Opportunity Cost of Precision Conservation

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Abstract.

Using spatial regression methods on 52 Michigan corn and soybean fields from 2020 to 2022, this study measures the distance and time effects of conservation areas on crop yield. We found that incorporating conservation areas was profitable for corn fields but not for soybean fields when considering the yield lost inside the conservation areas, effects of conservation areas on yield in the rest of the fields, and changes in production costs. This paper contributes to the literature in two ways: First, it employs a spatial regression approach that is replicable and expandable, effectively capturing the spatial dependencies and variations in crop yields influenced by conservation areas. This method allows us to extrapolate foregone yield in conservation areas and calculate the associated opportunity costs. Second, our preliminary findings estimate the opportunity cost of precision conservation, which can inform relevant subsidy levels in policies aimed at expanding precision conservation.

Keywords.

precision conservation; in-field conservation; biodiversity habitat; profitability; subsidy

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Introduction

Crop production and biodiversity conservation vie for limited land. Homogenous and simplified agricultural fields produce high yields, yet they aggravate biodiversity losses which lead to reductions in ecosystem services (Landis, 2017). Establishing conservation areas, despite withdrawing land from agricultural production, can deliver environmental benefits including reduced nutrient and sediment export (Schulte et al., 2017; Zhou et al., 2014; Helmers et al., 2012), wildlife habitat provision (King and Savidge, 1995; Lane et al., 2020), and enhanced soil productivity (De et al., 2020; Li et al., 2018). Balancing land use between crop production and conservation becomes imperative amid rising food demand and heightened environmental concerns.

Precision conservation, also referred to as targeted conservation, provides a potential solution for achieving a harmonious balance between environmental conservation and agricultural productivity. Leveraging spatial technologies such as global positioning systems (GPS), remote sensing, and geographic information systems (GIS), precision conservation allows for targeting specific areas that either minimize producers' costs or address significant environmental impacts, such as soil erosion or water quality improvement. This targeted approach allows farmers to simultaneously engage in both farming and conservation. This conservation strategy diverges from conventional conservation policy, notably the U.S. Conservation Reserve Program (CRP), which traditionally focuses on conserving entire fields, in contrast to the current approach of conserving selected portions of land within fields (Swinton, 2022).

This paper aims to examine the opportunity cost associated with precision conservation, specifically when a conservation area is placed on historically low-yielding areas, as illustrated in Basso (2021). Understanding the outcomes for farmers is crucial, given that they make land use decisions. Despite the societal benefits of conservation, it is the producers who bear the immediate costs, as their production is directly affected (Lynch and Brown, 2000). This study aims to investigate the feasibility and profitability of achieving conservation objectives with precision agriculture technologies.

Current literature mainly addresses measuring ecosystem services from conservation areas (Landis, 2017; Gleason et al., 2011; Bert et al., 2017), with limited focus on the cost of shifting cropland into conservation use. An analysis by Ansell et al. (2016) revealed that fewer than 50% of papers published between 1992 and 2014 referenced the costs incurred by farmers regarding the implementation of a conservation area on farmland. Among those discussing the cost of a conservation area, the existing literature uses accounting approaches based on land rent (Tyndall et al., 2013; Meng, McConnell, and Burger, 2022) or yield before implementing a conservation area (Capmourteres et al., 2018). No research so far has calculated the opportunity cost of newly created precision conservation areas based on statistical methods to predict lost yield and the associated change in net revenue.

This paper also contributes to the literature on the impact of conservation areas on crop yield. A conservation area can have both positive and negative effects on nearby crop yield. On the positive side, a conservation area can provide habitat for pollinators and beneficial predators, leading to enhanced pollination and pest regulation services (Ricketts et al., 2008; Tscharntke et al., 2005; Kemmerling, Griffin, and Haddad, 2021). Conversely, negative effects may arise due to factors such as weed presence (Hirsh et al., 2013), pests (Fiedler and Landis, 2007) within the conservation area, or competition for water and nutrients between crops and vegetation in the conservation area (Anderson et al., 2009).

There is no consensus on the net impact of conservation areas on crop yields in the existing literature. Schulte et al. (2017) and Dutter (2022) found no statistically significant effect of prairie strips on corn and soybean yields within 10 meters from the strips. Stamps et al. (2008) concluded that herbaceous conservation buffers had no significant impact on soybean yield. On the contrary, Udawatta et al. (2016) and Senaviratne et al. (2012) found a negative impact of conservation areas on corn yield. Udawatta et al. (2016) reported higher corn yield with increasing distance from the riparian buffer. However, they found no significant effect of riparian buffer on soybean yield. Senaviratne et al. (2012) examined the effect of a grass buffer established in 1991 on corn yield between 2004-2008. They found that the corn yield was 15-32% lower in the area 0-5m from the buffer area than in the area 15-20m from the buffer area. Yang et al. (2020) surveyed 245 farmers in China and reported lower crop yields by 7 - 24% within 40m of conservation areas, compared to fields without conservation areas. Conversely, in larger-scale analysis, crop yields were higher when in proximity to the conservation area. Galpern et al. (2020) examined crop yield in Alberta, Canada using data from 2012 and 2017 and found that fields located near non-crop land cover exhibited higher average yields compared to those situated farther away from non-crop land. The variability in these findings underscores the need for further research to disentangle the diverse effects of conservation areas on crop productivity.

