Precision Conservation: Linking Set-aside and Working Lands Policy

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Abstract:

Innovations in precision agriculture now enable the identification of crop field patches whose retirement offers high environmental benefits and low opportunity cost of crop yield loss. Precision conservation can lower costs to farmers and payment costs for government agencies. Precision conservation incentive policy should unite elements of land retirement (set-aside) and working lands policies that pay for environmental services. Key decisions surround how to bundle land fragments in a contract, keep contract design simple, evaluate environmental benefits, monitor compliance, and measure additionality of those benefits.

New knowledge about benefits to crops from adjacent biodiverse areas combined with new ways to manage the costs of conserving field fragments is creating a need for fresh approaches to U.S. agricultural conservation policy. Current policy is divided between programs that 1) retire (or "set aside") land for conservation uses or 2) encourage the adoption of environmentally beneficial practices on working lands. Land retirement programs (such as the Conservation Reserve Program [CRP]) and working lands programs (such as the Environmental Quality Incentives Program [EQIP]) both focus on whole fields or contiguous land areas. New developments in ecological research and precision agricultural technologies call into question whether the farm field should be the only defining unit for agricultural conservation policy. Can we—and should we—also target collections of field fragments?

U.S. agricultural conservation programs are largely voluntary. Their design has been driven by a benefit-cost calculation where environmental benefits to farmers and to society at large were balanced against financial costs to farmers. On the benefit side, growing scientific understanding of ecosystem services is clarifying our sense of where and when those environmental benefits occur. Early research that focused on soil erosion and sediment deposition highlighted the benefits of either retiring highly erodible land or else following field-level contour planting at whole-field scale. Newer research into biotic connections is identifying the value of proximate habitat for beneficial species like pollinators and natural enemies of agricultural pests (Landis, 2017) as well as benefits from site-specific nutrient management (Khanna et al., 2019; Schulte et al., 2017). In many instances, nearby habitat for beneficial species can enhance crop yields. In the past, "nearby" meant near field edges, but precision guidance technologies now make it possible to incorporate conservation areas into crop fields.

On the cost side, advances in precision farming technologies and associated crop management research are reducing the cost to set aside fragments of conservation land within crop fields. Yield maps make it possible to identify stable, low-yielding field fragments where the opportunity cost of giving up crop production is low or even negative (Basso, 2021; Brandes et al., 2016). Precision guidance technologies promise to reduce the cost of farming around fragments of non-crop land in farm fields (Lowenberg-DeBoer et al., 2020).

What the newly recognized conservation benefits have in common with new routes to lowering conservation costs is that both entail a more tailored approach to defining conservation lands. Given the U.S. history of focusing conservation policy on whole fields, these changes will require fresh approaches to the redesign of U.S. agricultural conservation policy. This paper sketches out the history of the two threads of U.S. conservation policy along with new developments in agro-ecological research and precision technologies that are enabling farmers to manage for production and environmental quality with far greater spatial discrimination. The paper closes with proposed areas for research to inform agricultural conservation policy at the intersection of land retirement and working lands programs.

History of U.S. Conservation Programs

The two tracks of U.S. conservation programs were originally developed to solve different problems. The first land set-aside program aimed to solve the twin problems of egregious soil erosion and low grain commodity prices during the Great Depression. The Soil Conservation and Domestic Allotment Act of 1936 addressed both problems by paying farmers to shift land from grain crops to grasses and legumes, thereby both reducing grain supply and abating soil erosion (Tweeten, 1979). The program was incorporated into core U.S. farm policy under the Agricultural Adjustment Act of 1938 (Cochrane, 1993). Land retirement programs have served as a countercyclical supply management tool ever since, waxing and waning as crop prices fell and rose. Major expansions of land retirement each followed closely upon periods of low crop prices under the Soil Bank program of 1956-72 and the current CRP, which began in 1985 (Claassen, Cattaneo & Johansson, 2008). The modern CRP, however, has broadened its environmental objectives far beyond soil conservation, to include water quality improvement, native species restoration, wildlife habitat establishment, and more. Under the CRP, the U.S. Department of Agriculture (USDA) allocates land retirement contracts via procurement auctions, using an Environmental Benefits Index (EBI) to reward the most cost-effective provision of environmental services (Hellerstein, 2017).

