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Using conservation auctions informed by environmental performance models to reduce agricultural nutrient flows into Lake Erie

Leah H. Palm-Forster [a,*,1], Scott M. Swinton [b], Todd M. Redder [c], Joseph V. DePinto [c], Chelsie M.W. Boles [c]

[a] Department of Applied Economics and Statistics, University of Delaware, 531 S. College Ave., Newark, DE 19716-2103, USA
[b] Department of Agricultural, Food, and Resource Economics, Michigan State University, 446 W. Circle Dr., East Lansing, MI 48824-1039, USA
[c] LimnoTech, 501 Avis Drive, Ann Arbor, MI 48108, USA

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ABSTRACT

Cost-effectively mitigating agricultural nutrient export requires an understanding of the biophysical characteristics of cropland as well as the behavioral and economic factors that drive land management decisions. Conservation auctions informed by models that simulate environmental outcomes have the potential to allocate conservation payments cost-effectively by funding practices that provide high predicted environmental benefits per dollar spent. This research tested two forms of conservation auctions. First, experimental auctions were used to analyze farmer preferences for different types of financial incentives for voluntary conservation, including direct payments, insurance, tax credits, and stewardship certification benefits. Second, conservation auctions were conducted in two Ohio counties to evaluate performance under real-world conditions. Supporting both types of auctions, the Soil and Water Assessment Tool (SWAT) predicted reductions in phosphorus exported as a function of the type of conservation practice and farm location. Results of the experimental auctions showed direct payments and tax credits to be the most cost-effective incentives to mitigate phosphorus export. The real auctions yielded two important lessons: 1) participation was very low, due to perceived transaction costs of participation—especially on rented fields and for group bids, and 2) the cost-effectiveness ranking of bids was highly sensitive to the parameters for soluble reactive phosphorus concentrations in the SWAT model. Future socio-economic research into payment for environmental services programs should seek cost-effective mechanisms with lower transaction costs for participants. Future biophysical research should strengthen our understanding of the factors governing soluble reactive phosphorus movement, so that models like SWAT can be more reliably parameterized.
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Introduction

In the Great Lakes region, agricultural nutrient loss via surface runoff and subsurface drainage is threatening aquatic ecosystems. In 2011, a harmful algal bloom (HAB) (*Microcystis* sp.) of unprecedented size and severity occurred in the Western Lake Erie Basin (WLEB) (Michalak et al., 2013). In 2014, another HAB in the WLEB contaminated water supplies for nearly half a million people living in and around Toledo, OH (Wynne et al., 2015). As a result of this and other coastal and freshwater re-eutrophication problems, significant effort is being dedicated to identify strategies that reduce nutrient loss from land in high-priority watersheds (US EPA, 2014, 2010).

In the United States, farmers generally hold the property rights to manage their land as they choose; therefore, most agri-environmental programs are voluntary and many involve payments for ecosystem services (PES) to create incentives to adopt conservation practices (Kroeger and Casey, 2007; Norris et al., 2008). However, payments must come from budgets, and budgets are constrained. Spending on federally funded conservation programs is projected to be over $5.5 billion annually during the 5-year life of the 2014 Farm Bill (Lubben and Pease, 2014). In order to make best use of these funds, there is growing interest in designing more cost-effective programs in order to generate greater benefits with a limited conservation budget. Researchers and practitioners have called for programs that "pay for performance," which refers to the desire to pay for environmental outcomes rather than paying for practices or inputs without considering the resulting impact on the environment (Sowa et al., 2016–in this issue; Weinberg and Claassen, 2006; Winsten and Hunter, 2011).

In order to obtain the greatest environmental impact from limited funds, two kinds of information are essential: 1) a reliable prediction of environmental benefits from using a best management practice (BMP) on a specific field, and 2) knowledge concerning the least costly incentive that a farmer would be willing to accept in order to adopt that

* Corresponding author.
E-mail address: leahhp@udel.edu (L.H. Palm-Forster).
[1] This research was conducted while L. H. Palm-Forster was a doctoral student at Michigan State University.

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BMP. Biophysical models have been developed to predict changes in ecosystem services (ES) that result from alternative farming practices. While these models are not perfect predictors of ES changes, they provide a scientifically validated basis for paying for environmental performance in PES programs. In practice, they can be used to predict environmental improvements (e.g., reduced nutrient export) in order to allocate payments to projects that will provide the greatest benefit per dollar spent.

On the cost side, the challenge is to identify the minimum payment amount that farmers would be willing to accept in order to adopt a BMP. That amount is based on direct costs, opportunity costs, risks, and personal benefits that are specific to each farmer but not known accurately by policy makers. One increasingly popular mechanism for allocating scarce conservation funding is the conservation auction (also called a procurement auction or reverse auction), because it can induce farmers to reveal the minimum payment that they are willing to accept in order to implement a BMP (Hellerstein et al., 2015). Conservation auctions create a competitive environment in which land managers compete for payments to fund BMPs.

Early auction-type mechanisms, like those used to enroll land in previous versions of the Conservation Reserve Program (CRP), evaluated bids based on cost alone in order to maximize the number of acres enrolled (Reichelderfer and Boggess, 1988). The CRP has evolved over the last 30 years to include a more complex bidding mechanism in which land is scored and ranked using the Environmental Benefits Index (EBI) that considers the ES provided by the land and the cost (e.g., the per-acre rental rate) to enroll the land in the program (Jacobs et al., 2014). The bidding system used in the CRP differs from the reverse auctions that we describe in this paper in two key ways. First, acreage enrolled in the CRP is removed from production whereas we describe an auction mechanism for working lands that will continue to be used for crop production. Second, the EBI provides a scoring system for CRP applications, but environmental benefits on submitted acres are not predicted using biophysical models as in the auctions described in this study.

Research has shown that auctions are more cost-effective when bids are evaluated based on both the cost of BMP implementation and the predicted environmental benefits estimated by appropriate biological simulation models (Connor et al., 2008; Duke et al., 2013; Messer and Allen, 2010; Rabotyagov et al., 2014). Fig. 1 illustrates a bid selection process that accounts for both the payment required by a farmer and the predicted environmental benefits in allocating funds to the conservation projects that provide the most environmental benefit per dollar spent. Compared to uniform payment programs, conservation auctions have the potential to increase total environmental benefits procured with a limited budget (Selman et al., 2008). However, there is a need for additional field-testing in order to evaluate the feasibility of scaling up the conservation auction approach, particularly when the program targets working agricultural lands with heterogeneous production practices.

One important factor influencing the potential cost-effectiveness of reverse auctions is the incentive or payment mechanism offered. The norm up to now has been offering a direct payment to the farmer. Previous research has focused on programs that offer cost-share or annual stewardship payments (Claassen et al., 2008), but little is known about farmer willingness to adopt BMPs in exchange for other incentives such as tax credits, specialized insurance products, and benefits associated with stewardship certification (e.g., price premiums, market access, reputational benefits).

In this study, we explored alternative payment incentives and the feasibility of scaling up reverse auctions in the Maumee River basin to promote adoption of BMPs that reduce phosphorus runoff to Lake Erie. In the first stage, we implemented four experimental reverse auctions across the Maumee basin to understand farmer preferences among different types of conservation incentives. In these experimental auctions, farmers received payment based on the budgeted performance of mock farms to which they were assigned in the economic experiment, but their auction bids did not affect BMPs implemented on their own real farms. In the second stage, we conducted two public conservation auctions in the Tiffin watershed, a subwatershed in the Maumee basin, in order to assess how the auctions could be implemented in the real world at farm field scale. Farmers were invited to submit bids to implement BMPs on their own farms, thus the level of participation in the bidding process was of particular interest.

For both sets of auctions, the Soil and Water Assessment Tool (SWAT) was employed to predict changes in agricultural phosphorus (P) watershed export (i.e., combined surface and subsurface delivery) that would result from implementing the BMPs. Between the two sets of auctions, the SWAT model was updated to a new version. It was also called upon to predict the reduction in phosphorus export from

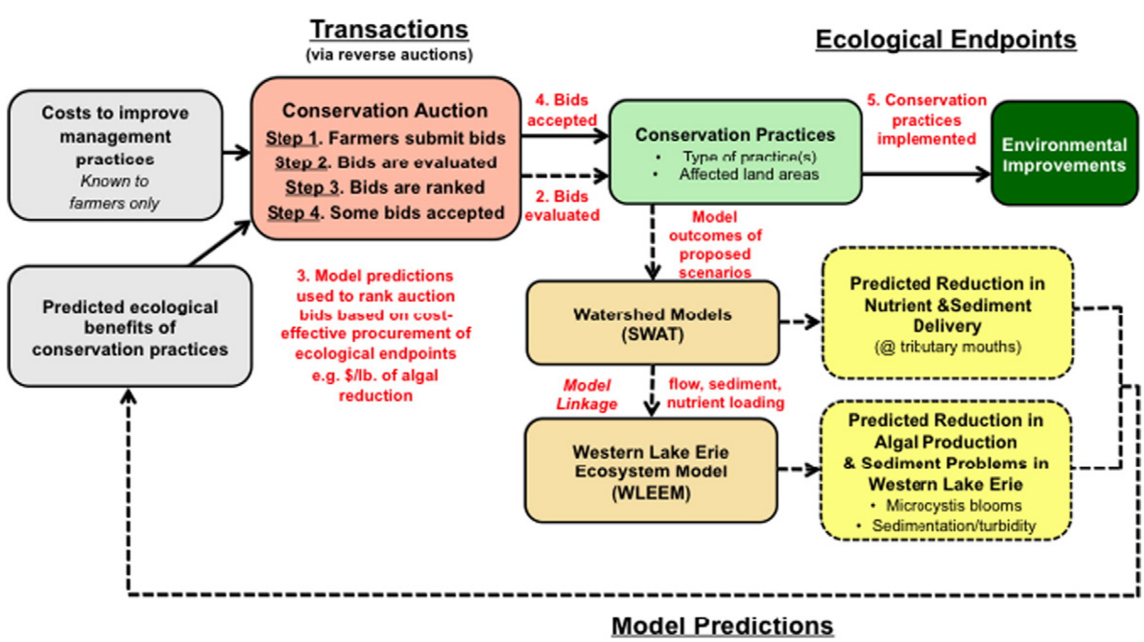

Fig. 1. Conceptual process model of this study. Farmers provide information about the cost of using conservation practices, while ecological models predict the benefits of these practices. Understanding the costs and benefits facilitates cost-effective transactions.

controlled subsurface drainage, a task that SWAT had not previously been called upon to simulate for public program purposes. Thus a secondary research objective was to assess the potential of using the SWAT model to reliably predict P movement, including from new technologies like controlled drainage structures.