Theoretical model

In this section, we construct a conceptual model to capture the dynamic impact of the ecosystem within conservation areas on crop yield in the surrounding field. We focus on how the effect evolves as the ecosystem develops after a conservation area is created. Given the lack of consensus on whether or not conservation areas benefit crop yield, the objective is to establish a model that facilitates determining whether the effect is positive or negative. We assume that the conservation area does not influence farmers' other practices or site characteristics.

There are two types of areas within a field: cropland, denoted by *i*, and conservation areas, denoted by *j*. Assume that crop yield y in area *i* is determined by farming inputs denoted as x_i. We assume that farmers aim to maximize profits through their choice of inputs, such as fertilizer and irrigation, and practices like tillage or cover crops. Crop yield is also affected by weather conditions ($weather_i$), and site-specific characteristics ($site_i$). Site characteristics encompass topography and static soil attributes that only change over extended temporal scales, such as the quantity of soil organic carbon and soil pH.

Crop yield is further subject to the influence of a conservation area *j* placed within the field. This influence is represented as ψ_{ijt} where *J* denotes the total number of areas designated as a conservation area. The influence of a conservation area (ψ_{ijt}) is assumed to be proportional to the age of the conservation area at time *t* (age_{jt}). This assumption reflects the notion that the ecological impact of a conservation area evolves and intensifies progressively over time as the ecosystem develops within it (Hirsh et al., 2013; Morandin and Kremen, 2013; Kordbacheh, Liebman, and Harris, 2020; Dutter, 2022). The influence of a conservation area is inversely proportional to the distance from cropland to a conservation area (d_{ij}), reflecting the diminished impact on crop areas located farther away from the conservation area (Nekola and White, 1999; Morlon et al., 2008; Mitchell, Bennett, and Gonzalez, 2015).

$$y_{it} = f(x_{it}, weather_{it}, site_{it}, \sum_{j=1}^{J} \psi_{\text{ijt}}) \quad (1)$$

$$\psi_{ijt} = g(age_{it}, d_{ij}) \quad (2)$$

Although we cannot directly measure the influence of conservation areas on crop yield, we can infer the direction of this influence by analyzing relevant factors and their correlations with yield. By examining variables such as the distance and age of conservation areas, we can understand how these factors interact with crop yield, allowing us to estimate the overall impact of conservation areas.

Given the assumption that the farmer seeks to maximize profit, the farmer would adopt an in-field conservation area only if the cumulative, discounted profit generated by the conservation area over its lifetime equals or exceeds the profit without establishing the conservation area. The disparity in profit between scenarios with and without a conservation area comes from the yield change resulting from the ecological influence on the conservation area, the foregone profit incurred by allocating land to conservation rather than production, the cost associated with implementing and maintaining the conservation area implementation cost, and potential government subsidies for conservation efforts. In other words, a farmer would choose to conserve part of their land only if the cumulative, discounted value of subsidy and revenue change is greater than or equal to that of the implementation cost and forgone profit. The time horizon for conservation areas to mature will depend upon the ecological setting. In early years, the net profitability effect can be evaluated annually as in Equation (3).

$$\frac{\partial y}{\partial \psi} \cdot p_y + subsidy \geq foregone\ profit + implementation\ cost \quad (3)$$

Based on Equation (3) and the estimated impact on yield of ecosystem services from conservation areas ($\frac{\partial y}{\partial \psi}$), we assess what current subsidy level would be sufficient to incentivize farmers to establish in-field conservation areas (and whether current subsidies can accomplish that).

Data

The data consist of three years of yield maps (2020 - 2022) from 52 commercial corn and soybean fields located on two Michigan farms. Corn and soybeans were planted on these fields following farmers' crop rotation schedules.

Each field is divided into a grid, with each grid cell's width set to one-fourth of the width of the fertilizer applicator. Both farms utilized 120ft wide applicators, resulting in 30ft by 30ft grid cells. Each grid cell serves as an observation unit for this analysis, and the average yield is computed for each cell. A cell is categorized as a conservation area if a conservation measure is installed on the majority of that cell. Cells are dropped from the sample if there is no yield, even if they are not categorized as conservation areas. Total number of observations used for the analysis is 289,867.

