7-19-2024

Cover Cropping: How Sustainability and Economics Can Work Hand in Hand

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Summer Fellows 2024

Introduction

Currently, over half of agricultural lands worldwide have been moderately or severely affected by soil degradation (Kopittke et al., 2019). This decline in soil health has largely been caused by conventional farming techniques, which can include practices such as fertilizer usage to the plowing and turning over of topsoil (Dragović & Vulević, 2020). Soil infertility is especially concerning due to its direct impact on crop yield and productivity. If proper soil health is not maintained, this will disrupt the amount of needed nutrients, water holding capacity, proper soil aggregation, and many other factors needed to promote crop growth. The continued persistence of this issue will only present a greater ongoing challenge for farmers who are growing needed crops.

This problem is further heightened by the fact that one of the largest barriers keeping farmers from shifting towards more sustainable agricultural practices is the potential economic cost that is associated with these techniques. For instance, it has been argued that agricultural research and policy has continued to focus on conventional agriculture due to the pursuit of greater short-term economic factors such as maximizing crop production, minimizing production costs, and overall increasing short-term profitability (Allan et al., 1991). This short-term focus ignores the long-term impacts to soil health along with environmental costs such as increased flooding and pollution over time. If soil degradation continues at its current rate, this is predicted to result in food production losses of up to 30% by 2050 (Gupta, 2019). This means that not only farmers will be harmed in terms of lost product, but consumers will also face the issue of diminished food availability. As many famers evidently show concerns over losing profits when using sustainable practices, this will likely only further increase the use of more harmful conventional agricultural practices unless sustainable techniques are shown to be more economically beneficial in comparison.

One sustainable agricultural practice that has been increasingly used across farms is a technique known as cover cropping. Cover crops are crop species that are typically planted between the growing seasons of cash crops to promote and sustain soil health. Cover crops have been found to increase the level of benefits provided (also known as "ecosystems services") to the soil. For example, cover crop usage has been found to decrease soil erosion, manage weed growth, increase the presence of soil organic carbon, and deal with pests (Sharma et al., 2018). Additionally, cover crops have been found to increase soil microbial populations. Previously, it has been found that the use of cover crops as a soil cover during the non-growing season increased soil microbial abundance by 27% and soil microbial diversity by 2.5% (Kim et al., 2020). Having a larger presence of soil microbes within soil is especially vital for soil health as they are vital components in promoting healthy soil characteristics like water storage, aggregation, and C and N cycling (Thapa et al., 2021).

Depending on what benefits a farmer wishes to give their soil, certain cover crops may be preferred over others. For instance, legume cover crops are known to increase levels of soil nitrogen supply (Pott et al., 2021). As nitrogen is a key component for plant growth, legumes have also been known to increase crop yields. Commonly used legume cover crop species include field peas and hairy vetch. Alternatively, cereal cover crops are known to increase carbon supply within soil which is needed to increase the presence of soil microbial communities. In addition to this, cereal crops help reduce the occurrence of nitrogen leaching. Commonly used cereal cover crop species include cereal rye and oats. Along with choosing specific species types to plant, farmers may also grow a mix of multiple different types of cover crops species at once to increase the overall ecosystem services offered to their soil (Sainju et al., 2005).

Previous literature has studied the ways in which cover crops usage can yield economic benefits along with soil health benefits. For instance, it has been found that certain types of cover crops can increase overall cash-crop yield. One study found that following a winter-legume cover crop treatment, cash crop yields had increased within a range of 79% to 131% higher as compared to crops grown where no cover crop treatment had been used (Bergtold et al., 2019). Additionally, Lichtenberg et al. (1994) found that the use of legume cover crop species like crimson clover and Austrian peas had decreased the need for nitrogen fertilizers by 20% and 43%, respectively. In other words, increased crop yields and fertilizer savings could potentially incentivize farmers to switch to this practice. This paper aims to expand previous research by analyzing whether the use of cover crops has a strong association with the level of net cash income[1] earned by farms specifically within the state of Pennsylvania. From this, a strong association may be used to explore the argument that cover cropping may offer another economic advantage to encourage farmers to switch to more sustainable practices.

This paper accounts for the major factors which influence the net cash income of Pennsylvanian farms. This will include a variety of factors ranging from different sources of expenses and income along with farmer characteristics that may impact the total net cash income earned by a particular farm. This paper will also aim to address how these major factors may contribute to possible variations in the level of net cash income earned across farms in Pennsylvania. Specifically, these factors will be used to determine if any significant association exists between the use of cover crops and the net cash income earned by Pennsylvanian farms.

[1] According to the USDA Census of Agriculture, Net Cash Farm Income of the operations is calculated by subtracting total farm expenses from total sales, government payments and other farm-related income.

Finally, this paper will aim to address additional ways in which the method of cover cropping can offer economic benefits to Pennsylvanian farmers. The analysis in this paper may provide evidence to encourage farms within Pennsylvania to adopt cover cropping practices.