The remainder of the paper is structured somewhat unconventionally. First, we provide background information about the SWAT model developed and parameterized for this study. We then present methods and results from the stage 1 experimental auctions. We follow by presenting methods and results from the stage 2 Tiffin Watershed BMP auctions. We close with discussion and conclusions covering both stages of the research.

Overview of the Soil and Water Assessment Tool

SWAT is a physically based, semi-empirical hydrologic and water quality model that can be used to simulate and calibrate daily watershed conditions to streamflow and water quality data available for a specific watershed area of interest (Gassman et al., 2007; Neitsch et al., 2011). The model was originally developed for the USDA Agricultural Research Service (ARS) in 1998 (Arnold et al., 1998). It has since been adapted to numerous watersheds, including the Maumee River basin and the Tiffin River watershed, located within the Maumee basin (Bosch et al., 2011; LimnoTech, 2013).

SWAT represents non-contiguous land areas that have consistent climate and drainage area characteristics (e.g., land use/cover, soil type, and slope) as representative hydrologic response units (HRUs). One or more user-defined HRUs are nested within a specific sub-basin (or subwatershed), which is nested within a larger drainage basin (watershed). For example, a particular sub-basin might include a number of physically separate (i.e., non-contiguous) but comparable agricultural fields (i.e., based on similarities in crop rotation, soils, and slope) that, if desired, can be represented by a single HRU in SWAT rather than as individual fields. The simulation of water movement in the HRUs associated with a particular sub-basin allows prediction of daily flow and mass loading of sediments and nutrients, such as P, from the land to a stream reach associated with the sub-basin. Reaches representing individual sub-basins are linked together in the model to represent the stream network(s) within the watershed, and flow and constituent mass are routed through this network to the watershed mouth. Instream processes represented for individual reaches in SWAT can result in either an increase or a decrease in mass as constituents such as P are routed through the stream network. Fig. 2 presents a conceptual diagram of water and nutrient flows in the SWAT model, including the inputs required and the outputs generated.

For the actual and experimental reverse auctions, calibrated SWAT models of the Maumee River basin and the Tiffin River watershed were applied to simulate the reductions in phosphorus export that would result from the implementation of specific BMP(s) for discrete (actual or hypothetical) farm fields. Because BMP performance can vary dramatically with soil type and topography, simulation provides a potentially useful way to predict environmental performance of BMPs at nonresearch sites where direct measurement of environmental outcomes is infeasible.

Stage 1: experimental auctions

The primary objective of the experimental auctions was to evaluate farmer preferences for alternative conservation incentives in order to identify the most cost-effective incentive design. The secondary objectives were to 1) evaluate how bids differed among four BMPs, and 2) analyze group bids versus individual bids for the same BMPs. Prior research has shown that farmers' willingness to accept PES to adopt new BMPs depends on traits of both the farm (e.g., area, equipment, soils, topography) and the farmer (e.g., attitudes, education, preferences) (Feder et al., 1985; Ma et al., 2012; Prokopy et al., 2008); therefore, the experimental auctions aimed to focus on how attitudes and preferences affected farmer bids, abstracting from the physical traits of the farm. This set of auctions also sought to evaluate farmer willingness to cooperate by bidding jointly to implement one or more BMPs on adjacent fields under different ownership.

The specific incentives of interest involved the following four payment mechanisms: direct payment, direct payment with "green insurance" (to protect against potential yield loss due to a BMP), income tax credit, and price premium for crops produced with certified stewardship. Preferences for the four incentives were evaluated by determining how the magnitude of a farmer's bids differed among the four incentives offered. Lower bids for a particular incentive were indicative of a higher willingness to enroll in that type of program. In other words, the farmer would require less financial incentive to adopt the BMP if that incentive were offered, relative to a different type of incentive for which he or she would demand more. Bids from individual farmers were also compared to bids from pairs of farmers and to bids from farmers when a phosphorus abatement target was announced for the entire group.

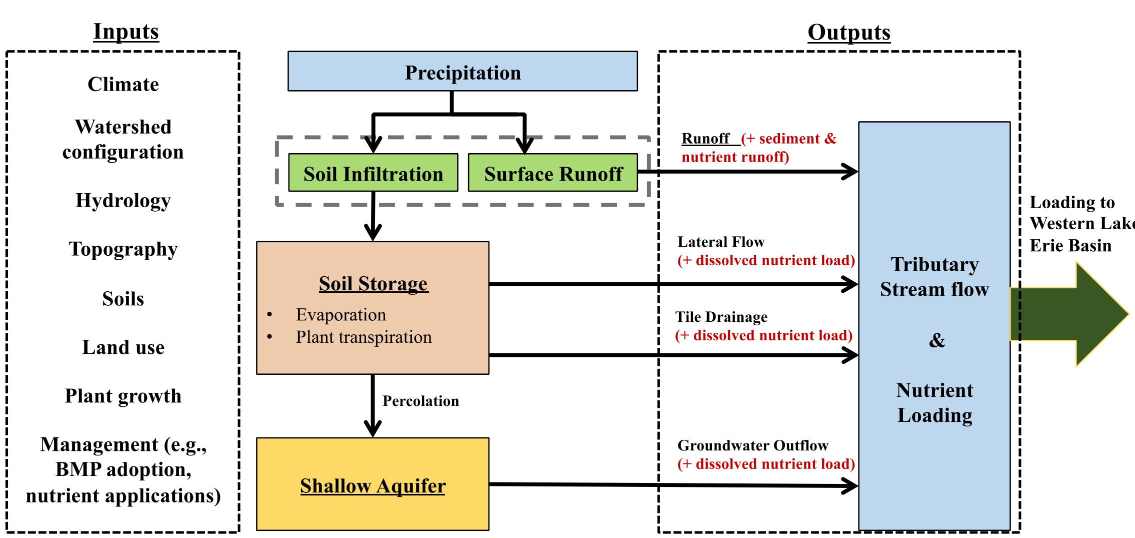

Fig. 2. Conceptual diagram of the Maumee Soil and Water Assessment Tool (SWAT) model. Adapted from Redder (2014). The key nutrient of interest for this research is phosphorus.

Methods: experimental auctions

In order to separate out the influence of specific farm circumstances while facilitating research about coordinated field management, the experimental auction research was based on artificial “mock farms” (Fig. 3). Farmer participants were asked to imagine that they were the manager of a mock farm whose resources were described on an information sheet given to each of them (Palm-Forster, 2015). In a series of auction rounds, participants were asked to submit bids for one or more of the following BMPs: (1) cover crops, (2) reduced tillage, (3) spring fertilization instead of fall fertilization, and (4) filter strips. Participants earned money in the experiment based on the profitability of their mock farms; however, their decisions in the experiment were not linked to real actions on farmland they owned.

A SWAT watershed model calibrated for the Maumee River basin (Bosch et al., 2011) was used to support the experimental auction by quantifying the benefits of specific BMP options for the mock farms presented to participants. The modeling evaluation included quantification of the “local” reduction in phosphorus export from individual mock farms and also the effective reduction in phosphorus export at the mouth of the Maumee River (i.e., based on simulating the effect of instream processes on ultimate phosphorus delivery). The modified Maumee basin SWAT model was used to evaluate and compile BMP effectiveness outcomes for each mock farm in advance of the experimental auction. This allowed the researchers to rank the bids during the auction session in order to facilitate the experiment.

Sixteen mock farms were designed to represent corn and soybean farms in the Maumee River basin. The individual mock farms were modeled by incorporating 16 new HRUs into the Maumee River basin SWAT model developed by Bosch et al. (2011). As shown in Fig. 3, farms were grouped in four clusters that each included four farms, and the clusters were positioned at various locations in the Maumee River basin in order to introduce variability in the transport pathways and distance from a given farm cluster to the Maumee River mouth (as dictated by the model's stream network). The clusters were assumed to be located in the St. Joseph River, Tiffin River, Lower Auglaize River, and Lower Maumee River watersheds.

Model input parameters were configured for each mock farm by consulting with experts to establish common cropping systems and practices in the region. Acreage, cropping system (i.e., tillage, rotation), and average crop prices were held constant across farms while soil type, average yield, and cost of conservation practices varied among mock farms to account for the heterogeneity among farms in the region. For simplicity, each mock farm totaled 200 ac (81 hectares) and was divided into two 100-ac (40.5-ha) fields. Among the 16 mock farms, eight unique geographic farm characteristics were established by assigning unique soil types to each pair of farms based on the two dominant soil types for the region in which each cluster was located.

Information was provided to participants about their mock farm, including acreage, soil type, cropping system, average crop yield and prices, baseline management practices, and costs of implementing conservation practices. Providing this information allowed us to control for factors that may influence farmers' willingness to adopt conservation practices, specifically the location effect on payment (soil type, location in watershed), yield risk, opportunity cost of land (yield, price), and direct cost of conservation practices. Participants were also told how much it would cost them to implement each BMP on their mock farm. Four BMP cost levels were assigned to the 16 mock farms using a main-effects orthogonal design, and costs ranged roughly from 50% to 150% of the payment levels set forth by the Natural Resources Conservation Service (NRCS) Environmental Quality Incentives Program (EQIP) for Ohio in 2012.