We generate the dummy variable, *edge*, by assigning a value of 1 when a cell is situated on the outermost edge of the field. To incorporate site characteristics, we utilize data from the Soil Survey Geographic Database (SSURGO), including the amount of soil organic carbon (SOC; g/m2) and available water storage (AWS; cm) in the top 100 cm of soil. Soil organic carbon (SOC) contributes to soil fertility as it affects soils' capacity to retain water and nutrients while mitigating topsoil loss (Reeves et al., 1997; Robertson et al., 2014). Available water storage (AWS) represents the maximum amount of plant-available water a soil can provide, a critical factor influencing corn yield (Leeper, Runge, and Walker, 1974). The National Commodity Crop Productivity Index from SSURGO is also included to account for the overall characteristics of soil.

To account for the effect of topography on moisture availability, we calculate the Topographic Wetness Index[1] (TWI). TWI predicts potential water accumulation in areas with elevation differences, considering slope and the upstream contributing area. A higher value of TWI indicates that water is more likely to accumulate and persist in an area, while a lower one suggests that water is less likely to persist. Using elevation data from the US Geological Survey's Digital Elevation Model (DEM), the average Topographic Wetness Index is generated for each cell.

We use daily weather data at a resolution of 800m from Parameter-elevation Relationships on Independent Slopes Model (PRISM) to construct the growing degree days[2] (GDD) and total precipitation for the duration of the growing season, spanning from April to September.

The foregone yield on a conservation area is translated into opportunity cost by utilizing grain

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[1] $TWI = \ln \frac{upslope\ contributing\ area}{\tan(slope\ in\ radians)}$

[2] $GDD = \sum Max[avg\ temp\ (°C) - 10, 0]$

price ($/bu) and input cost ($/ac). For crop prices, the Michigan average price in 2022 from USDA (USDA, 2023) is utilized. For input costs, the average of total non-land costs in 2022 from University of Illinois Crop Budgets (Schnitkey et al., 2021) and Purdue University (Purdue Extension, 2022) are applied.

Table 1: Price parameters used in the analysis

	Corn	Soybeans
Grain price ($/bu)	6.3	14.7
Input costs ($/ac)	673.5	365

Method

Yield data was acquired through on-farm field experiments, involving the conversion of a portion of the field into a conservation area where native perennial plants were cultivated. Subsequently, yield maps were collected annually to analyze the agricultural outcomes over time.

To assess the ecological impact of conservation areas on agricultural yield and quantify the opportunity cost associated with allocating land to conservation, we first estimate a yield response model. This model incorporates the influence of conservation areas, considering variables such as distance and age of the conservation area, while also accounting for various other factors, including site characteristics and farming practices.

Following this, we examine whether or not there exists an evolving conservation effect across time. Measuring the conservation effect on crop yield is complicated by the fact that conservation areas are intentionally located where crop yields are low. Hence, we need to disentangle the yield effect due to ecosystem services from the conservation area (whether positive or negative) from the yield effect due to the site characteristics (which is likely to be negative—meaning that yield would increase with distance from the low-yielding area set aside for conservation).

We then compute the foregone profit of allocating land to conservation by predicting the potential crop yield that could have been realized in the conservation area, utilizing the parameters derived from the yield function. We calculate the opportunity cost of conservation areas by adding the foregone profit inside conservation areas, establishment costs, changes in profit due to ecosystem services, and subsidies from conservation efforts. We then examine the amount of subsidies needed to incentivize farmers to adopt conservation areas.

Experimental design

This paper utilizes data from an on-farm experiment, examining the impact of adopting precision conservation on the financial performance of Midwestern agriculture. The study examines 52 commercial fields in corn or soybeans. Historical profit maps were employed to identify unprofitable areas within a field. The participating farmers selected subsets of these areas to exclude from production, based on farming convenience. The farmers chose native species to plant in the conservation areas.

The identification of low-yield areas was based on historical yield, average total production costs, and average grain prices reported by each farmer. Profit was calculated by multiplying yield and grain prices, subtracting total production costs. The annual profit was then averaged across years with available yield maps. Land where the average profit fell below -$15/ac was deemed unprofitable. After removing pockets of unprofitable area smaller than 2 acres within the profitable area, the unprofitable area was initially suggested as a potential conservation area. The suggested area example is illustrated in the top figure of Figure 1 top. Farmers selected the location and size of conservation areas based on the proposed suggestions (bottom of Figure 1), targeting regions with anticipated negative profitability while considering their farming practices. Compensation was provided at a rate of $175 per acre for forgone profits on the land withdrawn from crop production.

