Statistical Analysis of Unreplicated ONFARM Strip Trial Yield Data

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Introduction

When farmers are interested in implementing new practices on their farms, it is common to test the management change using on-farm strip trials. This involves one strip receiving a treatment while the neighbouring strip receiving another treatment or control. This allows the grower to evaluate which is the best practice for their operation and is the basis of the ONFARM program of the OSCIA. While this can be useful to improve decision making, the challenge with this method is that spatial variability across the farm may confound the trial results. In other words, a farmer can't be sure if the yield difference they observed was due to the treatment or the differences in soil types and productive capacity between the two strips.

Traditionally, this problem of spatial variation confounding results has been addressed by randomizing and replicating small plot experiments at research stations. While this improves the reliability of trial results, it is time consuming, expensive and limits the ability of farmers to directly test products and practices they are interested in on their own farms.

The introduction of combine yield monitors has increased the interest among farmers in conducting on-farm trials since these sensors measure yield in thousands of points across a farm. There are two main challenges in using this data optimally for the analysis of on-fam strip trials. The first is that each measurement of yield is not independent (positive spatial autocorrelation) and the second is the lack of randomization in strip trials, which results in confounding with spatial variability.

To address these issues, Caleb Niemeyer and his PhD advisor, Dr. John Sulik have been developing statistical methods to account for the lack of randomization and replication in yield monitor strip trial data.

Objectives

This report aims to demonstrate a new method which can be used to account for the influence of spatial variability on response to best management practices. This report will analyze yield monitor data from the ONFARM program of the OSCIA to and evaluate the statistical significance of treatment effects in these unreplicated and non-randomized strip trials.

Methods

Propensity score matching is an observational statistical technique commonly used in fields such as medicine or economics where randomization and replication is not feasible or ethical. Since these fields of research have needed to develop techniques to overcome challenges with traditional experimental designs similar to the issues faced in analyzing on-farm trials, these techniques may be a good fit to address these same challenges with agricultural data.

The propensity score matching method we have adapted aims to balance distribution of confounding variables between the treated and control strips. For example, if one strip has a higher average elevation than another, this method will correct for the difference in elevation between the strips, helping to ensure that the yield response observed is not due to elevation, but rather the treatment of interest. In reality, there are many more potential confounders than just elevation and this method is capable of correcting for multiple at the same time. In this analysis, the confounders selected were elevation as measured by the Ontario LIDAR data, terrain derivatives calculated from the digital elevation model, past yield patterns and historical imagery obtained from satellites. All of these layers can be included to correct for their possible confounding influence on the experiment. Additionally, a spatial model is used to address the presence of spatial autocorrelation in yield data.

After the propensity score matching method is completed, the two strips can be accurately compared and a test of statistical significance can be conducted to determine if a treatment yield differed significantly from another treatment. Cover crop and organic amendment treatments were applied in five sites as part of the ONFARM program of the OSCIA. Yield monitor data were collected in the years of 2021, 2022, and 2023. When multiple site-years of data are collected, the results of these trials can be combined using simple meta analysis techniques to estimate the overall effect of a treatment, rather than just the effect on one farm.

Results - Tables and Figures

Table 1. Yield response (bu/ac), associated statistics and 95% Confidence intervals of yield response to various best management practices. Rows with P values significant at > 0.05 are italicized.