Farmers were mailed personalized invitations to the experimental auction meetings. To enhance credibility, cover letters explaining the purpose of the meetings were co-signed by leaders in the agricultural communities where each auction was held. The auctions were held at four sites in the Maumee watershed. Upon arrival, participants were asked to sign a consent form, to accept a $50 participation honorarium, and to review the contents of a folder that included details about their mock farm and general instructions. Farmers were told the purpose of the auctions and informed that the auctions would be conducted in

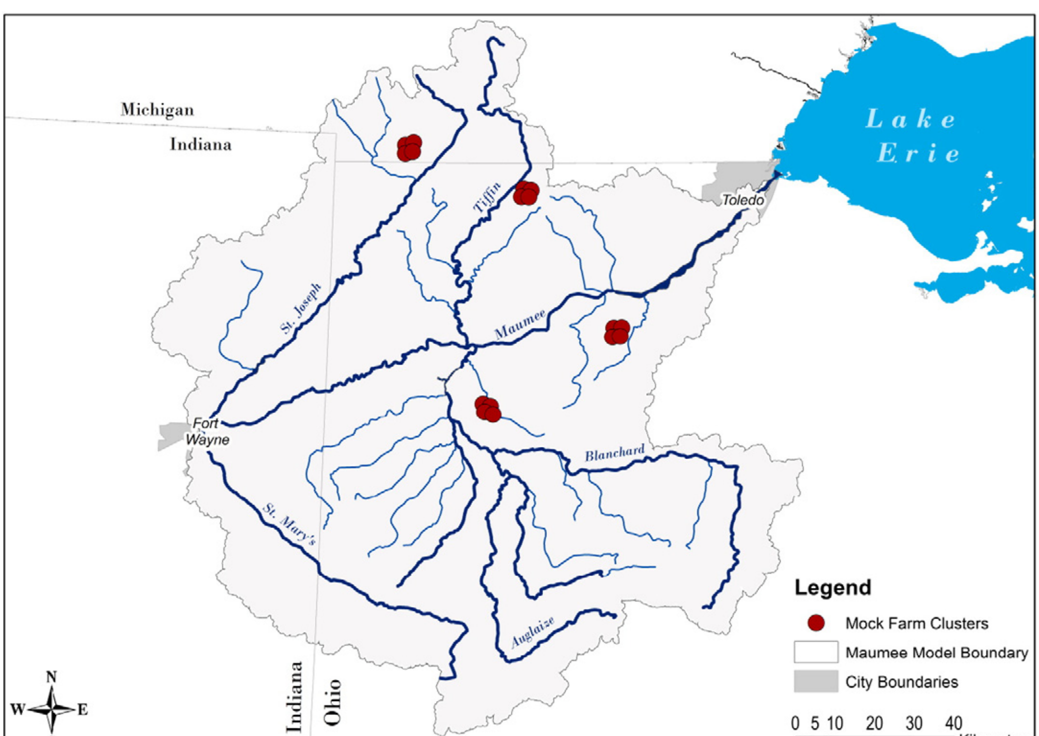

Fig. 3. Mock farm cluster locations in the Maumee River basin used in the experimental auctions.

series, but they were not told the exact number or type of auctions in which they would participate.

In the series of seven auction rounds, farmers submitted bids to adopt conservation BMPs with different types of financial incentives, making decisions as if the mock farms were their own. In the first four rounds, farmers submitted bids individually for different types of incentives. In the final three rounds, farmers submitted bids jointly. The order of the auction rounds was the same across the four sessions, so participants were always presented with the most familiar program first. If more sessions had been held, the order that the auctions were presented to participants would have been varied to control for anchoring and ordering effects that have been highlighted in the literature on experimental auction design (Lusk and Shogren, 2007).

In the first round of the auction, farmers submitted bids for a direct payment, which is the most straightforward transaction and the one typically used to promote voluntary conservation. Next, farmers were asked to submit another bid for a direct payment if they were also provided with fully subsidized (i.e., free) green BMP insurance. In the following rounds, farmers submitted bids for a tax credit and then a price premium per bushel that was tied to an environmental stewardship certification.

In all auction rounds, three protocols were consistently followed. First, farmers were invited to submit bids to adopt one or more of the following three in-field conservation practices: 1) cover crops, 2) conservation tillage, and 3) spring fertilization instead of fall fertilization. Farmers could also submit bids on a fourth practice, planting a filter strip, which would take that land out of crop production for the year. If a farmer bid on more than one practice, then the group of practices was evaluated as a package.

Second, the predicted reduction in total phosphorus (TP) export from adopting the conservation practices proposed in each bid was calculated using the Maumee River basin SWAT model. The SWAT model was configured to generate a “baseline” simulation, including selected soil types, land slopes, and representative management practices for the region. Additional simulations were developed to represent the implementation of each candidate BMP for each mock farm. Four BMPs were modeled including the three field conservation practices as well as implementation of filter strips to treat surface runoff generated by the farms. Each mock farm was simulated as a separate HRU that individually contributed runoff and TP load to the stream network in the model. For auctions in which farmers bid individually, no physical connection between the farms was represented, and BMPs simulated for a given farm had no influence on other mock farms. When farmers were permitted to bid jointly, farmers were informed that filter strips on one field could filter a portion of the runoff from an adjacent upland parcel. The results of the baseline and BMP simulations for each farm were used to compile a matrix of results, which included local TP yields (i.e., at the HRU scale), the ultimate TP yields to Lake Erie (i.e., taking into account transport through the stream network), and simulated corn and soybean crop yields. Based on this information, the relative changes in TP and crop yields were computed for each of the individual BMP scenarios relative to the baseline simulation. A spreadsheet tool summarizing the results was developed in advance of the auction event in order to facilitate rapid retrieval of results during the auction.

Third, bids were sealed and no information concerning outcomes was provided between rounds. Additionally, farmers only learned about bid acceptance at the end of the session; therefore, the potential for learning and strategic bidding during the auctions was limited.

In the auctions for direct payments, direct payment with BMP insurance, and tax credits, bids were ranked based on the predicted payment per pound of reduced TP export, where the payment equaled the bid submitted by the farmer. Mock contracts were offered to those farmers who made the most cost-effective bids (lowest cost per pound of TP reduction) until the budget was exhausted. The budget for each auction was set at $100,000 experimental dollars, but this was unknown to farmers.

A different procedure was followed to evaluate bids for price premiums. In those rounds, farmers bid for the price premium that they would require in order to become certified for adopting all three in-field BMPs (cover crop, conservation tillage, no fall fertilization). Filter strips were not required for the certification. A Becker–DeGroot–Marschak (BDM) mechanism was used to determine which bids were accepted in the experiment (Becker et al., 1964). To implement the BDM mechanism, participants submitted their bids and then random prices were drawn from known distributions to determine who was accepted into the program. Possible premiums were between $0 and $1 for corn and $0 to $2 for soybeans, in one-cent increments. If the farmer participant bid more than the randomly drawn price premium, the bid was not accepted. If the farmer bid less than or equal to the premium drawn, the bid was accepted and the price premium received by the farmer was the price that was drawn. The BDM mechanism was chosen in order to mimic how this type of certification program would work in reality. A price premium would be established, and then farmers would decide whether or not they were willing to adopt the required practices for that amount of money. Additionally, the BDM mechanism gives participants an incentive to bid the true amount of money that they would require instead of bidding strategically. Note that the price premium is based on BMP adoption alone, not on where the BMP is applied, so site-specific environmental performance is not factored into the contracting decision.

In the final three rounds of the experimental auctions, farmers were asked to submit bids jointly. In rounds five and six, farmers were paired based on the locations of their mock farms such that neighboring farmers were partnered together. In round five, farmers discussed their bids together, but bid individually (Joint Contract 1). Then, in round six, pairs of farmers submitted joint bids (Joint Contract 2). In both rounds, farmers could individually decide which practices they wanted to adopt and the level of payment that was required, but farmers discussed their bids together. In the last round, participants were asked to bid individually, but they were told that bids would not be accepted unless, as a group, TP export was reduced by 50% without exceeding the program budget. In this round, farmers were given additional information about the environmental vulnerability of their land by telling them if their farm was in a low-, medium-, or high-vulnerability area. Farmers were informed that adopting BMPs on fields in high vulnerability areas would result in more TP reductions than adopting the same BMPs in medium or low priority areas. In these rounds, farmers bid for the direct payment that they would require.

In addition to the $50 participation honorarium, participants received payments based on their performance in the auctions. Performance was measured by the total income generated by their mock farm in all auction rounds. Net winnings in each round equaled the difference in farm profits with and without the conservation program. So, for example, the filter strip BMP that took land out of crop production reduced crop revenues, but farmers could earn revenue from the new incentive payment. The additional payments based on auction performance ranged from $38 to $68 per auction participant, with an average payment of $52. See Palm-Forster (2015) for additional details about the implementation of the experimental auctions.

Results: experimental auctions

Fifty-one farmers participated in the experimental auctions. One participant was not a corn and soybean farmer and another failed to complete all of the questions, leaving 49 records eligible for the analysis. Auction participants included in this analysis were recruited using mailing lists from county Soil and Water Conservation Districts (69%), Ohio Farm Bureau (15%), an input supplier (10%), and property tax rolls (6%).

Since auction participants had been told the exact cost to their mock farm of adopting each BMP, it was possible to calculate a “net bid” for each BMP. Net bids were calculated as the amount the farmer bid for that incentive transaction minus the assigned cost of BMP implementation. A positive net bid indicated that the farmer demanded more than their expected implementation cost to undertake the BMP, whereas a negative net bid meant that the farmer was willing to give up some expected profit to adopt the BMP. Because many farmers value environmental stewardship, a negative net bid may be a rational statement of willingness to trade off income for improved environmental quality.

The results from the experimental auctions shed light on all three objectives. On the cost-effectiveness of the incentive types, the mean net bids were highest in the auction for payments with green insurance, meaning that this was the least cost-effective option. As shown in Table 1, net bids were lowest for the tax credit and the direct payment.

Bids for certification price premiums were not significantly higher than bids for direct payments, but as shown in Fig. 4, the bids were less cost-effective because payments were not spatially targeted. In these rounds, farmers were told that they would be enrolled in the certification premium if their bid was less than or equal to the randomly drawn price premium. Rather than reporting randomly drawn premiums, Fig. 4 presents the cost per pound reduction in TP when the certification premium is set at the mean premium bid submitted across the four auction sessions ($0.43/bu for corn and $0.90/bu for soybeans). As a practice-based premium, it did not involve ranking based on potential environmental benefits from the BMPs. Instead, land is enrolled in the program if the farmer is willing to accept the price premiums offered (i.e., enrollment occurs if the bid submitted is less than or equal to the per bushel price premiums). The resulting lack of spatial targeting explains the higher unit cost of TP mitigation under the price premium incentive mechanism.