In the left picture, the yellow shaded area represents the conservation area initially suggested based on the profit. The right picture shows the finalized conservation area chosen by a farmer, marked with an orange header.

Figure 1 Aerial image of a field with conservation area

Participation in the project required a commitment to maintaining the conservation area for a minimum of five years. Farmers taking part were responsible for establishing conservation areas, typically carried out in the fall after the crop harvest. The planting of these native perennial plants occurred only once, in the first year of participation. Commonly planted species included Indian grass (*Sorghastrum nutans*), big bluestem (*Andropogon gerardii*), and bergamot (*Monarda fistu losa*). These species were chosen for their low maintenance requirements and additional benefits, such as preventing soil erosion and supporting wildlife. While the seeds were provided free of charge, the actual seed costs amounted to $250 per acre.

Yield function

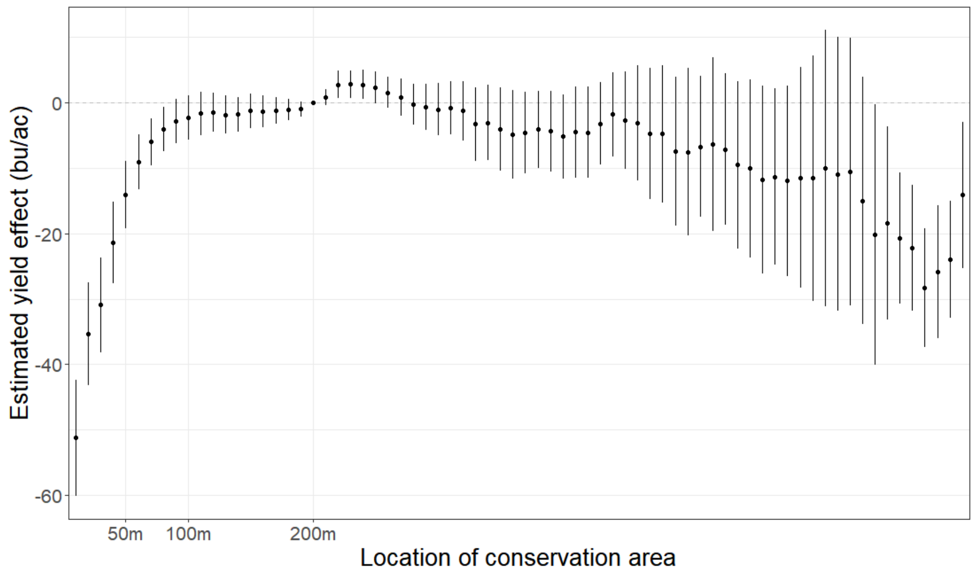
Key to measuring the opportunity cost of precision conservation is the yield function that measures the effect of increasing distance and age of conservation areas on crop yield. Based on the theoretical model (Equations 1 and 2), we estimate the following yield function:

$$y_{it} = \alpha \cdot age_t + \beta \cdot d_i + \gamma \cdot age_t \cdot d_i + \lambda_1 site_i + \lambda_2 weather_{it} + \lambda_3 Field_i \quad (4)$$

For site characteristics ($site_i$), we include available water storage (AWS), soil organic carbon (SOC), National Commodity Crop Productivity Index (NCCPI), and topographic wetness index (TWI). For weather variables, we use growing degree days (GDD) and the total precipitation during the growing season. Additionally, total precipitation is interacted with TWI to capture the combined influence of precipitation and topography on yield. For farming practices, as farmers applied uniform practices for each field (uniform rate of fertilizer, seeds, etc.), we proxy farming input variable with a field fixed effect ($Field_i$).

