sustainable future for Corn Belt agriculture in the United States have been framed from a number of overlapping,
systemic perspectives (e.g., Bell et al. 2004; Flora & Flora, 2007; Nassauer et al. 2007). To channel the discussion and start a dialogue, this essay purposely chooses one angle on which we, as an agricultural engineer and a natural resource economist, have unique, pointed perspectives: agro-environmental quality and the role of environmental technology in a “sustainable agriculture.”

In the agricultural domain, it is easier to recognize what is clearly not a sustainable condition than to identify what is; as such, a key point in closing a sustainability gap is to eliminate or mitigate the offending state of affairs (Boron & Murray, 2004). In the American Midwest, a key environmental indicator of declining Corn Belt sustainability is the acute deterioration of water quality due to nutrient and sediment loading, which has created cascading negative effects across multiple scales (Helmers et al. 2007). Expensive local drinking-water treatment, combined with national concerns about hypoxia in the Gulf of Mexico, means that the prime source for this nutrient pollution, Corn Belt agricultural drainage, needs to be a major starting point for addressing environmental sustainability (Goolsby & Battaglin, 2000; McMullen, 2001). Moreover, the timing is critical for addressing these agro-environmental issues as the 2008 Gulf Hypoxic Zone was the second largest on record and the 2009 zone was unusually severe in certain locations (USEPA, 2011). This hypoxia is one of the United States’ largest water-quality concerns; the resulting death of aquatic organisms represents a severe disruption of ecosystem function as well as lost economic opportunity for the Gulf’s associated aquatic industries.

The Role of Technology

In response, agricultural scientists have amplified their calls for the increased role of technology in sustaining agriculture and the environment (e.g., Aldy et al. 1998; Tilman et al. 2002; Secchi et al. 2008). Recent research regarding on-farm options for water-quality improvement has led to new ideas such as denitrification bioreactors for nitrate removal from agricultural drainage (Jaynes et al. 2008; Christianson et al. 2009; Woli et al. 2010).

Denitrification bioreactors are an innovative technology that maximizes the natural process of denitrification, a conversion of problematic nitrate to comparatively benign nitrogen gas by native soil bacteria. Denitrification technologies were originally used to treat nitrate pollution in groundwater in the 1990s (Schipper & Vojvodic-Vukovic, 1998), and this idea has now proven promising to treat agricultural drainage waters (van Driel et al. 2006; Schipper et al. 2010). In the case of agricultural drainage, a pipe that receives drainage water from between 8–20 hectares (ha) (20–50 acres) is intersected with a trench filled with woodchips (e.g., 3–6 meters wide and 30 meters long or approximately 10–20 feet wide x 100 feet long). Beneficial bacteria colonize the woodchips and use them as their carbon source (i.e., food) to provide energy for nitrate conversion as the nitrate-laden drainage waters flow by. This nitrate-mitigation strategy is promising for the American Corn Belt, reducing nitrate concentrations by over half and even as high as 99% depending upon a number of environmental factors such as flow rate and temperature as well as bioreactor design (Jaynes et al. 2008; Woli et al. 2010). In terms of nitrate-load reduction (i.e., considering volume of water treated in addition to nitrate-concentration changes), bioreactors may remove 33–55% of the total nitrate amount that would otherwise have gone downstream (Jaynes et al. 2008; Woli et al. 2010). After the upfront installation cost, to which governmental cost-sharing may apply, comparatively little maintenance cost or time is required over a life of at least ten years (Schipper et al. 2010).

Though denitrification bioreactors for agricultural drainage are still a new idea, a handful are operational in Iowa, Illinois, Minnesota, and Canada (van Driel et al. 2006; Christianson et al. 2009; Willette, 2010; Woli et al. 2010). To date, most installations have been via private groups (e.g., watershed associations, commodity groups) or research organizations (e.g., universities, United States Department of Agriculture’s Agricultural Research Service), though researchers think that eventually individual landowners will instigate installations. With “field-scale” treatment areas, bioreactors do not treat wide swaths of land but are ideal for individual Midwestern drainage systems. Bioreactors can be incorporated into existing conservation practices such as grassed buffers (Christianson et al. 2009), and their “edge-of-field” treatment means that they are minimally affected by variable in-field practices (e.g., no-till, fertilizer management, increased cropping due to demand for biofuel feedstock). Additionally, once installed, this technology has very low external energy requirements; as drainage water flows through the woodchips, the bacteria do the work. However, beyond the standard applied research questions regarding pollution-removal effectiveness and cost, critics have brought up a broader, equally important question: are edge-of-field technologies such as bioreactors simply physical and metaphorical band-aid approaches

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1 Though no denitrification bioreactors treating drainage waters have yet failed due to woodchip exhaustion, it is thought that utilized woodchips would be removed and the excavation refilled with new chips if treatment was to continue.
treat problematic symptoms rather than addressing the sustainability of agriculture as a whole?