My argument will proceed as follows. First, I provide a theoretical foundation by analyzing previous research that has studied the ways in which certain major farm characteristics and other factors have impacted the level of net income earned in the field of agriculture. The methodology section will then outline this study's approach. This will concern the data gathering process, including the rationale behind the chosen variables, data sources, and methods used. Next, this paper will present the findings collected from the data analysis based upon a specification that explores the relationship between net cash income and known sources of income, expenses, and other important farm characteristics. These findings will be used to determine whether any significant association between the use of cover crops and the net cash farm income earned exists to provide deeper insight as to whether this form of sustainable agriculture can offer financial benefits to Pennsylvanian farmers. Finally, this paper will go on to discuss the conclusions and policy implications that can be gleaned from my findings. This will include examining ways in which these results may be used to incentivize Pennsylvania farmers to adopt cover cropping practices, along with any limitations and future work that can be built upon this research.

Literature Review

Previous literature has examined the relationship between profitability and cover cropping in numerous ways. Lichtenberg et al. (1994) study the impact of using legume cover crops on profitability by measuring cash crop yields. Focusing specifically on the Mid-Atlantic region within the United States, the study compared profit-maximizing fertilizer rates applied to four different cover crop treatments (including hairy vetch, crimson clover, wheat, and Austrian peas) to that of a fallow control treatment.

As Lichtenberg et al. (1994) explain, data collected over the course of three years regarding crop yields and fertilization rates were pooled to create estimated nitrogen response functions. These functions were used along with the price of nitrogen and the price of corn (the cash crop grown directly after the cover crop treatments) to determine the marginal product of nitrogen and its price. In this way, the study was able to estimate the profit-maximizing yield for each treatment type, controlling average weather conditions throughout the three-year period. Finally, profit per hectare for each treatment was found by subtracting fertilizer expenditures based upon the profit-maximizing fertilizer application estimates, along with cover crop costs and other production costs that were assumed to be constant per hectare.

Lichtenberg et al. (1994) found that hairy vetch was the most profitable treatment compared to the other cover crop treatments as well as to the fallow control treatment. In particular, hairy vetch was determined to be 51% more profitable per hectare compared to the wheat and fallow treatments, 31% more profitable per hectare compared to the crimson clover treatment, and 24% more profitable per hectare compared to the Austrian pea treatment. The authors came to this conclusion largely because hairy vetch not only increased nitrogen effectiveness at a higher rate compared to the other treatments but was also found to cost significantly less. Thus, this study concluded that the evidence obtained can be used to motivate farmers within the Mid-Atlantic region to implement the of use hairy vetch cover crops within their agricultural systems.

Though Lichtenberg et al. (1994) is a prime example of measuring the impact of cover crop usage on farm profitability, this study and others like it are limited in that they collect data from local studies or surveys as opposed to greater aggregate data. However, studies that have focused more broadly on measuring farm profitability have used larger data sources. For instance, Behjat & Ostry (2013) measure the profitability of regional farms within British Colombia local health areas (administrative boundaries set by the Ministry of Health). In this study, the 2012 Canadian Agricultural Census was used for data collection and analysis.

The main objective of Behjat & Ostry (2013) was to better understand how to maximize long-term profit within the agricultural industry as this industry is considered one of the largest and riskiest sectors in the Canadian economy. Based on previous literature the study looked at, many other papers typically measured farm profitability by analyzing the relationship between net farm income or gross margin[2] with farm characteristics commonly known to impact a farm's ability to earn a profit. These characteristics ranged from farm size to number of laborers hired. From this, the study created a specification that took gross margin and analyzed its relationship with relevant farm characteristics within each local health area such as average farm size, total number of farms, average age of farm operators, number of farms with a soil conservation program, farm operating expenses per hectare, and total hectarage of farms. Through regression analysis, the authors were able to conclude that farm size, farm area, soil conservation, and operating expenses all had a significant and positive impact on gross margin. Additionally, the authors concluded that age of the farmer had a significant and negative impact on gross margin. Ultimately, the authors found that there was evidence to further support what factors are most relevant in determining the level of profitability that is earned within the agricultural industry.

In Schilling et al. (2014), aggregate data was again used to measure the impact of farmland preservation on farm profitability. The authors analyzed whether the implementation of

[2] Gross margin refers to the amount of total revenue left over after direct costs are accounted for.

public preservation investments to protect farmland increased the overall economic performance of impacted farms. In this study, the 2007 census of agriculture was used to pull data relating to various farm characteristics from New Jersey farms.