Fig. 5 illustrates the relative cost and benefits that could have been generated based on bids submitted in the experimental auctions for three in-field practices. It is important to note, however, that the exact values shown in the figure do not represent true costs or benefits on farmers' own fields because auction participants were submitting bids for mock farms and they were told their costs of adopting each BMP. Of particular interest are the relative differences among the number and magnitude of bids submitted and the predicted reduction in TP export. Interestingly, although the direct cost of shifting P fertilization from fall to spring was negligible ($0–3/ac ($0–$7.41/ha) on the mock farms), the net bids showed that farmers demanded a significant premium above costs due to 1) the perceived time conflict in spring between fertilization and planting activities and 2) concerns about soil compaction in the spring (see Table 2). Fewer people bid to adopt this practice and overall benefits generated were less than the other BMPs, which is reflected in the shorter cost–benefit curve shown in Fig. 5. Among the three in-field BMPs examined, cover crops appeared to yield the most TP reduction for a given budget although this practice was the most expensive.

Net bids by pairs of farmers and individual farmers in the experimental auctions were not significantly different. Fig. 6 presents the cost per pound (kilogram) of reduced phosphorus export. Although overall costs per pound of reduced TP export did not consistently change across the individual and group goal sessions, the variance in unit costs of TP mitigation increased between bids for individual payments (Individual Payment and Joint Contract 1) and bids when farmers bid jointly (Joint Contract 2). In Joint Contract 1, bids were evaluated jointly, but participants submitted their bids individually and were paid individually. In Joint Contract 2, participants had to jointly agree on a bid and agree on how the payment would be divided if their joint bid was accepted. The standard deviation of unit costs for in-field practices when participants bid individually and jointly was 22.1 and 37.7 $/ac (54.6 and 93.2 $/ha), respectively. Results suggest that groups may be affected by joint contracts differently. However, as we discuss in the Conclusions section, it is not clear whether the group bidding behavior displayed in the experimental auctions is representative of farmers' true willingness to bid jointly because they did not opt to do so in real auctions.

Consistent with previous research (Cason et al., 2003), there is some evidence that the environmental vulnerability information provided in the final auction session caused farmers with vulnerable lands to increase their bids to strategically extract larger payments from the auctioneer. However, small sample size and the design of our experiment limit our ability to draw causal inferences about the effect of information on bidding behavior in multiple auction environments. A valuable contribution of future research would be to test the impact of providing environmental information on participation decisions when farmers can submit bids individually and jointly.

Stage 2: Tiffin Watershed BMP auctions

The results of the experimental auctions set the stage for scaling up to a public auction at a county scale. Two reverse auctions were implemented in the Tiffin Watershed, which is a subwatershed of the Maumee River basin (Fig. 7). The auctions were administered by Michigan State University with support from the Fulton Co. and Defiance Co. Soil and Water Conservation District (SWCD) offices. The Tiffin Watershed BMP auctions used the direct payment incentive type, both because it was tied for the most cost-effective incentive in the experimental auctions and because it was tractable for researchers to implement with farmers (which a tax credit was not).

The Tiffin Watershed BMP auctions began with three objectives, but ended with four:

1) To field-test reverse auctions for the most cost-effective payment incentive type under county-scale public auction conditions. Specific sub-objectives were to evaluate how auction participation affects cost-effectiveness of P abatement and to evaluate large-scale use of SWAT on real farm fields.
2) To assess the willingness of different landowners to coordinate BMP and submit joint bids, and to evaluate the cost-effectiveness of those bids.
3) To test the effect on auction participation of providing landowners with information on environmental vulnerability of specific fields (as a clue to the likelihood of a winning bid).

Table 1
Summary statistics of net bids (i.e., bid minus the cost of BMP implementation) for in-field practices (cover crops, conservation tillage, and fall fertilization) among four transaction types. Units are $/ac/yr ($/ha/yr). All 49 participants submitted bids in the auction for a conservation payment; however, only 47 bids were submitted in the auctions for the alternative transactions. The participants who chose not to submit bids varied among the three auctions.

Auction transaction type	n	Mean	Std. dev.	Min	Median	Max
a) Payment	49	11.0	22.7	−42.0	7.0	64.0
		(27.2)	(56.1)	(−103.8)	(17.3)	(158.1)
b) Payment with green insurance	47	24.0	61.8	−46.0	3.0	249.0
		(59.3)	(152.7)	(−113.7)	(7.4)	(615.3)
c) Tax credit	47	3.4	30.1	−43.0	−1.0	96.0
		(8.4)	(74.4)	(−106.3)	(−2.5)	(237.2)
d) Certification price premium	47	8.7	40.3	−47.4	2.3	134.2
		(21.5)	(99.6)	(−117.1)	(5.7)	(331.6)

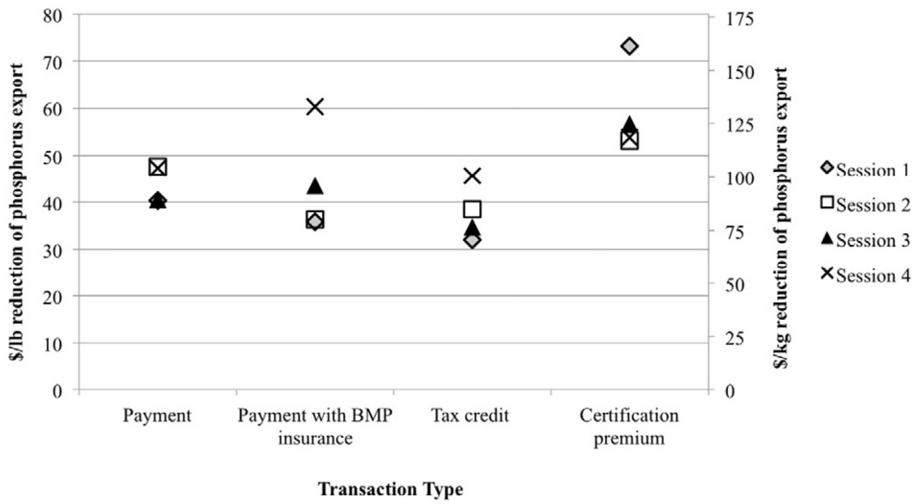

Fig. 4. Costs per pound (per kg on right vertical axis) of total phosphorus (TP) abatement for experimental auctions for four contract types using mock farms. Only accepted bids for in-field BMPs are represented. For each auction type, the cost per pound TP is calculated by dividing the total amount paid to farmers with accepted bids by the total predicted reduction in TP export generated by funded practices.

4) (Ex post) To evaluate the factors that determine nonparticipation in a conservation auction.

Methods: Tiffin Watershed auctions

The county-specific auctions were announced in June 2014 and bids were accepted between July and September 2014. To generate awareness about the auctions, notification letters were mailed to the owners of all eligible agricultural parcels ($n^{Defiance} = 507$; $n^{Fulton} = 578$). These letters explained the purpose of the auction and directed landowners to a county-specific website for more information. Using a postage-paid postcard, landowners could request a bidding packet by mail. Bid packets were also available at the local SWCD offices and on the auction websites. An informational meeting was held in each county in mid-July. Informational fliers were posted at local grain elevators, and the auctions were announced in local newspapers, the SWCD newsletters, and Farm Service Agency (FSA) emails that were distributed in both counties. Reminder postcards were mailed a month prior to the bidding deadline.

The auctions incorporated an environmental information treatment that differed between Defiance and Fulton counties. Landowners in Defiance County received a letter indicating the environmental vulnerability of one of their fields (high, moderate, or low). Landowners in Fulton County received no such information. Based on prior studies, environmental information was expected to boost participation (Glebe, 2013) and increase bid levels because participants may believe that they can get more money when their BMPs generate high ES (Cason et al., 2003).

Land managers were invited to submit bids to adopt three eligible BMPs, 1) winter cover crops (all varieties), 2) filter strips, and 3) subsurface drainage control structures. Although spring fertilization and conservation tillage were included in the experimental auctions, they were omitted from the real auctions because they cannot be observed easily for purposes of verifying compliance with a BMP contract. For the same reason, we did not include reduced fertilizer application as a BMP. Conservation tillage was omitted because this BMP is better suited to control phosphorus attached to soil particles, whereas the goal of the real auctions was to reduce soluble reactive phosphorus (SRP) due to its contribution to Lake Erie HABs. Drainage control structures were added because of growing farmer interest and their potential to hold back

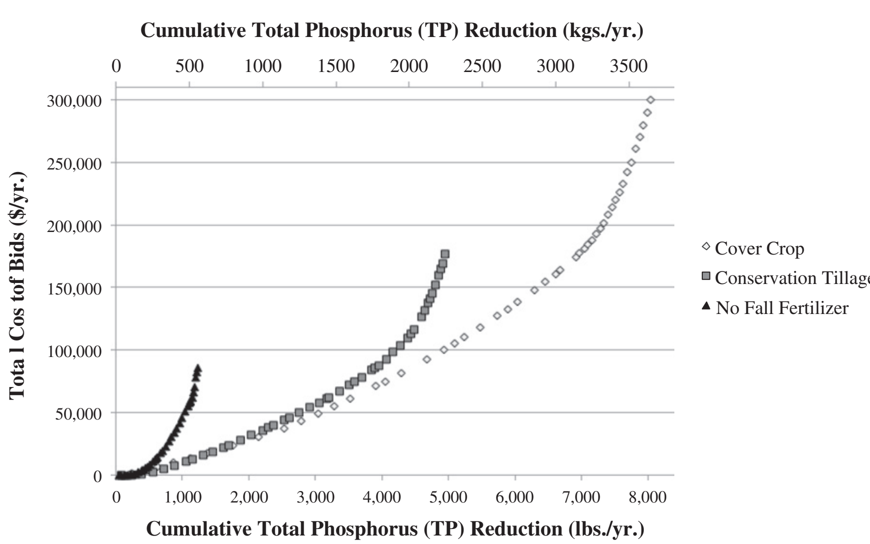

Fig. 5. Bids from the experimental auctions for individual direct payment contracts are plotted against the cumulative total phosphorus (TP) reductions (lbs. per yr on bottom horizontal axis, kg per yr on top horizontal axis) for four practices implemented on mock (hypothetical) farms.

Table 2
Net bids compared to range of direct costs for BMPs implemented on mock farms in experimental auctions. Units are $/ac/yr ($/ha/yr).