This is not a new question, as Allen et al. (1991) expressed concern that many technological approaches to agricultural sustainability seem to accept the current industrial evolutionary path of crop production as given. The concern that certain technologies seek “sustainable” approaches to “conventional” production paradigms suggests that such strategies may simply delay the inevitable collapse of an inherently unsustainable model. More recently, an article in the online journal *Grist* challenged bioreactors specifically by pondering why Midwestern researchers were pursuing denitrification-bioreactor research, as the technology “fall(s) flat when you realize it’s just a technical fix for the status quo of over-fertilized conventional commodity crops” (Hoffner, 2009).

We readily acknowledge that such concern is valid. However, we advance several reasons why technologies such as bioreactors do have a place in a sustainable agriculture. Further, arguments framed by concern regarding “techno-fixes” at the scale of individual technology (e.g., bioreactors) are likely too narrow in contextual scope and should be couched more broadly to examine a specific technology’s role in a sustainable, multifunctional agriculture.

**Denitrification Bioreactors—To What Side Of Sustainability Do They Lean?**

To give our discussion credence in the sustainability realm, we first address whether or not denitrification bioreactors might qualify singularly as a “sustainable technology” within the conceptual continuum of weak to strong sustainability (Turner, 1993). We then introduce a wider perspective on the role that bioreactors might play in agricultural landscapes. While the issues presented here are hardly exhaustive, it is our hope that this commentary spurs a broader dialogue within the sustainable agriculture community about technology’s role (in general, as well as specific to bioreactors) and to encourage broader philosophical reflection on various approaches to sustainable agriculture.

The notion of weak or strong sustainability seems a reasonable place to start in philosophically evaluating a particular technological approach to mitigating agricultural externalities. To a large extent, the distinction between weak and strong sustainability is the degree to which human-made capital can substitute for natural capital (in this case natural process). Table 1 articulates philosophical distinctions as described by Turner (1993) on a progressive continuum of “very weak” to “very strong” sustainability across different perspectives on resource use, substitutability, and economic growth. Agricultural

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Furthermore, while conventional agriculture often has path-dependent challenges (e.g., existing capital investment involving fixed costs often makes significant farm-scale change difficult), the use of the types of technologies discussed here is generally not limited by such barriers. That is, while a farmer’s use of technology such as a bioreactor may involve a new personal perspective on environmental management, Table 1 Spectrum of Overlapping Sustainability Positions (Adapted from Turner, 1993) with rationalizations of bioreactor “weak” to “strong” sustainability.

| Row Description | Very Weak | Weak | Strong | Very strong |
|------------------|-----------|------|--------|-------------|
| General perspective of position | Anthropocentric and utilitarian | Anthropocentric and utilitarian | Ecosystems perspective | Bioethical and eco-centric |
| The context of water-quality improvements associated with the use of bioreactors is clearly anthropocentric and its application is utilitarian in nature; nevertheless, these systems enhance naturally occurring biotic and abiotic interactive processes at localized scales. |
| Perspective on resource use | Resource exploitive | Resource conservationist | Resource preservationist | Extreme resource preservationist |
| Improved water quality brought about through bioreactor implementation is not exploitative of water resources. |
| Perspective on resource valuation and value timing | Natural resources are to be used at economically optimal rates. Market-based valuation is the only appropriate economic measure. The economy functions to satisfy private property rights and consumer values. Focused on current generation. | Recognizes concern for the distribution of costs and benefits within current generations as well as intergenerationally. | Interests of the human and ecosystem collective given more weight than those of the individual property owner. | Recognizes intrinsic value in nonhuman living organisms and critical abiotic requirements. |
| Valuing water quality as it affects downstream conditions (e.g., fishers in the Gulf Coast) speaks of valuing the collective. The land draining into a bioreactor may or may not be used at an economically driven rate (most likely so, though bioreactors can be used for diversified systems). Intergenerational concerns cannot be addressed with a given, individual bioreactor as the technology has a life span within one generation. However, an agricultural system that actively internalizes externalities (regardless of approach) could, arguably, be on a path that spans generations. |
| Perspectives on resource fungibility | Infinite substitution possible between natural and human-made capital; continued well-being assured through economic growth and technological innovation | Rejection of infinite substitution between natural and human-made capital; recognition of some aspects of the natural world as critical capital with regard to maximizing human welfare (e.g., some ecological functionality cannot be adequately substituted for with technology). | Recognizes primary value of maintaining functional integrity of ecosystems over and above secondary value through human-resource utilization. | Strongly influenced by the “rights” of nature, including abiotic elements that are critical to a system. Outright rejects utilitarian perspectives on resource use. |
| Bioreactors are distinctly an engineered, technologically-based approach to mitigate nitrate by “artificially” enhancing a natural process (thus recognizing a degree of substitution between systems that enhance denitrification—e.g., wetlands); yet we argue that the process of denitrification, and thus the ecological functionality of land where denitrification is occurring, cannot adequately be substituted with tertiary systems such as nitrate drinking-water treatment that occurs in the city of Des Moines, Iowa. |
| Perspectives on economic growth | Explicit decoupling of negative environmental impacts from economic growth. | Recognizes negative externalities and approves of technological fixes; still prioritizes economic growth. | Explicit internalization of externalities required. Full-cost accounting needed to balance the interests of the collective. Accepts qualitative economic growth (e.g., Genuine Progress Indicator), largely rejects quantitative economic growth (e.g., GDP). | Anti economic growth |