When Schilling et al. (2014) specified their econometric model, they defined their dependent variable as agricultural profit per acre. Agricultural profit per acre was determined from total farm sales per acre minus total farm expenses per acre. The study then defined dummy variables to determine whether a difference existed between the farms that belonged to the New Jersey farmland preservation program and those that do not. In addition, three categories of independent variables were used. This included farm and landowner characteristics such as gender and age, agricultural returns such as prices and expenses of the products produced for each farm, and development of potential land such as the distance between each farm and the nearest major city. This model revealed that preserved farms earned anywhere from $414 to $436 per acre more as compared to farms that were not preserved. From this, the authors concluded that the New Jersey farmland preservation program helped to increase economic performance of preserved farms by offering the financial means necessary for famers to better support their operations, investments, and debt payments. In addition, the authors argued that this study provided further evidence that small farms can expand into more lucrative ventures when included in the New Jersey farmland preservation program.

Studies like Lichtenberg et al. (1994) provide evidence that cover cropping is associated with increased farm profits. Though economic studies involving cover crops are limited in that they typically pull from small scientific studies, other studies such as Behjat & Ostry (2013) and Schilling et al. (2014) showcase how farm profitability can be measured at a much larger scale. Building on both kinds of literature, this paper will focus on whether cover cropping impacts farm profitability by using data from the United States Agricultural Census to analyze the relationship between profitability and other characteristics known to impact the economic performance of farms.

Background

Cover crops are specific types of plants which are planted between the growing seasons of crops grown for their commercial value, otherwise known as “cash crops”. Cover crops allow soil to receive benefits that would have otherwise been foregone if the land had been left barren or used for another cash crop. When cover crops perish (occurring either naturally or through manual termination[3]) before the planting of the next cash crop harvest, their residue is left to replenish the soil further as they decompose. Cover crops have been found to improve soil by increasing soil organic matter[4], reducing erosion, improving water availability, suppressing weeds, controlling for pests and diseases, and providing biologically fixed nitrogen, depending on the species used (Gliessman et al., 2014). In other words, cover crops and their residues can improve soil structure and activity which can allow cash crops to be provided with the healthy soil they need to grow successfully.

When choosing to plant cover crops, famers need to consider whether it would be more beneficial to use a diverse mixture of cover crops or to instead select only one species at a time. Under certain circumstances, planting only one species may be enough to provide sufficient benefits to the soil. For example, hairy vetch crops have been found to provide high amounts of nitrogen supply and increase yield (Pott et al., 2021). On the other hand, cereal rye crops have

[3] Manual Termination refers to the intentional removal of cover crops through chemical or mechanical methods such as the use of herbicides or mowing.

[4] Soil organic matter refers to the component of soil that consists of decomposing plant and animal tissue along with the microorganisms that reside within the soil and help break these tissues down.

been found to provide higher amounts weed suppression and improve levels of soil organic matter (Rorick & Kladivko, 2017). In other cases, using a mixture can offer a larger variety of benefits to soil as opposed to using a monoculture. However, famers may often need to be intentional about what specific species they choose to add to their mixture. For instance, one study compared a variety of different cover crop treatments and looked at how 18 different cover crop systems impacted the agroecosystem services of nitrogen retention, nitrogen provision, nitrogen supply, weed suppression, and subsequent crops yields. It was found that certain species mixes (both 4 species combination and 8 species combination) when compared to their results from the previous year, showed a decrease in the agroecosystem services of yield gain and nitrogen supplied (Finney et al., 2017). This highlights the fact that simply planting a larger number of species is not necessarily more beneficial for famers. When prior research is not done to investigate what combinations would be most beneficial, planting a random combination for the sake of increasing the number of species used may lead to the farmer losing both time and money. However, if done correctly, planting cover crop mixtures can be quite favorable in the right circumstances. For instance, having an increased mixture of intentionally picked cover crops can offer a greater number of ecosystem services since different crops are better suited for certain necessities within a properly functioning agroecosystem. The same study found that while species richness (the abundance of different species used) could only explain an increase in multifunctionality[5] by 5%, functional diversity (the abundance of different species traits present) was showed to explain the increase in multifunctionality by 15% to 38%. In other words, this meant that functional diversity was likely a much stronger predictor of multiple ecosystem services (Finney et al., 2017). What this means is that the abundance of certain traits within

[5] Multifunctionality refers to the level of total ecosystems services that are present within the soil.

differing species should be considered when choosing what species to include within crop mixtures. In this way, using crop mixtures that are chosen intentionally for varying traits may help the farmer to obtain the highest level of multifunctionality they desire for their specific agroecosystem.

Though many pieces of evidence exist to support the ways in cover crops can benefit the overall soil health, many farmers are often still hesitant to adopt this practice due to their concerns about possible financial losses. One obvious source of these possible economic costs stems from the direct costs that are likely to be incurred when using cover crops. For example, it was found through a 2012-2013 survey conducted by the Conservation Technology Information Center that 33% of all respondents cited seed prices are one of the greatest barriers from allowing them to adopt cover cropping. This is largely because seed costs in general are often highly variable depending on factors such as seeding rates or availability (Bergtold et al., 2019).