BMP	Range of BMP implemention costs for mock farms		Mean net bid	Std dev. of net bids	Range of net bids
Cover crops		[20, 32] ([49.4, 79.1])	6.2 (15.3)	13.4 (33.1)	[−20.0, 31.0] ([−49.4, 76.6])
Conservation tillage		[16, 28] ([39.5, 69.2])	−2.5 (−6.2)	10.0 (24.7)	[−23.5, 22.0] ([58.1, 54.4])
Spring fertilizer		[0, 3] ([0, 7.4])	9.8 (24.2)	9.4 (23.2)	[−1.0, 38.0] ([−2.5, 93.9])
Filter strip	installation	[28, 34] ([68.2, 84.0])	−165.2 (408.2)	191.0 (472.0)	[−378.0, 568.0] ([−934.1, 1,403.6])
	forgone profit	400 (988.4)			

nutrient laden drainage water at the time of peak nutrient delivery into Lake Erie. All funded BMPs were to be implemented during the following year (2015). Contract lengths were 1 year for cover crops and 2 years for filter strips and control structures. Bids were invited both from individual landowners and from pairs or groups. In addition to the bid, participants were required to fill out a management questionnaire describing the field and their status quo management regime. This information was necessary to parameterize the SWAT model so that it could predict the baseline amount of phosphorus emitted from individual fields in order to calculate how much export would be reduced by the proposed BMP. Landowners could drop off their bids at the SWCD office or submit via postal mail. All bids were private.

All submitted bids were evaluated via application of the Tiffin River SWAT (TRSWAT) model, which was originally developed and calibrated to provide a fine-scale simulation of hydrology and sediment and nutrient export from agricultural and other lands for more than 900 subbasins in the Tiffin River watershed (LimnoTech, 2013). The original HRU representation in the TRSWAT model was modified to incorporate a uniquely defined cropland HRU to represent each individual field for which a bid was submitted. The physical and baseline (i.e., current) land management characteristics for each bid-derived cropland HRU were defined based on either field-specific information provided by the bidder or publicly available spatial datasets. The dominant soil type and average slope for each field-based HRU were determined via a geographic information services (GIS) analysis of the NRCS SSURGO soils data layer and a 1-m digital elevation model obtained from the Ohio Statewide Imagery Program, respectively. Model inputs for field area, crop rotation, and the timing and type of tillage operations and nutrient application (i.e., fertilizer) practices were specified based on

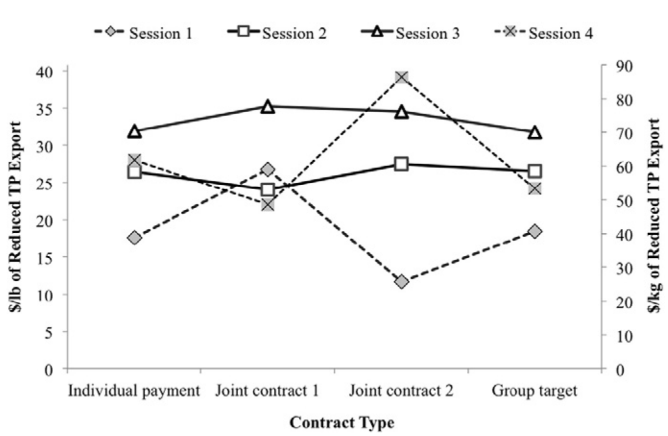

Fig. 6. A comparison of the average cost per pound of reduced total phosphorus (TP) export for bids submitted in experimental auctions for four contract types (cost per kg of TP on right vertical axis). Farmers bid on in-field BMPs and filter strips for mock (hypothetical) farms. Relative to auctions for individual payment contracts, there is greater variation in the cost per pound of reduced TP export when farmers bid in joint contracts; however, there is no statistically significant difference in bids.

information provided by each bidder. In addition, tile drainage was represented in the SWAT model for those field-based HRUs for which bidders indicated subsurface tile drainage was active.

Following the initial configuration of the TRSWAT model, a "baseline" simulation was generated based on the representation of current field conditions, including current management practices documented for each field identified in the management questionnaire that accompanied each bid. Next, the field-derived HRUs represented in the model were modified to represent the implementation of the BMP(s) cited in the submitted bid(s) for each field, and a second model simulation was executed to represent BMP conditions for each field. The results of the simulations were compiled and used to calculate the reduction in the export of bioavailable P (lbs/yr) from each individual field and to the mouth of the Tiffin River.

Unlike the experimental auctions, which had ranked bids by cost to reduce total phosphorus (TP), the Tiffin BMP auction ranked bids according to cost and predicted reductions in bioavailable phosphorus export to nearby streams. Bioavailable P is a weighted average that accounts for 100% of the soluble reactive phosphorus (SRP) and 30% of the particulate phosphorus (PP). Bioavailable phosphorus was identified as the target pollutant because this portion of phosphorus drives algal production in Lake Erie (Baker, 2010). SRP is fully available for biological processes. PP, including inorganic and organic forms, is sorbed to soil particles and makes up a large portion of total phosphorus, but studies of northwestern Ohio rivers have shown that only about 30% of total PP ultimately becomes bioavailable (DePinto et al., 1981). SRP concentrations reported in the literature are highly variable, ranging from 1 μgP/l to greater than 1000 μgP/l (Williams et al., 2015a, 2015b). Three assumptions about SRP concentrations in tile drains were tested to determine the effect of this assumption on bid rankings; the three assumptions were 35, 150, and 500 μgP/l.

Upon receipt of all bids, the final ranking of bids was based on TRSWAT model runs that were parameterized for the high SRP concentration (500μg P/l) in drain outflows (the midpoint of the reported concentrations range of 1 - 1,000 μg/l (LimnoTech, 2013; Williams et al., 2015a, 2015b)). The most cost-effective bids (lowest cost per pound reduction in bioavailable P export) were accepted in rank order until the budget for that county was exhausted ($25,000 per county). Bidders were notified about bid acceptance in mid-November and winning bidders signed contracts prior to December 31, 2014. Land managers with accepted projects were paid 50% of the payment when the contract was signed and 50% upon verification that the BMP had been installed according to the contract.

Follow-up questionnaire

Although not originally planned as part of this research, low participation in the public auctions prompted a follow-up survey of all nonparticipants in the auctions. The objective of the follow-up questionnaire was to identify participation barriers and deterrents for those landowners who did not submit a bid in the conservation auction. The

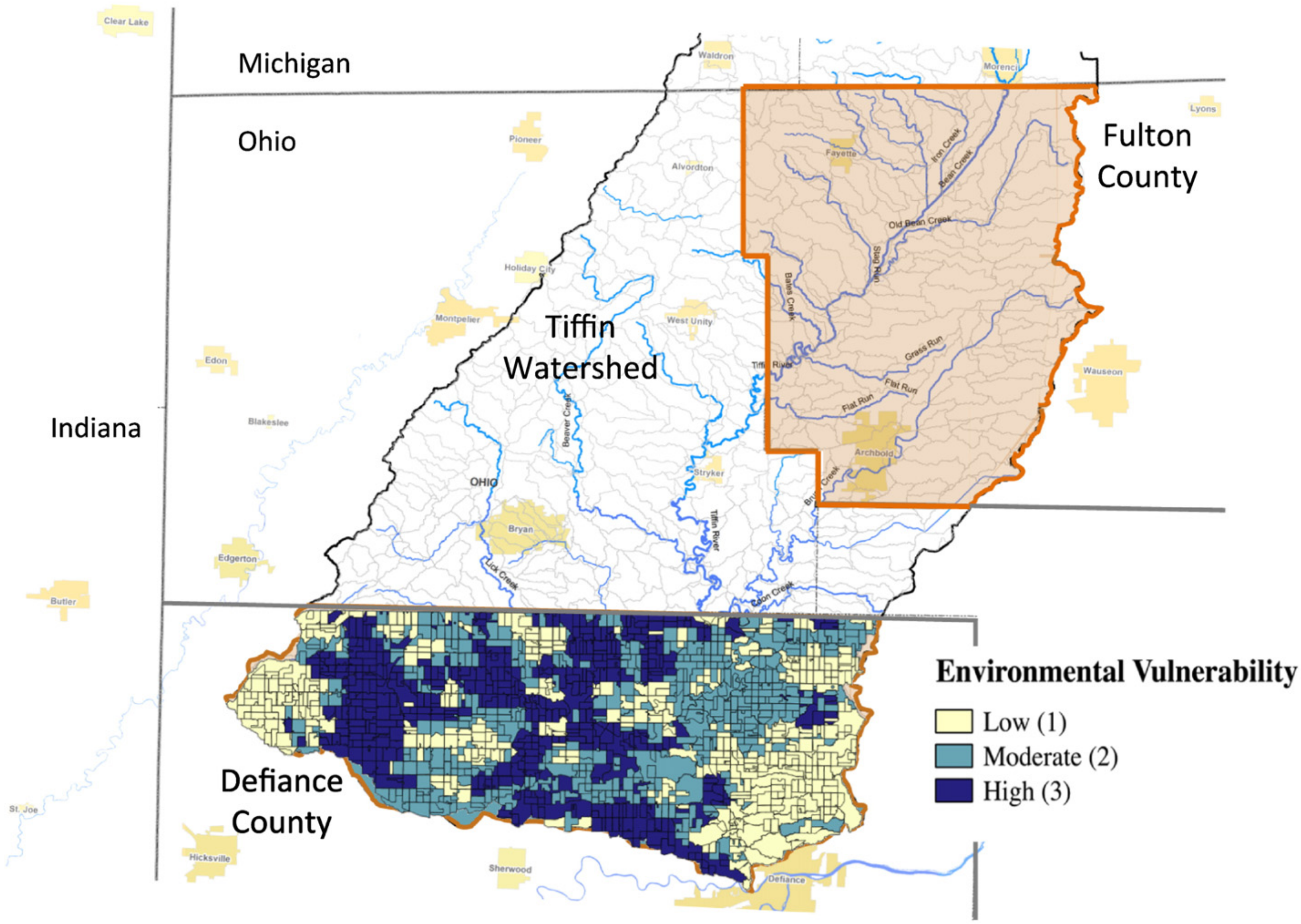

Fig. 7. Tiffin BMP auctions covered the areas of Defiance and Fulton counties in the Tiffin Watershed

questionnaire was mailed to the 1072 landowners in Defiance Co. and Fulton Co. who were originally invited to participate in the Tiffin BMP auctions but who did not submit a bid. The questionnaire was designed based on feedback received during the open bidding period of the BMP auctions. To maximize response rate, the questionnaire was limited in length to one, two-sided page. Furthermore, most of the questions could be answered by simply checking a box indicating "yes" or "no." The questionnaire is available in Palm-Forster (2015).