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While economic growth is important for the sustainability of most agricultural systems, negative externalities (i.e., nitrate loadings) are recognized and addressed with bioreactors. Though cost sharing for bioreactors is available, currently the landowner must partially invest his or her own resources to internalize this water quality externality with bioreactors.
it does not require significant modification of existing farm structure or management (Christianson et al. 2009).

A Role for Denitrification Bioreactors in a Multifunctional Landscape?

Despite our interpretation of bioreactors as being appropriate technology within a sustainable agriculture, we ultimately contend that such a perspective is far too narrow in contextual scope—that is, nontechnical, philosophical critiques positioned strictly at the technology level disregard what a sustainable agriculture probably is; one that is purposefully multifunctional and highly productive with minimal (and perhaps correctable) tradeoffs (e.g., Tilman et al. 2002; Wilson, 2007). In this case, the argument may well be contextualized by assessing the role a particular technology might play in a multifunctional landscape. Multifunctional agriculture will require, in varying degrees, a targeted approach to land use. Targeted agricultural land use is founded on the premise that strategically-placed conservation practices can produce more than proportionate ecosystem benefits relative to their total spatial extent (Secchi et al. 2008; Taylor-Lovell & Johnston, 2009). The determination of targeted land uses may be thought of as a two-stage process. The first stage involves identifying key locations at a watershed-scale where land-use modification or technological remediation could have significant impact. The second stage involves targeting land-use change at the field/farm-scale by examining localized variable source areas and soils and accounting for equipment requirements and other management considerations. Ultimately, such a targeted approach can significantly improve ecosystem-service delivery, minimize land-use tradeoffs, and efficiently use monies already allocated to conservation via various government programs (Secchi et al. 2008).

If a targeted approach to agriculture is truly a legitimate path toward sustainability, where then does a technology such as a bioreactor fit within this concept of multifunctional agriculture? The notion of targeted technologies continues to beg Hoffner’s (2009) implicit question, “Are these only band-aid’s?” A reasonable analysis of this question may begin by examining bioreactors in the context of the “economy of pragmatism.” Realistic, multifunctional farms in the American Midwest will still require artificial drainage to maximize economic profitability (Comis, 2005). The complexities of soil-water relationships and farm-level nutrient management suggest that runoff and nutrient leachate will remain remedial issues even in multifunctional systems (Coiner et al. 2001; Randall & Goss, 2001). Denitrification bioreactors and similar water-quality technologies can reduce nitrate loads in drainage from both conventional and alternative operations. Therefore, certain technologies will have a place even as ideas and patterns shift. The transition toward sustainability is a long and gradual process involving shifting agrarian paradigms that will invariably require the incorporation of a wide range of technologies, approaches, and philosophies.

Of course, there are other technologies that incorporate or augment natural processes to effectively provide the same denitrification (nitrate removal) process as bioreactors in addition to a host of other ecological functions. Foremost are restored or constructed wetlands that additionally provide services such as biodiversity and habitat, flood protection, groundwater recharge, and carbon sequestration (O’Geen et al. 2010). However, government programs or water-quality professionals do not intend (that we are aware of) to “pit” bioreactors against wetlands or suggest 1:1 fungability with regard to direct and indirect ecological outcomes (Christianson et al. 2009). In fact, in most cases denitrifying bioreactors complement other best management practices and do not preclude a variety of mitigation strategies (Woli et al. 2010). Ultimately, bioreactors are best utilized within a “suite of solutions” for achieving water-quality goals in an agricultural watershed (ISA, 2011). Because a degree of remedial immediacy is involved with local and regional water-quality goals, various technologies and best management practices are collectively required to gain aggregate benefits on a watershed-scale.²