Farm	Treatment	Year	Yield Response	p value	95% CI Low	95% CI High	Yield Response (%)
Site 3	control vs organics	2021	-0.81	0.6862	-4.78	3.15	-0.65
Site 3	control vs organics	2022	-1.14	0.1103	-2.54	0.26	-1.94
Site 3	control vs organics	2023	8.02	0.1406	-2.64	18.68	3.18
Site 3	control vs cover	2021	-0.51	0.8417	-5.56	4.53	-0.40
Site 3	control vs cover	2022	0.17	0.8989	-2.39	2.72	0.28
Site 3	*control vs cover*	*2023*	*6.12*	*0.0018*	*2.26*	*9.99*	*2.39*
Site 3	organics vs combo	2021	-0.31	0.7729	-2.39	1.77	-0.24
Site 3	organics vs combo	2022	-1.02	0.3495	-3.16	1.11	-1.74
Site 3	organics vs combo	2023	1.37	0.6096	-3.88	6.61	0.53
Site 7 east	control vs cover	2021	-0.36	0.7576	-2.67	1.94	-0.17
Site 7 east	control vs cover	2022	-0.67	0.2331	-1.7	0.42	-1.06
Site 7 east	*control vs cover*	*2023*	*9.40*	*0.0003*	*6.72*	*11.99*	*7.79*
Site 7 west	control vs cover	2021	-0.39	0.1002	-0.49	0.12	-4.65
Site 7 west	control vs cover	2022	0.93	0.0974	-0.16	2.02	1.66
Site 7 west	*control vs cover*	*2023*	*6.07*	*0.0084*	*1.54*	*10.59*	*5.40*
Site 12	control vs organics	2023	1.02	0.218	-0.61	2.66	1.85
Site 20	control vs cover	2021	-0.12	0.9480	-3.84	3.60	-0.27
Site 20	control vs cover	2022	7.45	0.3506	-8.19	23.09	5.72
Site 20	*control vs cover*	*2023*	*8.12*	*0.0110*	*1.85*	*14.37*	*29.3*
Site 20	*control vs combo*	*2021*	*3.39*	*0.0216*	*0.50*	*6.29*	*7.04*
Site 20	*control vs combo*	*2022*	*8.45*	*0.0000*	*4.46*	*12.43*	*6.17*
Site 20	*control vs combo*	*2023*	*5.03*	*0.0000*	*3.47*	*6.58*	*13.16*
Site 11	control vs organics	2022	0.07	0.8421	-0.65	0.80	0.11
Site 11	control vs organics	2023	-0.09	0.8523	-1.12	0.93	-0.10
Site 11	combo vs cover	2022	0.34	0.4089	-0.47	1.15	0.51
Site 11	combo vs cover	2023	0.36	0.7608	-1.94	2.66	0.35
Site 11	*combo vs organics*	*2022*	*2.41*	*0.0000*	*1.74*	*3.07*	*3.56*
Site 11	*combo vs organics*	*2023*	*2.82*	*0.0001*	*1.25*	*4.40*	*2.75*

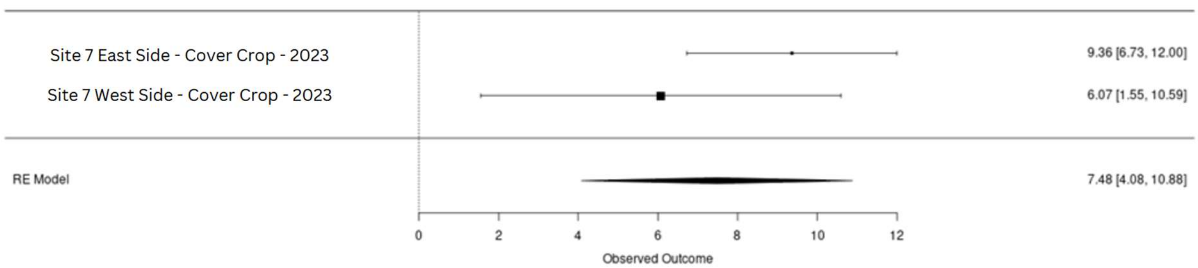

Figure 1. Treatment effects of cover crop treatments from two fields at Site 7. The central dot for each line graph represents the yield response (bu/ac) observed from the BMP, while the range of each line shows its 95% confidence interval. The overall effect of these treatments is shown in the bottom line as the RE model. Because each site's treatment strips vary in size, the contribution of each treatment's to the overall model is visualized by the size of it's yield response square.