Indirect costs may also be considered when using cover crops. As cover crops are not meant to be used as cash crops, this results in time and money being spent on planting a crop that will not result in any sort of direct monetary gain later on. Because of this, some farmers may not view the extra resources and effort spent on managing cover crops as a useful tradeoff for the possible gain of increased soil health in the near future (Bergtold et al., 2019). Along with this, farmers may also consider the opportunity cost they may incur by forgoing additional income that could be earned from cash crops. During certain periods of the year, the planting of cash crops may be just as feasible as the planting of cover crops. When this occurs, farmers may be more hesitant to plant cover crops when cash crops are more likely to offer the immediate economic benefits (Snapp et al., 2005), even if this comes at the cost of foregone soil health benefits. Cover crops may also impact potential earnings delayed planting or competition with cash crops. For instance, nonlegume cover crop residues from cereal crops have a slower release rate of nutrients. As a result, this delays when cash crops can be established which can decrease the time in which they can grow as a result. Additionally, cover crops that are not properly terminated can produce seeds which establish themselves as weeds. If this occurs, this will force cash crops will compete with these weeds which can raise the potential of decreased yields as a result (Snapp et al., 2005).

Even though the initial adoption process of cover crops can seem financially daunting to farmers, there has also been evidence to show that they can increase economic gains once they begin to take root in the soil. For instance, the ability of cover crops to introduce key nutrients into the soil such as nitrogen can decrease the overall cost of fertilizers used. In one study that measured the impact of winter legumes on the amount of nitrogen applied to corn crops, it was found that cover crops helped to reduce nitrogen fertilizer use to 50 – 100 pounds per acre as opposed to 200 pounds per acre when no cover crops were used (Larson et al., 1998). The ability of cover crops to suppress weed growth have also been found to reduce herbicide costs. In one study that measured the economic impacts of cover crops on corn and cotton cash crop systems, it was found that the level of weed suppression that occurred due to cover crop usage amounted in about $7.47 per acre in savings (Morton et al., 2006). As shown through previous literature, cover crops can dimmish operational costs for farmers once they are properly implemented. In this way, cover crops can act not only as a tool to improve the quality of agricultural soil but also as a means to reduce overall expenses farms incur through their daily activities.

It is also important to consider the wider environmental benefits that the use of cover crops can offer. As previously mentioned, cover crops improve soil in many ways ranging from increasing soil organic matter to decreasing rates of soil erosion. Without the presence of enough soil organic matter, maintaining the longevity of soil is threatened. Soil microbes are vital mechanisms needed to maintain soil health through recycling needed organic compounds and nutrients within the soil such as nitrogen. Additionally, soil microbes are essential for crop production. When enough soil microbes are present within the soil, plants gain additional benefits such as crucial elements which develop plant tissue (such as auxins and cytokinins) as well as coating plant roots to increase their resistance to infection (Shah et al., 2021). The longevity of soil health is often also threatened by soil erosion. Around 80% of all agricultural soils worldwide are impacted by severe soil erosion, depleting needed nutrients and water which can decrease cash crop yields as a result. However, when soil erosion is mitigated using conservation techniques such as cover cropping, water and nutrient losses are often found to significantly improve (Pimentel et al., 1995).

Though the growing issue of worldwide soil degradation may not always be on the forefront of many local farmers minds, the longevity of the life of agricultural soils will be at an increased risk if soils are not taken care of now. Without properly functioning agricultural soils, this may mean a decrease in total food productivity which would increase the rate of food insecurity as a result (Utuk & Daniel, 2015). Furthermore, degraded soils may threaten other areas of human health including introducing exposure to pollutants at higher rates due reasons such as the intensive application of agrochemicals (Siebielec et al., 2016). Even if the financial benefits of using cover crops may be minuscule at best for many farmers, it is imperative that they keep in mind the larger environmental and social benefits cover crops offer for the longevity of their soil and its ability to support food security and production.

Research regarding the environmental and biological benefits of cover cropping has often shown the numerous ways in which cover cropping can increase the overall quality of soil health. Whether through a monoculture or mixture, cover crops chosen intentionally for the qualities that best benefit the particular soil types and cash crops being grown can greatly benefit agricultural land in the long run. However, studies focusing on the economic benefits of cover cropping are not always as clear. Though some research has shown the ways in which cover crops aid in reducing operational costs, other parts of the literature have shown that the assumed direct and indirect costs of this process cause many farmers to be apprehensive in adopting this practice. Because of this, further research is needed to determine whether the use of cover crops can ultimately result in financial gains for the agricultural industry. If more evidence for this relationship is found, more farmers may be incentivized to switch over to cover cropping which will help the overall welfare of the agricultural sector and the social benefits it generates in the long run.