Working lands conservation started at the same time as the set-aside program, but with the goal of encouraging farmers to manage differently, rather than to shift land out of grain production. The Agricultural Conservation Program (ACP) of 1936 introduced cost-sharing to help farmers afford to build soil conservation structures, such as terraces and grassy waterways (Claassen, Cattaneo & Johansson, 2008). Cost-share programs for working lands remained much smaller than set-aside programs until the 1990's, and cost sharing was typically on a competitive basis. That changed after introduction of the Environmental Quality Incentives Program in 1996. Initially EQIP focused on the management of highly erodible lands. However, the 2002 Farm Bill authorized a major budget expansion that enabled EQIP to offer standard cost-share rates without competitive bidding (Cattaneo et al., 2005).

Although the set-aside and working lands programs operate independently (and are administered via two different USDA agencies), both are voluntary programs where farmers are encouraged to consult with local field offices of the USDA Natural Resource Conservation

Service (NRCS). Farmers weigh benefits and costs from their own perspectives in deciding whether to enroll individual fields in one of these programs.

Opportunity cost as disincentive to participate in conservation programs

Farmers weigh two kinds of costs when deciding whether to participate in a conservation program. The first covers the direct costs of variable inputs and equipment. The second is the opportunity cost of giving up income from a current activity, such as crop production or livestock grazing. Opportunity cost can be large, especially when shifting an entire field into a land retirement program. The opportunity cost of shifting land use from agricultural production to land retirement is driven by both biophysical yield potential and the commercial value of what is produced. The best yielding fields tend to remain in agricultural production. For poorer quality land, farmer interest in set-aside programs tends to rise when commodity prices are low and fall when they are high. This pattern leads to historical expansion and contraction of U.S. set-aside acres, with the cycle dampened by the 10 to 15 year duration of CRP contracts (Taylor et al., 2021). For example, the bioethanol-driven corn price boom of 2008-13 led U.S. farmers not to renew 64% of CRP contracts that ended during 2013-16 and to return 80% of the liberated land to crop production (Bigelow et al., 2020).

Offsetting the costs of land retirement is the rent-like payment that a farmer can receive from the USDA under a CRP contract. That payment is determined through a bidding process, where farmers compete to retire land with conservation practices that will yield the most cost-effective environmental benefits to the Federal government. The USDA Farm Services Agency (FSA) measures the cost-effectiveness of bids based upon the farmer’s bid price (the rent they are willing to accept, which represents a cost to the USDA FSA) and the environmental benefits from the proposed land retirement. The benefits depend upon the land itself (slope, soil type, location, etc.) and the proposed conservation practices. Although the CRP is administered by the FSA, it relies on conservation practices approved by the NRCS. Officially recognized NRCS conservation practices range from exotic perennial grasses to native grasses and forbs to special seed mixes that support vegetative habitat for pollinators and wildlife, as well as other purposes. The EBI weighs benefits based on geography, proposed vegetative cover, and the farmer bid (Hellerstein, 2017). Bids that offer large environmental benefits receive a high EBI score, which can potentially attract higher CRP rental payments (Kirwan, Lubowski & Roberts, 2005). EBI scores are underpinned by environmental research that is continually updated.