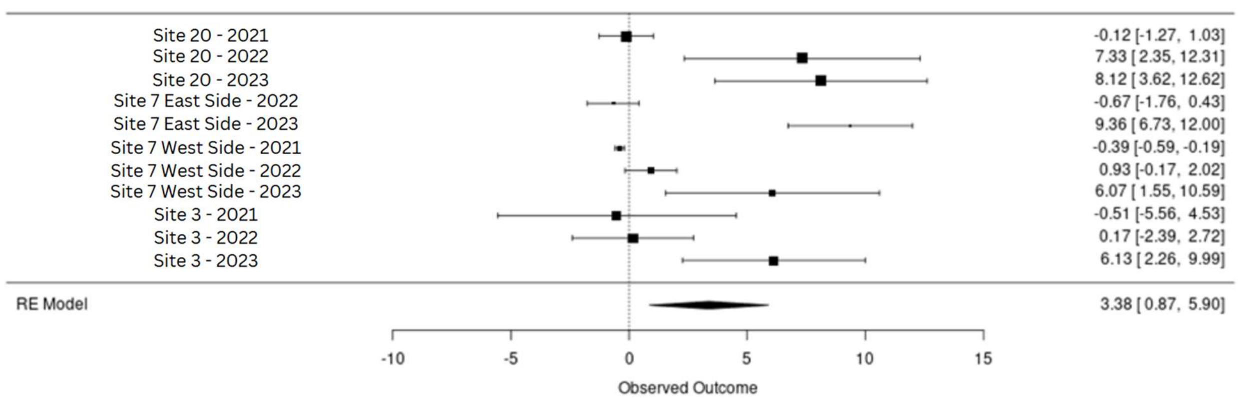

Figure 2. Treatment effects of cover crop treatments across all years and farms. The combined overall effect is shown in the RE model bar at the bottom of the chart. Treatment effect estimates are displayed as squares of various sizes depending on their contribution to the overall effect estimation due to sample variability differences between sites. 95% confidence intervals are displayed as horizontal bars on either side of the effect estimate.

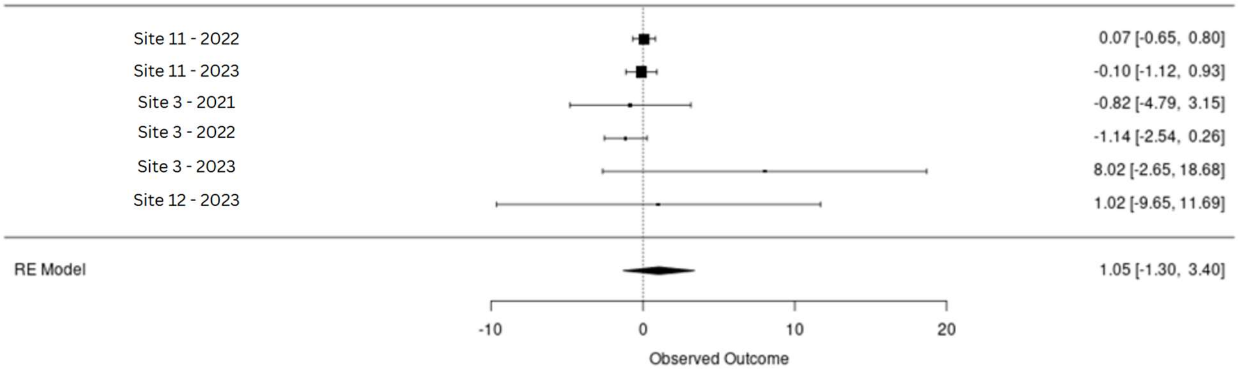

Figure 3. Treatment effects of organic amendment treatments across all years and farms. The combined overall effect is shown in the RE model bar at the bottom of the chart. Treatment effect estimates are displayed as squares of various sizes depending on their contribution to the overall effect estimation due to sample variability differences between sites. 95% confidence intervals are displayed as horizontal bars on either side of the effect estimate.

Table 2. Treatment effect of organic amendments at Site 12 by soil type zone in 2023

Soil Type	**Yield Response**	**p value**	**95% CI Low**	**95% CI High**
Fox	-1.097	0.6448	-5.76	3.57
Degraded Fox	-0.484	0.8427	-5.27	4.30
Depositional Fox	3.650	0.2768	-2.93	10.23
Hillsburgh	0.918	0.0054	0.272	1.56
Tuscola	0.712	0.6652	-2.51	3.94

Results and Discussion

At Site 3, there were no statistically significant treatments in 2021 and 2022. However, in 2023, yields in the cover crop treatment were higher than the control. Additionally, there was slight evidence (p=0.1406) in 2023 that the organic amendment treatment did increase yields relative to a control. There was no evidence to suggest that a combination of cover crops and organic amendments increased yields relative to organic amendments alone in any of the years studied.