Methodology

For this study, it was decided to specifically focus on one state. This choice was made in order to mitigate issues surrounding the involvement of multiple states where different crops are grown and different soil types are present. In other words, one state was used in order to somewhat decrease the occurrence of heterogeneity that is much more likely to be found across different states. The state chosen specifically for this study was Pennsylvania due to special interest surrounding its local agricultural industry.

The observations for each of the variables described in Table 1 were collected from the United States Census of Agriculture. The United State Census of Agriculture occurs once every five years and takes a complete count of all farms, ranches, and their respective operators across the country. This census considers a broad range of information ranging from production practices to land use and ownership characteristics. This data is collected by the National Agricultural Statistics Service (NASS) to communicate this information to farm and ranch operators, companies, government officials, and the public.

The variables included in the model for this study were chosen based upon their ability to substantially impact the total net cash income as shown through the theory that was previously discussed. As this study focuses specifically on the impact of total net cash farm income across the state of Pennsylvania, the data sample includes observations from each of its 67 counties. The data used within the sample was also collected from the year 2022, since the observations for each of the variables were fully available at that time, and the data was kept as current as possible. Below, Table 1 provides descriptions of the variables to be used within the regression model:

Table 1. Description of Variables

Name	**Symbol**	**Description**
Net Cash Farm Income	NI	Total net cash farm income within ith county. This will act as the dependent variable.
Percentage of Cover Crops	CC	Percentage of farms that use cover crops within ith county. This will act the independent variable.
Proportion in Farms	PIF	Proportion of total land area in farms within ith county. This will as a control variable.
Average Farm Size	AFS	Average farm size in acres within ith county. This will as a control variable.
No-Tillage Practice	NT	Percentage of cropland on which no-tillage practices were used by farms within ith county. This will as a control variable.

Reduced-Tillage Practice	RT	Percentage of cropland on which reduced-tillage practices were used by farms within ith county. This will as a control variable.
Intensive-Tillage Practice	IT	Percentage of cropland on which intensive tillage practices were used by farms within ith county. This will as a control variable.
Percentage of Male Producers	MALE	Percentage of farm producers who are male within ith county. This will as a control variable.
Percentage of Female Producers	FEMALE	Percentage of farm producers who are female within ith county. This will as a control variable.
Percentage of Young Producers	YOUNG	Percentage of farm producers who are less than 35 years old within ith county. This will as a control variable.
Percentage of Middle Age Producers	MIDDLE	Percentage of farm producers who are between 35 to 64 years old within ith county. This will as a control variable.
Percentage of American Native Producers	AN	Percentage of farm producers who are America Native within ith county. This will as a control variable.
Percentage of Asian Producers	AS	Percentage of farm producers who are Asian within ith county. This will as a control variable.
Percentage of Black or African American Producers	BL	Percentage of farm producers who are Black or African American within ith county. This will as a control variable.
Percentage of Pacific Islander Producers	PI	Percentage of farm producers who are Pacific Islander within ith county. This will as a control variable.
Percentage of White Producers	WH	Percentage of farm producers who are White within ith county. This will as a control variable.

Based upon previous literature, the model proposed within this study includes variables that show strong evidence in their ability to significantly impact net cash farm income and is as follows:

$$NI_i = \beta_0 + \beta_1 CC_i + \beta_2 PIF_i + \beta_3 AFS_i + \beta_4 NT_i + \beta_5 RT_i - \beta_6 IT_i + \beta_7 MALE_i + \beta_8 FEMALE_i + \beta_9 YOUNG_i + \beta_{10} MIDDLE_i + \beta_{11} AN_i + \beta_{12} AS_i + \beta_{13} BL_i + \beta_{14} PI_i + \beta_{15} WH_i + \varepsilon_i$$

Percentage of Cover Crops (CC) was chosen as the independent variable for this study as a means of measuring the impact of cover cropping on total net cash farm income earned by Pennsylvanian farms. As previously found through studies such as Lichtenberg et al. (1994), evidence can be used to support the theory that the use of cover crops is associated with increased farm profits. Thus, the proposed specification for this study also theorizes that if an increase in the total percentage of cover crops used within ith Pennsylvania county, then the total net cash farm income within ith county will also increase.

Proportion in Farms (PIF) was chosen as a variable to control for the level of agricultural productivity within ith Pennsylvania county. To measure for total agricultural productivity, the total land area in acres taken up by farms within each county was divided by the total land area in acres within each county in Pennsylvania. Additionally, Average Farm Size (AFS) was also chosen as a control variable to represent that average acreage size across farms within ith Pennsylvania county. As supported by evidence found in Behjat and Ostry (2013), both average farm size and total farm area (in hectarage) within each local health area were found to have significant and positive impacts on gross margin. In other words, it is expected through this proposed specification that the larger the average farm size and the more productive (meaning the larger amount of total county acreage that is dedicated to agricultural land), the more net cash farm income will also increase as a result.