New Evidence on Benefits of Perennial Conservation Areas in Crop Fields

Reference to land that is "set aside" connotes that the land ceases to be agriculturally active. However, a new approach to set-aside is to incorporate conservation strips of native species into crop fields. An expanding research oeuvre shows that far from being inactive, cropland that incorporates perennial conservation areas can provide various environmental benefits. Decades of research in the latter half of the 1900's documented that contour buffer strips of perennial grasses can provide benefits by abating soil and nutrient loss. These practices became codified as agricultural "best management practices" to support rural water quality (U.S. Environmental Protection Agency (EPA), 2003). Recent research reveals that prairie strips that mix native grass and forb species can enhance biodiversity benefits from insects, pollinators, and birds while also assuring the biogeochemical benefits of moisture retention, soil conservation, and reduced phosphorus loss to water bodies (Schulte et al., 2017).

Where native species have been planted in prairie strips, crop yields on the remaining cropland have remained stable (Schulte et al., 2017), a reassuring indicator that prairie strips have not served to harbor weeds and pests at damaging levels. The salient cost has been the opportunity cost of lost crop production (Schulte et al., 2017). A budgeting analysis of prairie strips in Iowa calculated that their opportunity cost to farmers represented only 15% of typical CRP payments (Tyndall et al., 2013). A 2018 stated preference survey of Eastern Corn Belt corn-soybean farmers found that 20% were willing to supply land for prairie strips that occupied 5% of their largest corn-soybean field in exchange for payments comparable to current CRP rental rates (Luther, Swinton & Van Deynze, 2022).

The emerging message is promising: Perennial prairie strips within crop fields can provide environmental services at costs that are affordable under current agricultural conservation policy. But the research base so far is limited in two ways. First, the research is based on average conditions. Second, research has focused on contour strips across fields that occupy a fixed 5-20% of the field area.

The benefit-cost ratio of setting aside conservation land within crop fields can be improved in both benefit and cost dimensions. Environmental benefits can be enhanced by targeting vulnerable sites where perennial conservation areas will offer the greatest value. In some settings, these may be highly erodible lands where the highest value benefits arise from abating erosion, sedimentation, and nutrient runoff (Khanna et al., 2003). In settings where certain beneficial species are scarce—pollinators, for example—the highest value benefits may arise from providing habitat for those species (Lonsdorf et al., 2009).

The potential cost to public programs of setting aside conservation land can be reduced in at least two spatially based ways. First, some landowners are willing to set aside land in exchange for lower compensation than others. Indeed, these differences in willingness-to-accept compensation are the basis for the prairie strip land supply curves in Luther, Swinton, and van Deynze (2022). The procurement auction mechanism used to allocate CRP contracts is designed to induce farmers to reveal the lowest compensation that they would willingly accept in order to put land into a conservation practice (Hellerstein, 2017). Second, fields are not spatially homogeneous in their yield potential (Basso, 2021; Brandes et al., 2016). Some areas have greater yield potential than others, and in some areas crops respond better to inputs such as nitrogen fertilizer (Liu, Swinton & Miller, 2006). Hence, the public costs of compensating farmers for in-field conservation areas could be reduced by identifying areas of low (or even negative) profitability potential.

Potential of precision conservation

The potential of precision conservation (PC) is to capitalize on in-field islands of low opportunity cost and high environmental benefit. The suite of precision agricultural technologies facilitates both identifying priority areas and reducing the cost to farm around them (Basso & Antle, 2020; Finger et al., 2019).

A classic challenge in identifying low-yielding field areas is to account for year-to-year effects of weather. In rainfed fields, low areas may yield well in dry years but poorly in wet years (due to waterlogging). But with the spread of yield mapping, over half of U.S. corn-soybean farms can now compare yield maps across years (Luther, Swinton & van Deynze, 2020; Schimmelpfennig, 2016). When researchers have done this, they find evidence of stable, low-yielding, sub-field areas (Maestrini & Basso, 2018). That such areas are stable over time means that from a profitability standpoint, they contribute little value because applied inputs like fertilizers tend to underperform. Whereas a conversion to perennial conservation use might have high opportunity cost for some field areas, that cost is low (or negative) for these stable, low-yielding areas.