At Site 7 there were two replications of cover crop treatments. Similarly to Site 3, there was not strong evidence that organic amendment had an effect on yield in 2021 and

2022, though both strips responded positively in 2023. Across those two strips, cover crops increased yield by 7.5 bu/ac with a 95% Confidence interval of 4.1 to 10.9 bu/ac (Figure 1).

At Site 20, the comparison between control and cover crop was non significant in 2021 and 2022 but was significant in 2023, similar to what was found at Sites 3 and 7. In the comparison between a control and a combination of both cover crops and organic amendment, every year studied saw a slight increase in yield.

At Site 11, the comparisons between the control and organic amendments were not significant. Additionally, the comparisons between a combination of cover crops and organic amendments and just cover crops was nonsignificant. However, the comparison between a combination of cover crops and organic amendments and just organic amendments was significant in both 2022 and 2023. This treatment effect size was small however.

At Site 12, there were no significant differences between treatments in any of the years studied. However, at this farm there is a separate digital soil type map available, provided by the precision agriculture business of Woodrill called Groundwork. These strips crossed over five unique soil types which included a Fox sandy loam (medium sands, rapidly drained), degraded Fox sandy loam, depositional Fox sandy loam, Hillsburgh sandy loam (fine sands, well drained) and Tuscola silt loam (very fine sands and silts, imperfectly drained). The propensity score matching method used allows for analysis of treatment effects by zone, in this case, soil type. In this analysis, all soil types except for the Hillsburgh sandy loam did not have strong evidence to suggest a response to organic amendments (Table 2). The Hillsbugh sandy loam did have a small but statistically significant positive yield response. While this suggests the Hillsburgh has a higher response to organic amendments, it should be noted that the power of the test for each soil type varies based on the amount of any particular soil type in the strip. For example, there was very little depositional fox in the strips (less than 5% of the area of the experiment) and as a result the 95% confidence interval is quite large. However, since well drained soils such as the Hillsburgh have lower organic matter, this result does suggest that these well drained low organic matter (OM) soils may respond more to organic amendments than soils with more water and more OM such as the Tuscola silt loam.

While individual farms, and soil types with farms, may have varying responses to best management practices, farmers and researchers may also be interested in determining overall treatment effects across several farms. This may help to inform generalized recommendations across a geographic area. To accomplish this, all available comparisons between a cover crop and control (Figure 2) and an organic amendment and a control (Figure 3) can be included in a simple meta analysis. This approach can determine what the best estimate of the treatment effect and 95% confidence intervals are. When looking at all available cover crop data, the average treatment effect was 3.38 bu/ac with a 95% confidence interval of 0.87 bu/ac to 5.90 bu/ac (Figure 2). This indicates that cover crops likely cause a small but positive change in yield. For organic amendments, the treatment effect estimate was 1.05 bu/ac with a 95% confidence interval of -1.30 bu/ac to 3.40bu/ac. This indicates there is insufficient evidence to conclude that organic amendment application has an effect on yield, either positive or negative. However, there is a slight numerical trend towards higher yields with organic amendment application.

Limitations

This is a new and experimental method for determining the statistical significance of treatment effects in unreplicated strip trials. When the assumptions of the models used are met, the results will be accurate, but violations of these assumptions may introduce uncertainty. These assumptions include the standard assumptions for most common statistical test which include independence of observations, normally distributed data and equal variances. Since yield data is spatially autocorrelated, observations are not independent, resulting in the need for a spatial model which was used in this study. This spatial model reduced spatial autocorrelation in the resulting residuals, indicating this assumption violation was addressed.

One of the important assumptions unique to the methods used in this study is that propensity score matching can create balance of confounders between treatment groups. The evaluation of covariate balance was not shown in this report but is important. While this method provides an improved analytical method compared to simply looking at strip average yields, the causal inferences suggested in this report are not as strong as the “gold standard” of randomized and replicated trials.

Summary

When combining results across several sites and years, there is a slight increase in yield due to cover crops that is statistically significant. There is not enough evidence to suggest that organic amendment application does or does not influence yields. However, there are patterns within each site that may be masked by an overall analysis. At several sites, the benefits of best management practices were not able to be seen for 2 years after the treatments were applied. This suggests the best management practices should be considered a part of a long-term soil management strategy, rather than providing a short-term increase to crop yields. Additionally, farmers may need keep reasonable expectations of short-term return on investment when implementing these practices.