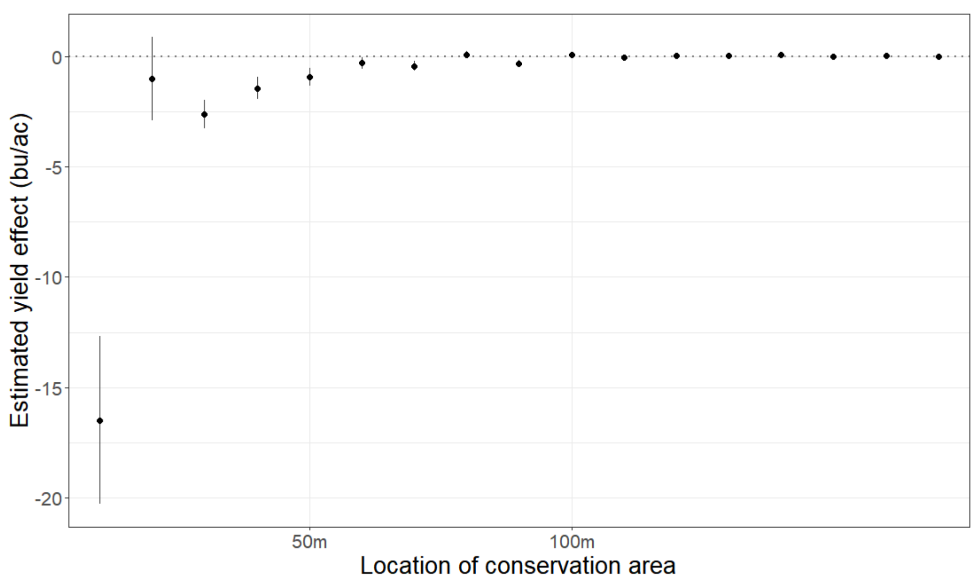
The distance variable (d_i) should account for three effects: proximity to a conservation area, size of the area, and its configuration. To comprehensively represent these factors, we use several models with different variables: 1) the distance from a crop area to the nearest conservation area (d_{ij}), 2) the total size of conservation areas located within specified distance intervals, with intervals set at every 10, 20, and 50 meters ($\underline{area_d}$), and 3) the sum of all in-field conservation areas' size weighted by their inverse distance from the crop area ($\sum_d \frac{area}{d^\gamma}$). For the first and second variables, all distances are incorporated as categorical variables (at set distances) to capture the potential nonlinear effects of distance. We test models with inverse distance weighting using different distance decay parameters (γ) and estimate the optimal distance decay parameter for each field following Halleck Vega and Elhorst (2015). We present only the results from corn fields in this section. The results for soybean fields are provided in the Appendix.

Both the model with the minimum distance and the model with the conservation area size show similar pattern of conservation distance effect on yield (Figure 2 and 3). The yield decreases as a crop area is located near a conservation area, or if a larger conservation area is present near the crop area. The influence from a conservation area is the most prominent when crop area is adjacent to a conservation area. Then the magnitude of the effect decreases until 50m. Beyond this range, the change in yield diminishes, reaching a point of relative consistency with marginal fluctuations. After 100m, there is no statistically significant effect of conservation area on yield. As the location approaches the edge of the field, farthest from the conservation area, there is a noticeable decrease in yield.



Note: Error bars indicate 90% confidence intervals; standard errors are clustered at the field level. The base level for the distance dummy variables is set at 200 meters.

Figure 2 Estimated corn yield effect from the model incorporating minimum distance to a conservation area



Note: Error bars indicate 90% confidence intervals; standard errors are clustered at the field level.

Figure 3 Estimated corn yield effect from the model incorporating conservation area size variable

The third specification utilizes the total size of conservation area weighted by inverse distance. This approach assumes that the effect of the conservation area decreases as the distance increases. A larger estimated distance decay parameter (γ) indicates that areas farther from the conservation area have less effect on crop yield. Since there is no definitive evidence for the most appropriate distance decay parameter from existing literature, we test values of one, two, and three. All three specifications show that having a larger conservation area nearby decreases yield.

Table 2: Estimated corn yield effect and standard errors (in parenthesis) by different distance decay parameters

Variable	Conservation area definitions		
	$\frac{area}{d}$ $(\gamma = 1)$	$\frac{area}{d^2}$ $(\gamma = 2)$	$\frac{area}{d^3}$ $(\gamma = 3)$
Conservation area	-38 *** (5)	-1260 *** (139)	-19596 *** (1903)
GDD	0.84 * (0.49)	0.80 (0.49)	0.78 (0.51)
Precipitation	1.40 *** (0.37)	1.34 *** (0.37)	1.25 *** (0.37)
Precipitation*TWI	-0.002 (0.001)	-0.002 (0.001)	-0.002 (0.001)
TWI	1.02 (0.76)	0.95 (0.77)	1.01 (0.78)
AWS	0.16 * (0.09)	0.16 * (0.09)	0.16 * (0.09)
SOC	-0.001 *** (0.0003)	-0.001 *** (0.0004)	-0.001 *** (0.0003)
Edge	-29 *** (3)	-28 *** (2)	-30 *** (3)
Adj. R^2	0.54	0.55	0.53

***, **, * represent statistical significance at the 1%, 5%, and 10% levels and all standard errors are clustered in the field level.

Finally, we estimate the distance decay parameters for each field. The optimal distance decay parameter is determined by iteratively estimating the parameter while keeping the other coefficients constant, and then estimating the other coefficients while keeping the distance decay parameter constant, until convergence is achieved. For a more detailed explanation, see Halleck Vega and Elhorst (2015). On over a third of the 43 corn fields, the estimated distance decay parameters are larger than 4, indicating that the effect of conservation area decreases faster than the inverse of the distance to the fourth power.