If stable, low-yielding areas look ripe for conservation use from a profitability perspective, what about an environmental perspective? We can divide environmental benefits between biogeochemical and biodiversity benefits. Considerable evidence indicates that converting these areas to conservation uses can yield biogeochemical benefits. Nitrous oxide is both the most potent major greenhouse gas and the one that has the biggest footprint in agriculture (U.S. Energy Information Administration, 2011). Nitrogen fertilizer is a major source of both nitrous oxide and of water-borne nitrate and phosphorus nutrients that have been implicated in the spread of harmful algal blooms and hypoxia—most notably in the Gulf of Mexico (Alexander et al., 2008). The crop that uses the most nitrogen fertilizer in the United States is corn. Reactive nitrogen losses (in the forms of nitrous oxide and nitrate) were found to be highest on the stable, low-yielding areas that constituted 26% of corn area in a recent simulation study of remotely sensed cropland in ten Midwestern U.S. states (Basso et al., 2019). Another recent simulation study finds evidence of carbon sequestration by switchgrass, a native perennial that can be planted in conserved areas (Martinez-Feria & Basso, 2020). Bottom line: PC is likely to generate positive climate and water quality effects, particularly via spatial targeting to reduce unnecessary nitrogen fertilizer application that causes environmental damage (Basso & Antle, 2020; Khanna et al., 2019).

Research into the potential biodiversity effects of islands of perennial, conservation plantings in crop fields is actively underway. As noted above, experiments with prairie strips show clear biodiversity benefits in addition to benefits from abatement of nutrient losses (Schulte et al., 2017). A recent meta-analysis of global literature on biodiversity effects in agriculture found that non-crop diversification, which results from non-crop area within and surrounding crop fields, is a significant contributor to beneficial ecosystem services of natural pest control and pollination (Tamburini et al., 2020). The emerging evidence points to net benefits from introducing limited plant diversity into crop landscapes.

In sum, PC promises potential net benefits from averting environmental costs at low opportunity cost from crop revenue loss. But previous research has found that other costs may still tip the balance against PC. Specifically, the costs of farming around irregularly scattered islands of conserved land could overwhelm the benefits. Zhang, van der Werf and Swinton (2010) found that despite greater environmental benefits from scattered islands of conserved habitat, cross-field habitat strips were the most cost-effective spatial configuration for conserved areas that provide habitat for natural enemies of a crop pest.

In the decade since that research was completed, advances in automated guidance technology have lowered the cost of farming irregularly shaped field areas. By 2016, 65 percent of U.S. corn farmers had guidance systems on their tractors and/or combine harvesters (Schimmelpfennig, 2016). A 2019 literature review of profitability analyses of robotic and automated guidance in row crops found evidence of profitability, at least in studies of using prototype equipment (Lowenberg-DeBoer et al., 2020). As these technologies become standardized and the cost of rural GPS access declines, automated guidance will get cheaper. Indeed, Lowenberg-DeBoer et al. (2019) imagine a medium-term future where low-cost, auto-guided, precision machines can operate in swarms to farm irregularly shaped areas at costs well below those of the recent past. While “swarm robotics” may never materialize, what is materializing rapidly is lower cost guidance systems for farm equipment—including the ability to maneuver with consistent accuracy around irregularly shaped conservation islands in a crop field.

Policy Re-Design to Enable Precision Conservation

Emerging evidence shows that precision conservation 1) can target land patches with high environmental benefits and low opportunity cost of crop yield loss, and 2) can do so at declining management cost, thanks to improving guidance systems. These scientific and technological trends are converging with federal priorities in the United States.