In the context of targeted land use at multiple scales, bioreactors have a number of key technological advantages. They can easily be targeted at the field/farm level to optimize impact while requiring a relatively small surface footprint (approximately 0.1% of the drainage area); this is an important factor when minimizing land-use costs is paramount. Further, bioreactors can be installed in locations where wetlands cannot be built (ISA, 2011) and many farmers may have access to required excavation equipment and be able to use on-farm materials (e.g., wood chips), lowering installation costs. However, as Christianson et al. (2009) note, these two technologies offer options for different scales: bioreactors are primarily intended for farm-scale with a relatively small treatment area of 8 to 20 ha (20 to 50 acres),

² A potential unintended consequence of the use of mitigation technology is that producers may feel somewhat insulated from potential off-farm effects and be prone to overfertilization or intensifying tillage. Nevertheless, since the usage of mitigation technology is voluntary (often motivated by an active desire to manage environmental risk) we believe that this type of moral hazard is limited.
while wetlands are able to treat far greater drainage areas of 405 to 1,012 ha (1,000 to 2,500 acres); used together multi-scale synergies can result, which can reduce the overall cost of subsurface-drainage treatment in a watershed (ISA, 2011). Ultimately, as noted above, improved water quality is an aggregative function of several management interventions across numerous farms within a watershed. Within this context, we believe it is clear that denitrifying bioreactors can, at least, play an effective incremental role.

A Word or Two Beyond the Physical

Even though bioreactors are a focused technology to improve the environmental sustainability of agriculture as narrowly indicated by nitrate loads, it is thought their use and promotion (e.g., via demonstration projects, participatory research, and cost-share programming) may provide a unique opportunity to open the door for proactive mindsets and a broader discussion about sustainability (e.g., Willette, 2010; this phenomenon of social learning and dialogue is common in the context of agricultural demonstration and on-farm research within the American Corn Belt (Lemke et al. 2010; Petrehn, 2011) as well as international agricultural contexts (e.g., Verstraeten et al. 2003). With on-farm communication about innovative technologies such as bioreactors comes something even more powerful with regard to motivating farmer-management intentions: education about the relationship among land use, environmental quality, and agricultural sustainability (Lemke et al. 2010).

The idea here is that bioreactors and other applied technologies can (to some degree) be a technological segue to increased interest in environmentally sustainable agricultural. The novelty of bioreactors, as well as their scaled technological advantages and complementary nature, provides an interesting and complex backdrop for landowner education regarding innovation, environmental quality, and potential roles for farmers as land stewards. This feature could indeed contribute to positive but nuanced social outcomes that enhance and expand the role a “community of farmers” might have in defining regional identity by better protecting social and environmental amenities (Bell et al. 2004). Work is currently underway in Iowa to explore this educational dynamic and to characterize farmer opinions, concerns, and potential intentions regarding the use of bioreactors (Christianson & Helmers, 2009).

Final Thoughts

It is important that research not lose sight of the reality of conventional agriculture while trying to achieve land use that leans toward the stronger side of sustainability. In agriculture, land use (to a large degree) dictates the suite of “goods” and “bads” associated with that landscape. Water-quality dilemmas in the American Midwest are creating social pressure of remedial immediacy—to deny a well thought-out water-quality management approach seems counterproductive in this context. Technology, such as the denitrification bioreactor, that is effective for nitrate mitigation, scale appropriate, compatible with other technology/management, affordable, and broadly appealing to farmers has an enhanced probability of being embraced. As noted earlier, the adoption of bioreactors reflects a pointed private interest in stewardship with a degree of internalized responsibility (i.e., internalized cost at private expense) toward agro-environmental quality. This may reflect farmer behavior, motivation, and interest that, in the aggregate, helps “pave the pathway” toward a more sustainable agriculture. To the degree that a technology helps initiate broader understanding of the link between land stewardship and sustainability, all the better. This dynamic surrounding bioreactors strikes us as a technological approach to a pragmatically defined issue that not only treats symptoms of socially inefficient land use but also promotes a different agricultural paradigm. The American ecological designer William McDonough has articulated, “Sustainability takes forever—that’s the point.” Some critics argue that bioreactors and related technology cannot play a potential role in agriculture on the assumption that such technology belies the complexity of sustainability (e.g., Hoffner, 2009); we wonder if they are themselves failing their own assumptions by assuming a complex, systemic change will occur all at once.

Ultimately, we freely admit that we struggle philosophically with this issue and are broadly seeking insights. It is our hope that this article initiates the kind of dialogue that will encourage others to be reflective about their research and to contemplate the broader philosophical implications of technology in agriculture.

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