No-Tillage Practice (NT), Reduced-Tillage Practice (RT), and Intensive-Tillage Practice (IT) were all used to control for the percentage of farms that apply certain land use practices within ith Pennsylvania county. According to the study by Nouri et al. (2019), the use of cover crops when combined with conservation tillage practices (such as no-till and reduced-till) have been thought to improve soil structure and quality at an accelerated rate. The study went on compare cover crop treatments with both no-tillage and conventional tillage techniques over the course of 34 years. From this, it was found that the mixture of cover crop and no-till treatments significantly improved soil physical properties along with increased yields for cotton cash crops as compared to the cover crop and conventional tillage treatment mixture. As supported by Nouri et al. (2019), the specification for this study theorizes that the amount of tillage used by impact the level in which cover crops can effectively improve soil health and thus inadvertently impact the amount of net cash farm income earned within ith Pennsylvania county as a result.

As supported by Behjat & Ostry (2013) and Schilling et al. (2014), variables representing the gender (MALE and FEMALE), age (YOUNG and MIDDLE), and race (AN, AS, BL, PI, and WH) of farm operators all acted as additional control variables within the theoretical model proposed for this study. These control variables were included to better represent common characteristics that may impact the amount of profit farm operators are ultimately able to earn. More specifically, factors such as age, gender, and race may impact farm profits depending on certain levels of experience or prejudices certain groups may face as compared to others.

The data used within this study will be analyzed through R programming using Ordinary Least Squares (OLS) regression analysis. After initial testing, additional econometric tests will be used to confirm whether the regression is BLUE (best, linear, unbiased, and an estimator). As the data used within this study is cross-sectional, the model will be tested for heteroskedasticity using the Breusch-Pagan test due to the risk of having non-constant variance within the error term. In addition, the model will also be tested for the presence of multicollinearity (using a correlation matrix and VIF test) as well as for specification error (using the Ramsey Rest test) to guarantee a more representative model.

Results

Table 2. Descriptive Statistics

Statistic	N	Mean	St. Dev.	Min	Max
sfdata.NI	67	48,779,701.00	97,591,888.00	-5,226,000	673,170,000
sfdata.CC	67	17.55	9.12	0	44
sfdata.NT	67	24.91	11.68	3	57
sfdata.RT	67	12.61	5.04	0	21
sfdata.IT	67	17.03	7.22	4	39
sfdata.PIF	67	24.47	13.85	0.40	62.70
sfdata.AFS	67	152.16	66.54	9	540
sfdata.MALE	67	65.58	3.61	54	76
sfdata.FEMALE	67	34.40	4.01	24	46
sfdata.YOUNG	67	11.39	5.02	0	24
sfdata.MIDDLE	67	54.27	4.45	44	72
sfdata.AN	67	0.12	0.29	0.00	2.08
sfdata.AS	67	0.24	0.44	0.00	2.14
sfdata.BL	67	0.22	1.07	0.00	8.70
sfdata.PI	67	0.03	0.09	0.00	0.65
sfdata.WH	67	98.98	1.37	91.30	100.00

Based upon the results of the summary statistics listed within Table 2, it was found that there was a noticeably large variance between the observations for Net Cash Farm Income (NI). Though there the average income per Pennsylvania county stands at $48,779,701, the observations range anywhere from $-5,226,000 in Montgomery County up to $673,170,000 in Lancaster County. Additionally, the standard deviation also stands quite large at $97,591,888. This large amount variability between observations indicates that the sample is representative of both high earning and low earning counties within the state of Pennsylvania.

It was also found that the Percentage of Cover Crops (CC) had a somewhat noticeable variability between observations, ranging from 0% in Cameron County to 44% in Lancaster County. This is also indicative that both counties that implement no cover crop treatments as well as those that have almost half of all farms that use cover crop treatments are represented within this sample. Additionally, the average Pennsylvanian farm is about 152.16 acres, and the average Pennsylvania farm operator is more likely to be male (at an average of 65.58% per county), between the ages of 35 to 64 years old (at an average of 54.27% per county), and white (at an average of 98.98% per county).

Figure 1. Naïve Regression

	Dependent variable:
	NI
CC	6,310,674.00***
	(1,071,748.00)
Constant	-61,986,761.00***
	(21,166,139.00)
Observations	67
R^2	0.35
Adjusted R^2	0.34
Residual Std. Error	79,414,779.00 (df = 65)
F Statistic	34.67*** (df = 1; 65)
Note:	*p<0.1; **p<0.05; ***p<0.01

Based upon the naïve regression results as shown in Figure 1, it was found that Percentage of Cover Crops (CC) had a positive and significant association at the 1% level with Net Cash Farm Income (NI) earned by Pennsylvania farms in 2022. In other words, it was shown that for every 1% increase in cover crop usage, net cash farm income would increase by approximately $6,310,674 within ith Pennsylvania county. Additionally, it was found that the variable CC could only explain 34% of the variation in NI as represented by the adjusted R^2.