The year 2021 witnessed a steady drum beat of federal initiatives to mitigate climate change and find ways for agriculture to be part of the process. In January, the White House issued an executive order on mitigating climate change (https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/). In April, the USDA Farm Services Agency announced a plan to expand CRP acreage from 20.8 million to its 2021 cap of 25 million acres by raising CRP rental rate offers (https://www.fsa.usda.gov/news-room/news-releases/2021/usda-expands-and-renews-conservation-reserve-program-in-effort-to-boost-enrollment-and-address-climate-change). In June, the bipartisan "Growing Climate Solutions Act" bill passed the Senate; the bill would provide certification services to enable farmers and foresters to participate in voluntary carbon markets (https://www.congress.gov/bill/117th-congress/senate-bill/1251). In November, during the United Nations Climate Change Conference, the White House announced a new plan to reduce U.S. methane emissions and introduce climate-smart agriculture (https://www.whitehouse.gov/briefing-room/statements-releases/2021/11/02/fact-sheetpresident-biden-tackles-methane-emissions-spurs-innovations-and-supports-sustainable-agriculture-to-build-a-clean-energy-economy-and-create-jobs/).

Looking ahead to the next Farm Bill in 2023, the public priorities, scientific evidence, and technological innovation point toward a role for precision conservation. But given the historic U.S. farm policy distinction between set-aside conservation programs (administered by the FSA) and working lands programs (administered by the NRCS), how compatible is PC with existing programs?

A PC program would presumably enroll collections of irregular land fragments that combine traits of low crop yield with high environmental value. As such, it would embody elements of both set-aside and working lands programs. As under CRP, the land would be retired for multiple years under intentionally selected perennial plantings. As under EQIP, the system would be designed to enhance ecosystem services on annual crop land. Unlike either CRP or EQIP, PC would entail a set of irregularly shaped plots of land.

The special features of precision conservation land parcels raise several special questions for program design that merit consideration for the 2023 Farm Bill:

1. *What minimum allowable size for field parcels?* For the sake of compliance monitoring and of payment processing, there should be a minimum area for each individual parcel and for the set of parcels entered in a multi-year contract. Current CRP rules allow prairie strips to be as narrow as 30 feet (Farm Service Agency (FSA), 2019) and pollinator habitat to be as small as 0.5 acres (Farm Service Agency (FSA), 2013). These dimensions could represent reasonable lower bounds on the area of precision conservation parcel. Given the high potential cost of monitoring a set of small, irregularly shaped parcels, an alternative minimum size consideration might be the

smallest area that would reliably register as a pixel from satellite monitors. What might be the largest allowable area over which the parcels could be assembled? The logical frame of reference would be a farm field, but it is easy to imagine that if a single unit of land is not required, there will be a need to define a continuous area in which collections of parcels are located—perhaps some classic unit like a quarter section of land (160 acres).

2. *How to allocate contracts?* From the public standpoint, contracts should be allocated so that they maximize the value of public benefits relative to costs. The current practice of allocating CRP contracts via procurement (or "reverse") auctions aims to do that. But the cost of participating in terms of farmers' time and effort can be prohibitive. Even with individual, full-sized fields, these transaction costs can deter willing participants (Palm-Forster et al., 2016; Rolfe et al., 2018). If miniature parcels and field fragments were treated similarly, merely preparing a set of bids for a procurement auction could be an insuperable barrier to participation. A more practical approach would be to permit bundling of PC parcels into an individual bid—perhaps supported by a GIS data file with specific location and land feature details. More attractive yet might be a program that offered a fixed payment per acre (like an EQIP cost-share), without requiring more detail than the location of component parcels and the aggregate land area.
3. *How would environmental benefits be calculated?* The Environmental Benefits Index (EBI) for CRP bids is based on land traits and the proposed conservation practice (Hellerstein, 2017). If precision conservation areas provide habitat for beneficial species like pollinators or natural enemies of crop pests, then the spatial dispersion of precision conservation parcels might justify a benefit associated with the projection of these

ecosystem services over the intervening cropped area. Defining a zone over which spatial benefits are projected has been vetted by hypothetical modelers (Zhang, van der Werf & Swinton, 2010), but remains to be tested under real programmatic conditions. Presumably the existence of such a zone would depend upon the vegetative mix of the conservation practice, such that one that supports habitat for pollinators (Farm Service Agency (FSA), 2013), natural enemies of crop pests, or other mobile, beneficial species.