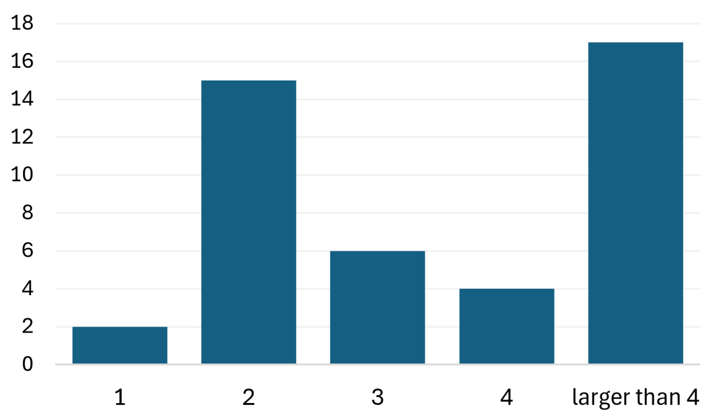


Figure 4*:* Histogram of estimated distance decay parameters

As the three models using different measures of distance to conservation area all consistently provide similar results, we utilize the second variable, size of the area within specific distance intervals, as our main specification. This variable effectively captures both the size and proximity of the conservation area. Previous results suggest that the effect is the largest in adjacent cells, decreases up to 100m, and becomes statistically insignificant beyond that distance. We incorporate four distance ranges: 0-10m, 10-50m, 50-100m, and 100-150m. We include the interaction of age and distance variables to examine how the effect of conservation area evolves.

$y_{it} = \alpha \cdot age_t + \sum_d \beta_d \cdot consrv_{id} + \sum_d \mu_d \cdot age_t \cdot consrv_{id} + \lambda_1 site_i + \lambda_2 weather_{it} + \lambda_3 Field_i$ (5)

The coefficients of interest are β_d, and μ_d, which represent the distance and age effects. As explained in the theoretical model, these coefficients enable us to examine the impact of the conservation area on crop yield. For example, if β_d increases as *d* increases, it means the yield increases as it gets further away from conservation areas ($\frac{\partial y}{\partial d} > 0$), and therefore indicates a negative impact of conservation area ($\frac{\partial y}{\partial \psi} < 0$).

Estimation of the opportunity cost

The opportunity cost of the conservation area is defined as the sum of three key components: 1) the foregone profit on crops not grown inside the conservation area, 2) changes in crop yield in the cultivated area due to the presence of the conservation area, 3) the cost of establishing the conservation area, and 4) potential subsidy. Specifically, the foregone profit on the conservation area entails the lost revenue from crop yield minus the input costs saved by not applying inputs to the conservation area.

To estimate the foregone yield inside the conservation area, we extrapolate the yield based on the previously estimated yield function. Regarding the yield change inside the crop area due to the influence of the conservation area, we first examine whether there is any evidence of an ecological yield effect stemming from the conservation area. If there is evidence indicating that yield changes due to the conservation area, we estimate the disparity between the actual yield observed in the data and the yield predicted by the estimated yield function. Subsequently, the estimates of foregone yield inside the conservation area and yield change inside the crop area are converted into profit using the grain price and input cost parameters.

The total cost of establishing the conservation area includes labor, machinery use, and seed. Preparing a conservation area requires no specialized machinery beyond what farmers already possess, so seed costs constitute the primary expenditure. While the seeds planted in a conservation area were supplied to the farmers at no cost in this project, at market prices, their cost amounted to $250/ac. As perennial species were planted, implementation costs were only incurred in the initial year. We amortize these costs over five years, aligning with the minimum required maintenance period for the conservation area by farmers. Using straight-line depreciation with zero salvage value and ignoring interest costs (which were low at the time) results in an annual implementation cost of $50/ac.

Results

Estimated yield function

Consistent with Figure 3, conservation areas reduce yield for both crops, with the negative effect being the most pronounced within 10 meters and diminishing by 100 meters.

For corn, the coefficient for *age · consrv* of the nearest area is not statistically significant, suggesting that the distance effects do not significantly change with age. This lack of statistical evidence for the interaction term implies that there is no observable impact on crop yield due to ecosystem services from a conservation area that vary with the age of the conservation area. Therefore, we reject the hypothesis that the evolving ecosystem services from a conservation area positively affect yield.