Figure 2. Regression Results

Regression Results

	Dependent variable:
	NI
CC	5,608,911.00**
	(2,388,003.00)
NT	-3,323,147.00
	(2,209,286.00)
RT	-2,124,391.00
	(2,938,594.00)
IT	375,058.80
	(1,501,173.00)
PIF	3,882,142.00***
	(963,399.90)
AFS	-56,570.59
	(201,084.90)
MALE	954,484.90
	(6,738,053.00)
FEMALE	-385,364.70
	(5,433,611.00)
YOUNG	5,086,512.00**
	(2,424,782.00)
MIDDLE	3,839,563.00
	(2,947,931.00)
AN	-20,850,494.00
	(34,386,668.00)
AS	18,587,491.00
	(39,738,814.00)
BL	-10,587,098.00
	(19,442,301.00)
PI	52,741,317.00
	(108,598,545.00)
WH	7,480,092.00
	(18,979,814.00)
Constant	-1,089,906,656.00
	(2,037,636,519.00)
Observations	67
R^2	0.61
Adjusted R^2	0.50
Residual Std. Error	69,041,911.00 (df = 51)
F Statistic	5.39*** (df = 15; 51)
Note:	*p<0.1; **p<0.05; ***p<0.01

Based upon the total regression results as shown in Figure 2, it was found that the variable CC has a positive and significant association at the 5% level with the variable NI earned by Pennsylvania farms in 2022. In other words, it was shown that for every 1% increase in cover crop usage, net cash farm income would increase by approximately $5,608,911 within ith Pennsylvania county. It was also found that Percentage of Young Producers (YOUNG) had a significant and positive association with the variable NI at the 5% level and Proportion in Farms (PIF) had significant and positive association with the variable NI at the 1% level. Additionally, each of the variables included within the model can only explain 50% of the variation in NI as represented by the adjusted R^2.

Figure 3. Ramsey Reset Test to Test for Specification Error

```
        RESET test

data:  model4
RESET = 45.133, df1 = 3, df2 = 48, p-value = 5.184e-14
```

The Ramsey Reset test was used to determine the likelihood of specification error within the total regression model. Within this test, a null hypothesis represents that no specification error is present whereas the alternative hypothesis represents the presence of specification error within the model. If the Ramsey Reset test produces a significant result, this indicates that specification error exists due to the fit of the model showing significant improving through the addition of proxy terms. As seen in Figure 3, the p-value was given as 5.184^{-14} meaning that the result was well below the 5% significance level. This shows evidence that the null hypothesis should be rejected, and that specification error is likely present within the model.

Figure 4. Breusch-Pagan to Test for Heteroskedasticity

```
        studentized Breusch-Pagan test

data:  model4
BP = 26.605, df = 15, p-value = 0.03212
```

The Breusch-Pagan test was used to determine the likelihood of heteroskedasticity within model due to the use of cross-sectional data along with the presence of large variances between observations of certain variables. Within this test, a null hypothesis represents that no heteroskedasticity is present whereas the alternative hypothesis represents the presence of heteroskedasticity within the model. As shown in Figure 4, the p-value was given as 0.03212. As this result was below the 5% significance level, the null hypothesis should be rejected. This indicates that there is evidence to support the presence of heteroskedascity within the model.

Figure 5. Variation Inflation Factor Test for Multicollinearity

CC	NT	RT	IT	PIF	AFS	MALE	FEMALE	YOUNG	MIDDLE	AN	AS	BL	PI	WH
6.568428	9.214989	3.032396	1.624357	2.466682	2.478463	8.212983	6.578469	2.049876	2.386730	1.411252	4.282187	5.973655	1.284177	9.366010

To test for multicollinearity, a correlation matrix was first used to determine whether any strong correlation existed between variables within this model. A result higher than the absolute value of 0.80 is indicative of multicollinearity between two variables. Based on the results of this test, the only two variables that showed evidence of correlation between one another were the variables of MALE and FEMALE at a value of -0.911. Though there was minimal evidence to show that multicollinearity existed through the correlation matrix, further testing was conducted using the Variation Inflation Factor (VIF) test. A value of 5 or more indicates that the extent in which a certain independent variable can be explained by a combination of the other independent variables is high. As seen through the results in Figure 5, it can be determined that there is further evidence to support the presence of severe multicollinearity for the variables MALE and FEMALE. The variables of CC, NT, BL, and WH also have VIF values above 5, meaning that they too show evidence supporting the presence of severe multicollinearity within this model. Ultimately, the correlation matric and VIF test both show evidence that severe multicollinearity within this model.

Discussion

Based upon the results obtained in Figure 2, the Percentage of Cover Crop Use (CC) had a significant and positive coefficient value as originally predicted within the proposed theoretical model. However, it is still important to note that certain limitations within this study prevent this outcome from being used as direct evidence to support the claim that the use of cover crops can increase the level of Net Cash Farm Income (NI) earned by Pennsylvania farms.