4. *How would monitoring be done?* Just as parcels for normal CRP are registered in order ensure that the land is placed and maintained in the agreed conservation practice, so too precision conservation parcels would need to be registered and have their GPS coordinates recorded for monitoring purposes. Given the spatial dispersion of these parcels across and around cropped fields, remote monitoring might best be the most cost-effective. If "remote" were to mean by satellite (which is definitely low cost), then the minimum parcel size would depend on the minimum pixel area and quality permitted by the remote imagery to be used.

5. *How much additional conservation would PC provide on top of what farmers would do anyway?* For voluntary conservation policy to be most cost-effective, payments should be targeted to effect adoption of conservation practices where they would not have been adopted otherwise. The technical term is "additionality," which describes the proportion of additional conservation behavior triggered by the payment. Two factors can undermine additionality. First, farmers who already wanted to adopt the practice for private reasons are more likely to try to enroll in a program that pays them to do that (Ferraro, 2008). Second, and particularly for practices where only first-time adopters are eligible (with the goal of ensuring additionality), farmers may delay adopting an

attractive practice in the hope of being paid to adopt it at a future date (Pates & Hendricks, 2020). Recent research that controls carefully for the first problem finds that policies that set aside land have tended to provide greater additionality than ones that paid farmers for working lands practices like nutrient management (Claassen, Duquette & Smith, 2018). This suggests that PC could have higher additionality than most working lands practices. However, there remains the second concern of whether the existence of a PC payment program would have the counterproductive effect of inducing delayed adoption in the hope of future payment. A third concern specific to PC is the risk that as whole-field CRP contracts expire, instead of re-enrolling them, farmers may switch them to PC and resume farming higher yielding field areas. Such decisions could undermine the additional conservation benefits of PC.

Conclusion

The convergence of innovation in precision technologies with policy priorities to mitigate climate change and meet other environmental goals has created an opening to introduce precision conservation in the 2023 Farm Bill. PC has the potential to meet environmental needs at modest public cost via payment-for-environmental services that farmers are likely to adopt if the policies are designed right. Proper design for an attractive, voluntary PC policy calls for cost-effective ways 1) to define and describe bundles of field fragments to enroll for set-aside under perennial conservation set-aside, 2) to allocate contracts via a process free of burdensome participation costs, 3) to estimate for bid evaluation purposes the environmental benefits that habitat for beneficial species may offer to nearby crops, 4) to monitor compliance with agreed conservation practices, and 5) to assess *ex ante* the likely additionality of PC compared to existing programs to induce voluntary adoption of conservation practices.

References

Alexander, R.B., R.A. Smith, G.E. Schwarz, E.W. Boyer, J.V. Nolan, and J.W. Brakebill. 2008. "Differences in Phosphorus and Nitrogen Delivery to The Gulf of Mexico from the Mississippi River Basin." *Environmental Science and Technology* 42(3):822-830.

Basso, B. 2021. "Precision Conservation for a Changing Climate." *Nature Food* 2:322-323.

Basso, B., and J. Antle. 2020. "Digital Agriculture to Design Sustainable Agricultural Systems." *Nature Sustainability* 3:254-256.

Basso, B., G. Shuai, J. Zhang, and G.P. Robertson. 2019. "Yield Stability Analysis Reveals Sources of Large-Scale Nitrogen Loss from the US Midwest." *Scientific Reports* 9(1):5774.

Bigelow, D., R. Claassen, D. Hellerstein, V. Breneman, R. Williams, and C. You. 2020. "The Fate of Land in Expiring Conservation Reserve Program Contracts, 2013-16." EIB-215. Economic Research Service, U.S. Department of Agriculture, Washington, DC.