For soybeans, while the sign and statistical significance of the interaction term vary by distance, the coefficient for *age · consrv* in the nearest area to a conservation area is statistically significant and positive. The positive effect implies that while the site characteristic of conservation area reduces yield, the growing ecosystem within these areas leads to an increase in soybeans yield over time

Table 2: Estimated effects of conservation areas on yield of corn and soybeans

Variable	Coefficient (Std. Err.)	
	Corn	Soybeans
age	-41.4 * (11.4)	29.1 * (8.9)
consrv.10	-19.0 *** (0.9)	-6.1 *** (0.1)
consrv.50	-1.3 * (0.3)	-0.6 ** (0.1)
consrv.100	-0.1 ** (0.1)	-0.04 * (0.01)
consrv.150	0.04 (0.02)	0.02 (0.01)
consrv.10 · age	0.9 (0.6)	1.4 * (0.4)
consrv.50 · age	-0.3 (0.2)	0.1 0.1
consrv.100 · age	-0.05 ** (0.001)	-0.03 * (0.01)
consrv.150 · age	-0.04 (0.01)	-0.04 ** (0.01)
edge	-28.2 ** (5.9)	-8.4 ** (1.3)
GDD	0.7 (0.3)	-0.001 (0.2)
Precipitation	1.3 ** (0.2)	0.1 (0.1)
Topo. wetness (TWI)	1.0 (0.5)	0.1 (0.1)
Available water (AWS)	0.2 * (0.1)	0.03 (0.03)
Soil organic carbon (SOC)	-0.001 (0.001)	-0.0002 (0.0002)
TWI · Precipitation	-0.002 (0.001)	-0.0001 (0.0001)

***, **, * represent statistical significance at the 1%, 5%, and 10% levels; all standard errors are clustered in the field level.

Significant negative edge effects are observed across both crops. For corn, being on the edge results in a 28 bu/ac decrease, constituting 17% of the average corn yield. Although the distinction between the headland and the long side of the edge was not made, this estimate aligns with the findings of Sunoj et al. (2021), who reported a 14% lower yield in the headland for corn grain in their study encompassing 4145 fields in the United States.

Opportunity costs

Based on Equation (3) from the theoretical model, opportunity costs can be estimated considering 1) the ecological impact on yield of a conservation area, 2) foregone profit inside a conservation area, 3) implementation costs (50 $/ac in our case), and 4) subsidies.

In the case of corn, we observe no influence of conservation area on yield that evolves over time. Therefore, we assume there is no ecological yield impact of a conservation area on corn. The average foregone yield for corn inside conservation areas is predicted to be 56 bu/ac. Since conservation areas are strategically placed in low yielding areas, foregone yields are expected to be low. For corn, the value of the estimated foregone yield inside the conservation area is insufficient to cover the input costs. Hence, if a farmer had cultivated corn inside the conservation area, they could expect a financial loss due to inadequate yield. At 2022 prices, the negative foregone profit translates to $ 241/ac of averted loss. After accounting for the implementation costs of establishing a conservation area, farmers save an average of $191/ac by establishing conservation areas. Since incorporating conservation area increases the profit, farmers would be incentivized to adopt conservation areas even without any subsidy.

For soybeans, we observe an evolving conservation influence within 10 meters of a conservation area, suggesting a potential ecological yield impact. This impact increases yield by 1.4 bu/ac with the addition of one 30ft by 30ft conservation area and further increases to 2.8 bu/ac in the second year. In our sample, an average of 1 acre within field is affected by a conservation area, resulting in a $3/ac increase in profit.

The average foregone yield inside the conservation area is estimated to be 27 bu/ac. At 2022 prices, after accounting for input costs, this translates into an average of $42/ac in foregone profit. Considering the ecological impact on in-field yield, the foregone profit, and establishment costs, incorporating conservation areas into soybean field cost the farmers an average of $89/ac. Therefore, in the case of soybean fields, while we observe the ecological increase in crop yield due to the conservation area, it is not enough to cover the high crop price and low input cost savings (Table 1). Therefore, a subsidy would be necessary to incentivize profit-oriented farmers to install conservation areas. Any subsidy larger than the amount of $89/ac would increase farmers' profit.

Discussion and Conclusion

Using spatial regression methods for 52 Michigan corn and soybean fields over the years 2020-22, we measure the distance and time effects of conservation areas on crop yield. Based on the value of yield lost inside the conservation areas, their effects on crop yield in the rest of the fields, and changes in costs of production, we find that the addition of conservation areas was profitable in fields of corn but not soybean. However, the long-term impact on farm profit requires further investigation with an dataset of at least five years, supplemented by a price sensitivity analysis. Positive ecological yield effects and higher input costs would amplify the profitability of conservation areas, while negative ecological yield effects and higher crop prices would detract from profitability.