The first four sections of the questionnaire were designed to identify factors that influenced knowledge of the auction, eligibility to participate, and willingness to submit a bid. To gauge knowledge, the first section asked respondents to indicate the sources from which they had learned about the auction. In the second section, respondents were asked if they had received a bid packet from a list of sources. Acquiring a bid packet indicated that the individual had made an active attempt to participate. The third section explored barriers and deterrents to participation by providing a list of potential reasons for not submitting a bid and asking respondents to indicate which reasons applied to them. Eligibility and willingness to adopt were also evaluated in section four in which respondents were asked to indicate which BMPs they currently use and the extent of their adoption. The fifth section of the questionnaire used a set of Likert scale questions to elicit landowner attitudes toward the environment, stewardship, and conservation programs. The final set of questions asked about land ownership and rental as well as the percentage of household income earned from farm-related activities.

Questionnaires were mailed using a three contact survey method, including 1) a cover letter with the questionnaire and one dollar incentive payment, 2) a postcard reminder, and 3) a replacement questionnaire. Overall, 455 questionnaires out of 1072 were returned. Ten were returned blank. The response rate was 42% overall, with response rates of 38% in Defiance Co and 45% in Fulton Co. (Palm-Forster, 2015).

Results: Tiffin Watershed auctions

Relative to the first objective of field-testing the reverse auction at county scale, the auctions yielded important results regarding participation, and how it affects cost-effectiveness. Participation was very low: only 1% of invited landowners submitted bids for the Tiffin BMP auctions. All bids came from individual bidders; none were submitted by pairs or groups of bidders. Bids for cover crops ranged from $30 to

Table 3
Summary of bid submission in the Tiffin BMP auctions

	Unit	Fulton	Defiance	Total
Land managers who submitted a bid	Bidders	6	4	10
Total number of bids submitted	Bids	23[a]	12[b]	36
Number of bids for cover crops	Bids	19	8	27
Number of bids for drain control structures	Bids	1	4	5
Number of bids for filter strips	Bids	4	0	4
Total land area proposed to be treated with BMPs	Acres (hectares)	998 (403.9)	510 (206.4)	1,508 (610.3)
Total funding requested	$	$35,926	$26,620	$62,546

[a] Twenty-four bids were submitted, but one was ineligible because the field was located east of the Tiffin watershed.
[b] Three bids were withdrawn prior to bid evaluation.

$50/ac/yr ($74.1–$123.5/ha/yr), those for filter strips ranged from $6 to $31/treated ac/yr ($14.8–$76.6/treated ha/yr), and subsurface drainage control systems ranged from $1200 to $2000/structure.

A total of ten landowners participated, submitting bids on 36 parcels of land. Six participants submitted bids in Fulton Co., and four participants bid in Defiance Co. This participation outcome is similar to an auction conducted in a Kansas watershed in which 12 landowners submitted 24 bids for BMPs (Smith, Nejadhashemi and Leatherman 2009). Table 3 presents a summary of bids submitted in each auction. In Defiance County, cover crop bid averages were $36/ac ($89/ha) for cereal rye, $50/ac ($124/ha) for an oat/radish mix, and $50/ac ($123.5/ha) for annual ryegrass (weighted by acreage). Bids for drainage control structures averaged $1700 per structure, and each structure would treat an average of 23 ac (9.3 ha). In Fulton County, cover crop bids averaged $34/ac ($84/ha) for cereal rye, $35/ac ($86/ha) for clover, and $50/ac ($124/ha) for oats (weighted by acreage). Oats are not typically funded as a cover crop in most conservation programs; however, a SWAT analysis predicted substantial reductions in bioavailable P runoff. Therefore, the bid was permitted. One bid of $1200 was submitted for a drainage control structure that treated 8.4 ac (3.4 ha). Four filter strip bids were submitted between $75 and $400 per location, which treated 5–53 ac (2–21.4 ha) per filter strip.

Prior to bid evaluation, one Defiance County landowner withdrew his three bids so he could apply instead to another program. One of the bids in Fulton County was outside of the Tiffin subwatershed and thus ineligible for the program. Thirty-two bids were evaluated and ranked to determine which offered the most cost-effective reductions in bioavailable P export.

After bid evaluation, 29 bids were accepted into the program (20 in Fulton and 9 in Defiance). The funding agency awarded an additional $651 to Defiance County to fund all of the bids. Table 4 provides a summary of accepted bids. One farmer did not accept his approved contract for cover crops because he decided he was not yet willing to try the new BMP. Low participation led to funding bids with high cost–benefit (CB) ratios at the margin. Most high CB ratios occurred on fields where TRSWAT predicted small reductions in bioavailable P export. Overall predicted cost-effectiveness for each auction was $302/lb bioavailable P/yr ($666/kg bioavailable P/yr) in Fulton Co. and $929/lb bioavailable P/yr ($2048/kg bioavailable P/yr) in Defiance Co.

Fig. 8 shows the cost–benefit contract curves for bids submitted in each auction. As the predicted reduction in bioavailable P export rises, costs per unit of bioavailable P reduction increase slowly at first but then rise sharply for the lowest ranked bids, creating a hockey-stick-shaped graph. As noted above, these rankings were based on the baseline assumed SRP concentration in drain outflows of 500 μg/l.

Filter strips were the most cost-effective BMP for bioavailable P mitigation. Their average cost of export reduction of $31.53/lb ($69.51/kg) bioavailable P per year, right in the middle of the range of outcomes from a similar reverse auction in the Conestoga Watershed in Pennsylvania, where the cost-effectiveness of grassed waterways ranged from $2.84/lb. ($6.26/kg) to $54.41/lb ($119.95/kg) of reduced total phosphorus (Selman et al., 2008). Under the baseline assumption on SRP concentrations, costs to reduce bioavailable P with cover crops ranged from $216/lb/yr ($476/kg/yr) to $4739/lb/yr ($10,448/kg/yr). Costs to reduce bioavailable P with drain control structures ranged from $406/lb/yr ($895/kg/yr) to $2310/lb/yr ($5093/kg/yr).

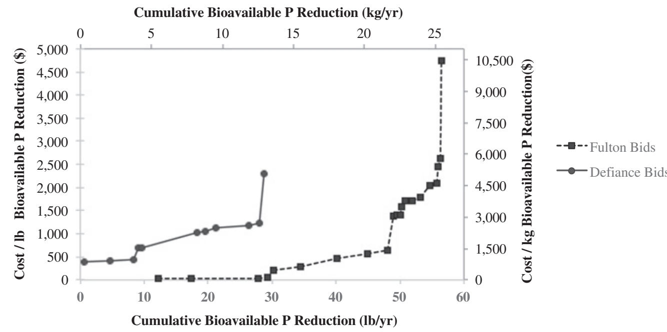

Fig. 8. Contract curves reflects bids and associated cost per pound of bioavailable P reduction submitted in the Tiffin BMP auctions (based on 500 μg/l concentration of soluble reactive P in drain water).

Although filter strips were the most cost-effective BMP for all levels of SRP concentration tested, the ranking of cover crops and drainage management varied considerably. Table 5 shows the effect of three parameterizations of SRP concentration in drainage tile outflows on a) predicted bioavailable P outflows, b) the resulting cost–benefit ratio, and c) the resulting bid ranking. Drainage management was the most sensitive to the SRP concentration parameters because SRP is the main form of P in tile drainage water. Compared to the baseline SRP concentration of 500 μg/l in drain outflows, if the assumed SRP level had been 150 or 35 μg/l, the Fulton County DM treatment would have dropped from bid rank no. 6 to no. 23 (of 23), while the two leading DM bids in Defiance County would have dropped from no. 2 and no. 3 to no. 12 and no. 11 (of 12), respectively (Table 5).

Low participation in the auctions was associated with the results for the second and third objectives of the county-scale auctions. No bids were submitted by pairs or groups of landowners. Likewise, there was no discernable effect of the environmental information treatment offered in Defiance County. Although the mean cost per lb (kg) bioavailable P/yr averted in Defiance County was observed to be higher (as one might predict when information about environmental benefits is revealed), the number of bids submitted was lower (contrary to expectations), and the tiny number of bidders prevents any statistically sound inferences.

In order to understand what caused such low participation in the auction, the follow-up survey data were analyzed to identify barriers and deterrents that limited participation in the auction. The key factors are summarized in Fig. 9. Two primary barriers were identified: 1) lack of information or knowledge of the auction program, and 2) respondents' perceived ineligibility to submit a bid. Conditional on having knowledge about the auction and being eligible to participate, we identified the primary reasons stated for not submitting a bid. Chi-square tests of independence were used to test for relationships among farmer characteristics and the reported participation barriers and deterrents.

Table 4
Summary of bids accepted in the Tiffin BMP auctions.

	Units	Fulton	Defiance	Total
Total number of bids accepted	Bids	20	9	29
Number of bids accepted for cover crops	Bids	15	5	20
Number of bids accepted for drainage control structures	Bids	1	4	5
Number of bids accepted for filter strips	Bids	4	0	4
Total treated land area accepted	Acres (hectares)	755 (305.5)	459 (185.8)	1214 (491.3)
Bioavailable phosphorus reduction	lbs/yr (kg/yr)	50 (22.7)	28 (12.7)	78 (35.4)
Total funding requested	$	$24,924	$25,651	$50,575

Table 5
Effect of three TRSWAT model parameterizations of SRP concentration in drainage tile outflows on a) predicted bioavailable P outflows, b) the resulting cost–benefit ratio, and c) the resulting bid ranking for each county. BMPs include the following: CC = cover crop; FS = filter strip; DM = drainage management.