Brandes, E., G.S. McNunn, L.A. Schulte, I.J. Bonner, D.J. Muth, B.A. Babcock, B. Sharma, and E.A. Heaton. 2016. "Subfield Profitability Analysis Reveals an Economic Case for Cropland Diversification." *Environmental Research Letters* 11:article 014009.

Cattaneo, A., R. Claassen, R. Johansson, and M. Weinberg. 2005. "Flexible Conservation Measures on Working Land." Economic Research Report No. ERR 5. Economic Research Service, U.S. Department of Agriculture, Washington, DC.

Claassen, R., A. Cattaneo, and R. Johansson. 2008. "Cost-Effective Design of Agri-Environmental Payment Programs: U.S. Experience in Theory and Practice." *Ecological Economics* 65:737-752.

Claassen, R., E.N. Duquette, and D.J. Smith. 2018. “Additionality in U.S. Agricultural Conservation Programs.” *Land Economics* 94(1):19-35.

Cochrane, W.W. 1993. *The Development of American Agriculture: A Historical Analysis*. 2nd ed. Minneapolis: University of Minnesota Press.

Farm Service Agency (FSA) (2019) “Conservation Reserve Program: Clean Lakes, Estuaries and Rivers (CLEAR) Initiative: Prairie Strip Practice (CP-43).” U.S. Department of Agriculture, Washington DC.

--- (2013) “CP42 Pollinator Habitat.” U.S. Department of Agriculture, Washington DC.

Ferraro, P.J. 2008. “Asymmetric Information and Contract Design for Payments for Environmental Services.” *Ecological Economics* 65(4):810-821.

Finger, R., S.M. Swinton, N. El-Benni, and A.M. Walter. 2019. “Precision Farming at the Nexus of Agricultural Production and the Environment.” *Annual Review of Resource Economics* 11:313-335.

Hellerstein, D.M. 2017. “The US Conservation Reserve Program: The Evolution of an Enrollment Mechanism.” *Land Use Policy* 63:601-610.

Khanna, M., B.M. Gramig, E.H. DeLucia, X. Cai, and P. Kumar. 2019. “Harnessing Emerging Technologies to Reduce Gulf Hypoxia.” *Nature Sustainability* 2(10):889-891.

Khanna, M., W. Yang, R. Farnsworth, and H. Önal. 2003. “Cost-Effective Targeting of Land Retirement to Improve Water Quality with Endogenous Sediment Deposition Coefficients.” *American Journal of Agricultural Economics* 85(3):538-553.

Kirwan, B., R.N. Lubowski, and M.J. Roberts. 2005. “How Cost-Effective Are Land Retirement Auctions? Estimating the Difference between Payments and Willingness to Accept in the

Conservation Reserve Program." *American Journal of Agricultural Economics* 87(5):1239-1247.

Landis, D.A. 2017. "Designing Agricultural Landscapes for Biodiversity-Based Ecosystem Services." *Basic and Applied Ecology* 18:1-12.

Liu, Y., S.M. Swinton, and N.R. Miller. 2006. "Is Site-specific Yield Response Consistent Over Time? Does it Pay?" *American Journal of Agricultural Economics* 88(2):471-483.

Lonsdorf, E., C. Kremen, T. Ricketts, R. Winfree, N. Williams, and S. Greenleaf. 2009. "Modelling Pollination Services Across Agricultural Landscapes." *Annals of Botany* 103(9):1589-1600.

Lowenberg-DeBoer, J., K. Behrendt, R. Godwin, and K. Franklin. 2019. "The Impact of Swarm Robotics on Arable Farm Size and Structure in the UK." Paper presented at 93rd Annual Conference of the Agricultural Economics Society, Warwick, UK, April 15-19, 2019.

Lowenberg-DeBoer, J., I.Y. Huang, V. Grigoriadis, and S. Blackmore. 2020. "Economics of Robots and Automation in Field Crop Production." *Precision Agriculture* 21: 278-299.