This paper contributes to the literature in two ways. First, it employs a spatial regression approach that is easily replicable and expandable, effectively capturing the spatial dependencies and variations in crop yields influenced by conservation areas. By applying this method, we can extrapolate the foregone yield inside conservation areas along with ecological yield effects on the crop, calculating the associated monetary opportunity costs. Second, our preliminary findings suggest relevant subsidy levels for policies aimed at expanding precision conservation.

For corn, the low crop yield in conservation areas combined with high input costs made incorporating conservation areas profitable even without subsidies. For soybeans, however, the opportunity cost is estimated to be $89 /ac on average. As the beneficial yield effects from conservation areas develop over time, the foregone yield is expected to increase as well as the opportunity cost. To incentivize farmers to adopt conservation areas, a subsidy exceeding $89 per acre will be needed. Of course, these findings are specific to two southern Michigan farms and 2022 crop prices and input costs.

In the context of precision conservation, where only low-yield areas are put into conservation, the required subsidies to incentivize farmers can be lower compared to scenarios where entire fields are conserved. For example, the average Conservation Reserve Program (CRP) rate for the sample fields was $144 /ac in 2022 (USDA, 2024), which exceeds the estimated necessary subsidies identified in this paper. By targeting low-yielding areas and conserving land at a relatively lower cost, precision conservation can serve as a cost-effective tool for promoting sustainable agricultural practices.

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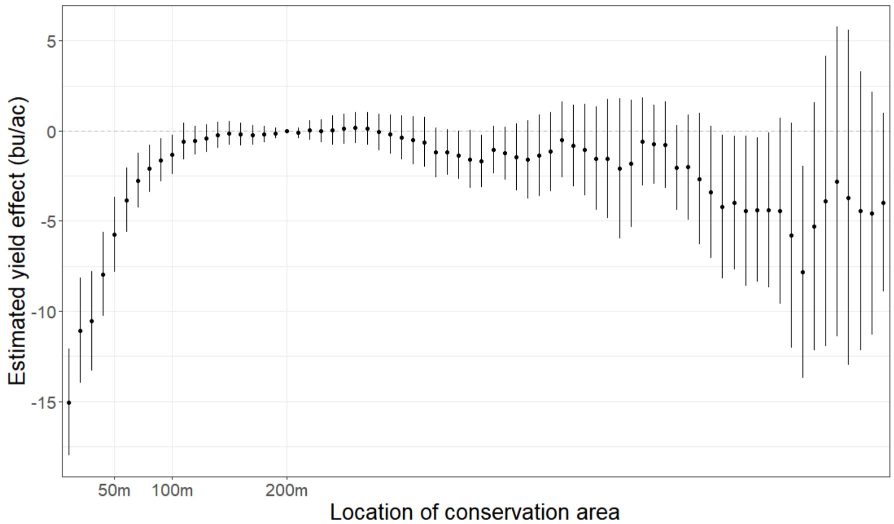
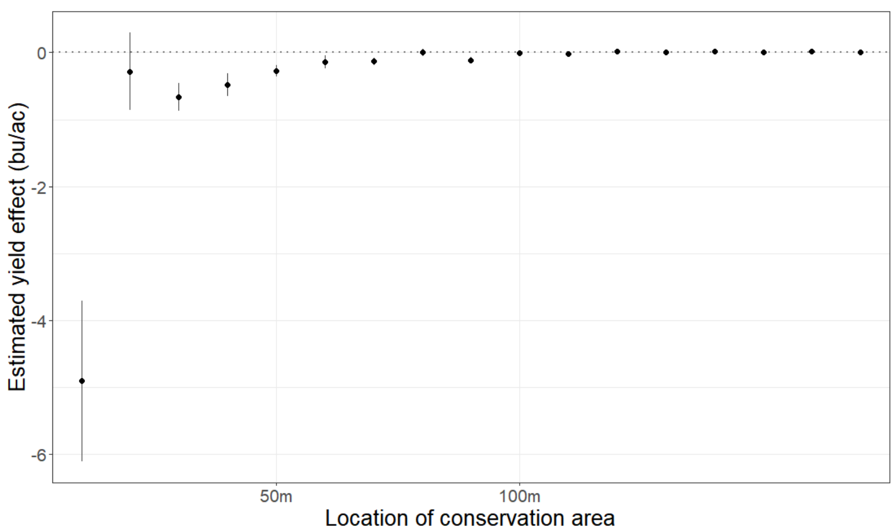
Appendix

Yield function estimation results for soybean fields



Note: The error bars indicate the 90% confidence interval, and all standard errors are clustered at the field level. The base level for the distance dummy variables is set at 200 meters.

Figure 5 Estimated coefficients from the model incorporating minimum distance to a conservation area



Note: The error bars indicate the 90% confidence interval, and all standard errors are clustered at the field level.

Figure 6 Estimated coefficients from the model incorporating conservation area size variable