ID	BMP	Bioavailable P yield reduction and ranking (at the Tiffin River mouth)								
		SRP concentration in tile effluent = 500 μg/L			SRP concentration in tile effluent = 150 μg/L			SRP concentration in tile effluent = 35 μg/L		
		P yield decrease lb/yr (kg/lb)	Cost:Ben $/lb/yr ($/kg/yr)	Bid rank	P yield decrease lb/yr (kg/lb)	Cost:Ben $/lb/yr ($/kg/yr)	Bid rank	P yield decrease lb/yr (kg/lb)	Cost:Ben $/lb/yr ($/kg/yr)	Bid rank
Fulton County										
1	FS	12.11 (5.49)	24.76 (54.59)	1	34.35 (15.58)	8.73 (19.25)	1	34.35 (15.58)	8.73 (19.25)	1
2	FS	5.22 (2.37)	28.72 (63.32)	2	14.99 (6.80)	10.01 (22.07)	2	14.99 (6.80)	10.01 (22.07)	2
3	FS	10.50 (4.76)	38.11 (84.02)	3	29.84 (13.54)	13.40 (29.54)	3	29.84 (13.54)	13.40 (29.54)	3
4	FS	1.50 (0.68)	49.85 (109.90)	4	1.49 (0.68)	50.30 (110.89)	4	1.49 (0.68)	50.45 (111.22)	4
5	CC	0.79 (0.36)	215.63 (475.38)	5	0.76 (0.34)	222.87 (491.34)	6	0.75 (0.34)	225.35 (496.81)	6
6	DM	4.30 (1.95)	279.33 (615.81)	6	−3.08 (−1.40)	–	23	−4.51 (−2.05)	–	23
7	CC	5.74 (2.60)	462.19 (1018.94)	7	5.97 (2.71)	444.11 (979.08)	7	5.09 (2.31)	521.31 (1149.28)	8
8	CC	4.77 (2.16)	565.87 (1247.52)	8	18.52 (8.40)	145.80 (321.43)	5	18.82 (8.54)	143.50 (316.36)	5
9	CC	3.09 (1.40)	647.42 (1427.30)	9	1.00 (0.45)	1999.06 (4407.13)	17	0.31 (0.14)	6365.79 (14034.02)	20
10	CC	0.87 (0.39)	1387.15 (3058.11)	10	0.67 (0.30)	1802.92 (3974.72)	15	0.60 (0.27)	1999.87 (4408.91)	17
11	CC	0.62 (0.28)	1413.85 (3116.97)	11	−0.19 (−0.09)	–	21	−0.45 (−0.20)	–	21
12	CC	0.48 (0.22)	1419.92 (3130.36)	12	0.33 (0.15)	2037.81 (4492.56)	18	0.28 (0.13)	2377.79 (5242.08)	18
13	CC	0.23 (0.10)	1578.17 (3479.23)	13	0.21 (0.10)	1781.73 (3928)	14	0.20 (0.09)	1860.59 (4101.86)	16
14	CC	0.58 (0.26)	1707.95 (3765.35)	14	0.44 (0.20)	2224.08 (4903.21)	19	0.40 (0.18)	2469.26 (5443.73)	19
15	CC	1.03 (0.47)	1710.09 (3770.06)	15	2.85 (1.29)	621.79 (1370.80)	10	2.80 (1.27)	631.02 (1391.15)	10
16	CC	1.39 (0.63)	1793.59 (3954.15)	16	1.63 (0.74)	1530.27 (3373.63)	13	1.71 (0.78)	1459.85 (3218.39)	14
17	CC	1.48 (0.67)	2041.81 (4501.37)	17	4.91 (2.23)	616.84 (1359.89)	9	4.91 (2.23)	616.86 (1359.93)	9
18	CC	0.98 (0.44)	2086.92 (4600.82)	18	2.39 (1.08)	858.74 (1893.18)	12	2.34 (1.06)	875.22 (1929.51)	12
19	CC	0.22 (0.10)	2459.13 (5421.40)	19	0.80 (0.36)	686.45 (1513.35)	11	0.80 (0.36)	680.00 (1499.13)	11
20	CC	0.43 (0.20)	2619.94 (5775.92)	20	2.18 (0.99)	518.28 (1142.6)	8	2.23 (1.01)	504.97 (1113.26)	7
21	CC	0.13 (0.06)	4739.31 (10448.28)	21	0.30 (0.14)	1973.51 (4350.8)	16	0.36 (0.16)	1655.98 (3650.77)	15
22	CC	−0.54 (−0.24)	–	22	−0.63 (−0.29)	–	22	−0.67 (−0.30)	–	22
23	CC	−3.14 (−1.42)	–	23	1.51 (0.68)	2717.58 (5991.18)	20	3.04 (1.38)	1352.22 (2981.10)	13
Defiance County										
1	CC	0.67 (0.30)	392.69 (865.72)	1	0.30 (0.14)	880.83 (1941.88)	3	0.18 (0.08)	1489.00 (3282.65)	6
2	DM	3.94 (1.79)	405.95 (894.96)	2	−0.59 (−0.27)	–	12	−2.08 (−0.94)	–	12
3	DM	3.64 (1.65)	439.32 (968.52)	3	−0.49 (−0.22)	–	11	−1.85 (-0.84)	–	11
4	CC	0.90 (0.41)	697.54 (1537.80)	4	0.80 (0.36)	790.65 (1743.07)	2	0.76 (0.34)	826.92 (1823.03)	2
5	CC	0.48 (0.22)	698.61 (1540.16)	5	0.59 (0.27)	568.57 (1253.47)	1	0.62 (0.28)	535.80 (1181.22)	1
6	CC	8.71 (3.95)	1019.84 (2248.34)	6	8.41 (3.81)	1055.46 (2326.87)	5	8.32 (3.77)	1067.71 (2353.87)	4
7	CC	1.18 (0.54)	1059.78 (2336.39)	7	1.23 (0.56)	1023.20 (2255.75)	4	1.24 (0.56)	1011.72 (2230.44)	3
8	DM	1.76 (0.80)	1137.18 (2507.03)	8	−0.16 (−0.07)	–	9	−0.79 (−0.36)	–	10
9	CC	5.00 (2.27)	1175.32 (2591.11)	9	4.10 (1.86)	1432.30 (3157.65)	7	3.81 (1.73)	1543.16 (3402.05)	7

(continued on next page)

Table 5 (*continued*)

ID	BMP	Bioavailable P yield reduction and ranking (at the Tiffin River mouth)								
		SRP concentration in tile effluent = 500 μg/L			SRP concentration in tile effluent = 150 μg/L			SRP concentration in tile effluent = 35 μg/L		
		P yield decrease lb/yr (kg/lb)	Cost:Ben $/lb/yr ($/kg/yr)	Bid rank	P yield decrease lb/yr (kg/lb)	Cost:Ben $/lb/yr ($/kg/yr)	Bid rank	P yield decrease lb/yr (kg/lb)	Cost:Ben $/lb/yr ($/kg/yr)	Bid rank
Defiance County										
10	CC	1.79 (0.81)	1234.67 (2721.95)	10	1.79 (0.81)	1234.67 (2721.95)	6	1.79 (0.81)	1234.67 (2721.95)	5
11	DM	0.69 (0.31)	2310.23 (5093.13)	11	−0.26 (−0.12)	–	10	−0.57 (−0.26)	–	9
12	CC	−0.08 (−0.04)	–	12	−0.08 (−0.04)	–	8	−0.08 (−0.04)	–	8

Of the 445 respondents who filled in at least part of the questionnaire, 309 (69%) had some knowledge about the BMP auction. The majority of respondents reported learning about the auction from the original letter that was mailed to them to describe the auction. Landowners who reported being engaged with conservation agencies were more likely to have knowledge about the auction, ($\chi^2(1, N = 369) = 5.17, p < 0.05$). Some landowners attributed their lack of knowledge to not having to make agricultural management decisions because their land is rented. One respondent wrote, "I have a farmer that operates the acreage for me, so I do not keep up with all the current happenings." Another noted, "I knew nothing about this… I cash rent." A chi-square test confirmed a negative relationship between having knowledge about the auction and renting out land, ($\chi^2(1, N = 388) = 8.62, p < 0.01$), which suggests that landowners who rent out land may be less aware of opportunities to fund conservation practices.

Only new BMPs were eligible for funding. Producers currently using BMPs could bid to adopt additional (new) practices, but they could not receive funding for existing BMPs. Nearly 37% of people who knew about the auction program reported being ineligible because they already used the BMP(s). Consistent with previous research (Prokopy et al., 2008), there was a positive relationship between current participation in another program that pays for BMPs and 1) believing that farmers' choices affect water quality ($\chi^2(1, N = 373) = 7.66, p < 0.01$) and 2) believing that farmers have a responsibility to protect water quality ($\chi^2(1, N = 373) = 5.50,\ p < 0.05$). This result suggests that a subset of people who are aware of the impact of agriculture on water quality and have strong environmental stewardship attitudes did not participate in the auction because they were already engaged with programs that promote BMP adoption, such as NRCS's EQIP.

Six primary bidding deterrents (not mutually exclusive) were reported by the 195 individuals who indicated that they had knowledge about the auction and were eligible to submit a bid. Seventy-four (38%) reported that the auction seemed complicated or time consuming or that they did not understand how to submit a bid. Fifty (26%) respondents stated that they did not want to adopt one of the three eligible BMPs. Fifty-five (28%) respondents reported that rental agreements made participation difficult and 36 (18%) indicated that they did not bid because they did not think their bid would be accepted. Twenty-seven (14%) respondents did not bid because the program was a "new research project" and 10 (5%) reported that they simply missed the deadline.

Although fifty-five (28%) of potential participants stated that rental agreements made participation difficult, this statistic does not capture the full effect of land rental on auction participation. In total, 109 questionnaire respondents indicated that land rental was one of the factors deterring their participation. As discussed earlier, land rental may reduce awareness of conservation programs. There also seemed to be confusion about how rental agreements influenced program eligibility. Some landowners allow renters to make all farm management decisions. Such respondents typically did not feel like they were in a position to participate or were not eligible to bid. One respondent noted, "I rent all my land out and they decide how to farm it. I think they do a good job with conservation." Another wrote, "Our farm land is under our son's management – rented to him. Therefore I don't feel I'm eligible."