Luther, Z., S.M. Swinton, and B. van Deynze. 2020. "What Drives Voluntary Adoption of Farming Practices that Can Abate Nutrient Pollution?" *Journal of Soil and Water Conservation* 75(5):640-650.

Luther, Z.R., S.M. Swinton, and B. Van Deynze. 2022. "Potential Supply of Midwest Cropland for Conversion to In-Field Prairie Strips." *Land Economics* 98(2) (in press).

Maestrini, B., and B. Basso. 2018. "Drivers of Within-Field Spatial and Temporal Variability of Crop Yield Across the US Midwest." *Scientific Reports* 8(1):14833.

Martinez-Feria, R., and B. Basso. 2020. "Predicting Soil Carbon Changes in Switchgrass Grown on Marginal Lands Under Climate Change and Adaptation Strategies." *GCB Bioenergy* 12(9):742-755.

Palm-Forster, L.H., S.M. Swinton, F. Lupi, and R. Shupp. 2016. "Too Burdensome to Bid: Transaction Costs and Pay-for-Performance Conservation." *American Journal of Agricultural Economics* 98(5):1314-1333.

Pates, N.J., and N.P. Hendricks. 2020. "Additionality from Payments for Environmental Services with Technology Diffusion." *American Journal of Agricultural Economics* 102(1):281-299.

Rolfe, J., S. Schilizzi, P. Boxall, U. Latacz-Lohmann, S. Iftekhar, M. Star, and P. O'Connor. 2018. "Identifying the Causes of Low Participation Rates in Conservation Tenders." *International Review of Environmental and Resource Economics* 12(1):1-45.

Schimmelpfennig, D.E. 2016. "Farm Profits and Adoption of Precision Agriculture." Economic Research Report No. ERR 217. Economic Research Service, U.S. Department of Agriculture, Washington, DC.

Schulte, L.A., J. Niemi, M.J. Helmers, M. Liebman, J.G. Arbuckle, D.E. James, R.K. Kolka, M.E. O'Neal, M.D. Tomer, J.C. Tyndall, H. Asbjornsen, P. Drobney, J. Neal, G. Van Ryswyk, and C. Witte. 2017. "Prairie Strips Improve Biodiversity and the Delivery of Multiple Ecosystem Services from Corn–Soybean Croplands." *Proceedings of the National Academy of Sciences* 114(42):11247-11252.

Tamburini, G., R. Bommarco, T.C. Wanger, C. Kremen, M.G.A. van der Heijden, M. Liebman, and S. Hallin. 2020. "Agricultural Diversification Promotes Multiple Ecosystem Services without Compromising Yield." *Science Advances* 6(45):eaba1715.

Taylor, M.R., N.P. Hendricks, G.S. Sampson, and D. Garr. 2021. "The Opportunity Cost of the Conservation Reserve Program: A Kansas Land Example." *Applied Economic Perspectives and Policy* 43(2): 849-865.

Tweeten, L. 1979. *Foundations of Farm Policy*. 2nd ed. Lincoln, NE: University of Nebraska Press.

Tyndall, J.C., L.A. Schulte, M. Liebman, and M. Helmers. 2013. "Field-Level Financial Assessment of Contour Prairie Strips for Enhancement of Environmental Quality." *Environmental Management* 52(3):736-747.

U.S. Energy Information Administration. 2011. "Emissions of Greenhouse Gases in the United States 2009." U.S. Department of Energy, Washington, DC.

U.S. Environmental Protection Agency (EPA). 2003. "National Management Measures to Control Nonpoint Source Pollution from Agriculture." EPA 841-B-03-004. Office of Water, U.S. Environmental Protection Agency, Washington, DC.

Zhang, W., W. van der Werf, and S.M. Swinton. 2010. "Spatially Optimal Habitat Management for Enhancing Natural Control of an Invasive Agricultural Pest: Soybean Aphid." *Resource and Energy Economics* 32(4):551-565.