One limitation that is worth noting is the fact that Pennsylvania as a state is still quite heterogeneous in terms of soil types. For instance, it has been found that the state of Pennsylvania is divided into three different physiographic areas and seven different soil "provinces" or types. These soil provinces are described as the Coastal Plains, Piedmont Plateau, Allegheny Mountains, Limestone Valleys, Glacial, Glacial Lake and Terrace, and River Flood Plains and Terraces (Shaw, 1914). Even though the issue of heterogeneity was somewhat mitigated through using only one state within this study as opposed to using multiple, the state of Pennsylvania still has diverse soil types within itself. Because this issue may still exist, it may have caused a level of bias within the regression results that were obtained due to reasons such as differences in types of cash crops grown or types of cover crops most beneficial for certain soil types. Along with this, the use of the Breusch-Pagan test gave further evidence that heteroskedastic elements likely exist within the error term. In other words, unmeasurable differences such as diverse soil types between Pennsylvania counties likely do exist and cause unreliable hypothesis testing as a result.

It is also worth discussing the possible limitations from the results obtained by the other econometric tests used. For instance, the likely existence of specification error within the model could have been caused by possible omitted variables. As unknown control variables that ultimately impact the level net cash farm income earned were likely left out of the model, this would cause omitted variable bias as a result. Additionally, evidence of multicollinearity will cause standard error and t-statistic estimates to be biased. In other words, biased hypothesis testing means that the estimated coefficient values may not be as accurate and thus means the model itself may not as reliable as a result.

The use of aggregate data is also a limitation within this study. As aggregate is more an overall average set of data as opposed to individual responses, this makes it different to make an explicit casual claim from these results. Additionally, this also makes it more likely that reverse causality may have occurred. Since there are many factors that cannot be controlled at the aggregate level, this means that the correlation between the use of cover crops and amount of net cash income earned may not indicate that cover crop usage is necessarily causing an increase in farm profit. Instead, it is possible that this could indicate that farms who have a higher net income may use cover crops as they have the financial means to cover an potential costs that come with adopting this practice.

Even with these limitations, the results obtained from the total regression still offer valuable information. Though it cannot be said that this model can be used as evidence to support a direct cause, it can still be used to suggest a strong association exists between the variables CC and NI at the aggregate level. Though the use of smaller scale data if often more useful in given information regarding whether specific significant relationships exist, the use of aggregate data is still important in telling information that can be used to describe certain trends that may exist at a larger scale. Again, as previous studies regarding the impacts cover crops have on the profitability of farms primarily focus in at the individual level, the results from this study offer a different approach to analyzing this relationship at a much wider scale.

Conclusion

The growing occurrence of soil degradation due to conventional agricultural techniques have given rise to the creation of more sustainable practices in attempts to alleviate this issue. One sustainable techniques that has proven to be effective in improving soil health is known as cover cropping. By using cover crops in between growing seasons of cash crops, agricultural soils can gain improved structure and quality to better ensure that the land can continue to sustain plant growth well into the future. However, even with these obvious benefits, many farmers still hold concerns surrounding direct and indirect costs they may incur by adopting this practice. Finding ways to show how the use of cover crops can be beneficial not only for their sustainable concerns but also for their potential financial benefits can better incentivize farmers to switch to this practice.

The study used regression analysis was used to detect whether a significant association existed between Percentage of Cover Crop Use (CC) and the amount of Net Cash Farm Income (NI) earned by each of the 67 counties within Pennsylvania. Through the results of this test, it was found that the variables CC and NI had a significant and positive association at a 5% significance level. Though limitations of this study prevent any sort of definitive causal claims about this relationship, this information is still valuable in revealing a significant correlation between cover crop use and profitability at a larger scale.

To expand upon this research the future studies, steps can be made to improve on this data sample. For instance, the incorporation of more control variables can help alleviate the presence of omitted variable bias within the model. Further research can reveal what additional control variables may also impact the net cash income earned by farms. Along with this, future studies can also take the time to collect more specific, individual observations across each county to obtain more representative results. Examples of this can include collecting information through surveys regarding fertilizer costs, herbicide costs, and/or cash crop yields. From this, more specific comparisons regarding costs incurred and profit earned can be made between farms who use cover crops versus those who do not.

The evidence collected through this study can be used to gain a better understanding regarding the association between cover crop usage and net farm income earned within the state of Pennsylvania. Additionally, these results can be expanded upon in future studies surrounding the profitability of cover crop usage on Pennsylvanian farms. Based upon these current findings along with any future additional findings, policymakers can use this information to make more informed decisions surrounding certain subsidy programs or tax incentives they can use to help motivate farmers to transition to this practice. Ultimately, the continuing to evaluate the relationship between cover cropping and profitability will allow for an improved understanding as to how to best implement this practice within Pennsylvanian and other states in order to secure soil health and food production for years to come.

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