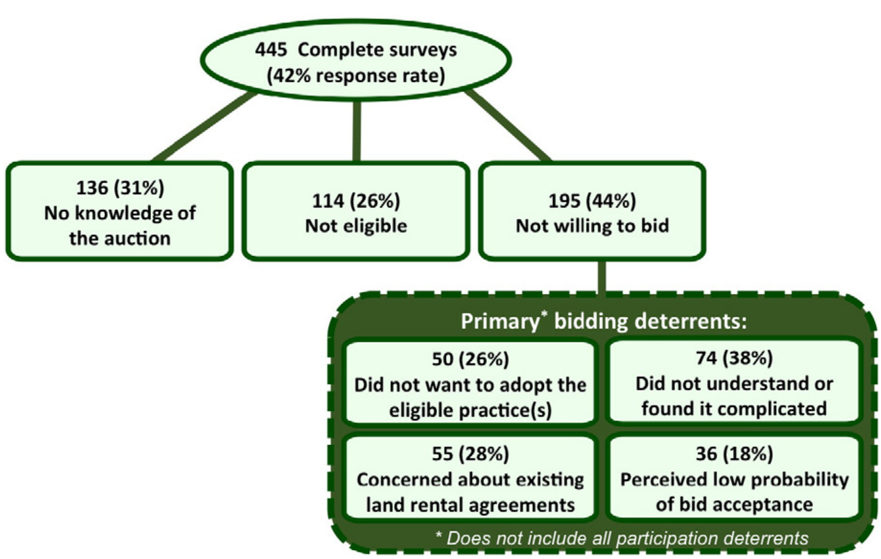

Fig. 9. Results of the follow-up questionnaire after the Tiffin Watershed BMP auction show the primary bidding deterrents, n = 445.

Rental agreements likely deterred participation because coordinating with a landowner or renter increased the time and effort required to submit a bid. One respondent knew about the project and knew he was eligible to participate, but his land was co-owned and rented out and he did not want to consult with other decision makers about the auction. He wrote, “I am one of four family members who own. I did not want to take the time to consult with them on the project. We rent the acres to OH area farmer.”

A simulation model of how transaction costs and the perceived probability of making a winning bid was developed based on findings from the follow-up survey of nonparticipants (Palm-Forster et al., 2016). The model illustrates how burdensome transaction costs can reduce participation in conservation auctions, thus limiting cost-effectiveness of auctions relative to more streamlined programs that target land in high priority areas.

Discussion and conclusions

Innovative agri-environmental programs have the potential to enhance the provision of ecosystem services (ES), but to be cost-effective, payments must be allocated to projects that generate the most benefit given the limited budget for conservation. In this project, two distinct research stages were designed with an overarching goal of identifying cost-effective ways to allocate conservation funding for agricultural practices that reduce phosphorus (P) export to Lake Erie. In the first stage, we used experimental conservation auctions to evaluate farmer preferences for different types of conservation contracts. The objectives of this stage were 1) to determine which type of incentive contract resulted in the greatest reduction of P export per dollar of conservation funding and 2) to test farmer willingness to bid jointly with another farmer. In the second stage of research, real conservation auctions were conducted in two NW Ohio counties. Objectives of this stage were 1) to field-test auctions for conservation practices using cost-effective incentives identified in stage one, 2) to test the impact of environmental information on bidding behavior, 3) to analyze farmer willingness to submit bids jointly or in groups, and 4) to identify participation barriers and deterrents that limited bid submission.

Perceived transaction costs affected farmers' preferences among alternative conservation incentives in the experimental auctions and limited participation in the real auctions. This finding is consistent with results from recent studies that have highlighted the negative impact that transaction costs can have on both participation and cost-effectiveness of agri-environmental programs that pay farmers to provide environmental services (McCann and Claassen, 2016; Peterson et al., 2014; Whitten et al., 2013). Results from the experimental auctions suggested that, because of low perceived transaction costs, direct payments and tax credits were more cost-effective conservation incentives than BMP insurance. The outcomes of the real conservation auctions and information collected with a follow-up questionnaire revealed how perceived transaction costs of participation can undermine the theoretical cost-effectiveness of reverse auctions by severely limiting the number of bids submitted. When few bids are submitted, agencies are less likely to be able to identify a set of projects with low costs per unit of benefit, thus funding may be allocated to less desirable projects. Preliminary simulations of bidding behavior with plausible parameters indicate that transaction costs can be major deterrents to cost-effectiveness of voluntary conservation programs (Palm-Forster et al., 2016; Palm-Forster, 2015). Finding ways to streamline program enrollment and lower perceived transaction costs could enhance participation and overall performance of voluntary conservation programs as long as the enrollment mechanism can target and fund high-impact projects in the watershed.

In the real auctions, land rental proved to be a major deterrent to participation and responses from the follow-up questionnaire suggested that perceived transaction costs were one barrier that limited contracts involving rental agreements. Land rental agreements inherently involve multiple parties, thus requiring additional time and effort to coordinate efforts in the process of applying for conservation programs. Mechanisms to reduce the burden of enrolling rented land are needed to bolster participation in voluntary conservation programs. This is especially important in the Midwest where more than half of cropland is rented (National Agricultural Statistics Service (NASS), 2014).

Coordinating joint bids also requires additional time and effort, which may explain why no joint bids were submitted in the real conservation auctions. Farmers were willing to submit joint bids during the experimental auctions, but it is unclear whether they would have done so if they were bidding to adopt practices on their own land rather than the mock farms used in the experiments. There may be ways to engage groups of farmers in auctions or other voluntary programs, but high costs of coordination, concerns about contract noncompliance, and potential social repercussions generate considerable doubt as to whether joint contracts are feasible or desirable. Research is needed to identify if and when it would be beneficial for farmers to coordinate conservation actions and under what conditions farmers would be willing to jointly enroll in conservation programs. While controlled experiments are useful for understanding some farmer behavior, results of this research highlight the value of engaging farmers in field experiments and randomized control trials in which the decisions that they make have greater consequence in their daily lives. These studies are especially informative because they reveal observed behavioral responses to various policy interventions.

Future work should aim to identify incentive mechanisms with minimal transaction costs that can allocate conservation payments cost-effectively. One direction for additional research on conservation auctions is to find ways to streamline the bidding process by limiting the amount of information that farmers are required to provide and using bidding menus or other mechanisms to reduce the cognitive burden on landowners and farmers. Another direction for future work is to focus on how to design targeted programs that are informed by biophysical models but do not use auctions to allocate conservation funding.

An original objective of the real conservation auctions was to test the impact of providing landowners with information about the potential environmental impacts of BMP adoption on their farms; however, low participation limited our ability to draw meaningful conclusions about this treatment. As discussed in the literature, it is unclear whether this information would reduce cost-effectiveness because of strategic bidding or improve performance by expanding the pool of projects available for funding. Using field experiments to test the effect of environmental information on participation in voluntary conservation programs would be a valuable contribution to the literature.

Targeting funding to high priority lands is critical for cost-effective voluntary programs. Results from both the experimental and real auctions show the value of targeting. Results from the experimental auctions suggest that the inability to spatially target financial incentives to high priority land caused stewardship certification to be less cost-effective than direct payments or tax credits, despite the fact that bids for the certification were no higher than bids for direct payments. In the real auctions, differences in costs per unit of environmental benefit were generated not by large differences in bid amounts, but rather by substantial differences in predicted reductions in bioavailable P export.

In order to target funding effectively, biophysical models must be able to accurately predict environmental benefits generated by BMPs throughout a watershed. A watershed model that has been appropriately parameterized by site-specific flow and water quality data via calibration provides a technically defensible tool for quantifying benefits in terms of reductions in phosphorus (or nitrogen) export from particular field(s) or from a broader region. Further, a watershed model such as SWAT has the capability to predict the effective delivery of nutrients, or the effective reduction in nutrients, from the watershed system (i.e., at the watershed outlet point) to a coastal ecosystem such as

Lake Erie, where excessive nutrient loads can potentially drive the formation of harmful algal blooms.

While the value of modeling was evident in this study, the application of SWAT and other watershed models to support reverse auctions or other transactions requiring cost/benefit evaluations has several limitations. If a model has not been developed and calibrated for a particular watershed of interest, a significant investment of resources will likely be needed to develop a tool that can be reliably used to estimate benefits due to BMP implementation. Further, calibration of a SWAT or other watershed models requires the availability of sufficient instream flow and water quality data to appropriately parameterize the model prior to its use in evaluating BMP effectiveness. If insufficient data exist for a particular watershed, development and execution of a stream monitoring program will probably be required prior to moving forward with model calibration and application.

Once a watershed model has been developed and appropriately calibrated, detailed information concerning physical characteristics and cropland management practices prior to and after BMP implementation must be integrated into the model to evaluate baseline and post-BMP conditions. Additional information requirements contribute to transaction costs of program application if the farmer is expected to provide detailed documentation concerning current agricultural management. Advancements in information technologies (e.g., GIS software) and satellite imagery may offer mechanisms to reduce the information burden on the farmer. Pilot scale tests are needed to ensure that this information can be used effectively to target funding to high priority areas of a watershed.

A critical data gap that was identified through the modeling process for the bids was the SRP concentration in flows routed through subsurface tile drainage systems. Although flow through Midwestern tile systems is reasonably well understood (Boles et al., 2015), recent research suggests that SRP concentrations in tile flows are highly variable, ranging from 1 μgP/l to greater than 1000 μgP/l (Williams et al., 2015a, 2015b). SRP concentrations in tile drainage are likely to vary through time (both on an event basis and seasonally) and also among individual fields (King et al., 2014). Therefore, in the absence of research quantifying the relationship between tile drainage SRP concentrations and other field-specific characteristics (e.g., dominant soil type), site-specific monitoring is needed to quantify the importance of subsurface tile drainage as a pathway for bioavailable P export from an agricultural field. The model application discussed here for the Tiffin watershed reverse auction assumed a mid-range concentration from the literature of 500 μgP/l for all fields evaluated. However, an informal sensitivity analysis of this assumption indicated that lower assumed SRP concentrations significantly altered cost/benefit results for bids where tile drainage was involved and thus influenced the final ranking of the auction bids for each county.

In conclusion, we recommend two important directions for future research aimed at improving voluntary conservation programs in agricultural watersheds. First, we need to improve measurement of transaction costs on behalf of both the farmer and conservation agency and incorporate these costs into cost-effectiveness analysis in order to identify mechanisms to improve program performance. Due to the current costs associated with implementing conservation auctions, it may be more cost-effective to design voluntary programs that target high-impact land without using an auction to allocate payments. Second, it is critical that we improve the modeling and measurement of factors that influence SRP concentrations in tile drainage systems in order to more accurately predict the benefits generated by agricultural BMPs. Developing reliable models to predict site-specific changes in SRP export will enhance our ability to use environmental simulation models to support pay-for-performance policies in Midwest watersheds.

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