The Environmental Impact of Intercropping Through a Financial Perspective: A Comparative Cost-Benefit Analysis of a Single Succession Agricultural Experiment

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Abstract

All methods of agriculture degrade the environment in one way or another, however the severity of this damage differs depending on the growing strategy used. Currently monoculture has been the predominant farming practice in America, which is becoming ever more criticized due to the environmental harm it causes: fertilizer runoff pollution, increased carbon emissions, etc. The purpose of this study was to environmentally compare the practice of monoculture to the practice of intercropping (planting more than one crop variety in a single farm bed), using a single succession sample of cucumbers, beans, and lettuce. Over the course of one growing season on the UW Farm, yield and soil quality data were collected on six experimental plots, each one resembling either a monoculture or an intercropping technique. In order to standardize the evaluation process, this data was translated into a handful of different environmental factors, all of which were finalized in dollar-specific units. The summation of these factors accumulated into an environmentally driven cost-benefit analysis for each growing method. The final results drastically differ between the growing methods in favor of intercropping. Additionally, the evaluation of these factors prioritizes which environmental problems need to be addressed in the agricultural industry. Financially accounting for the environmental effect of agriculture has the potential to beneficially expand the bottom-line budgets of farm operations, no matter the size.

Evaluating and acknowledging the environmental impact of agriculture opens the door for favorable changes in individual farming methodology, policy, and land use.

Introduction

The Great Plains are arguably one of America's greatest assets, mainly due to the arability of the region; the Midwest is known for its fertile soil and access to large pools of water, such as the Mississippi River. However, due to the current state of uniform agriculture, the Great Plains are environmentally degrading at an astonishing rate. The demand for corn is causing the agricultural industry to focus on producing as much of the crop as possible, no matter what the consequences of increased fertilizer runoff, carbon emissions, and soil nutrient depletion have on the long term vitality of the environment.[1] Therefore, it is of the utmost importance to find a new method of agriculture that can meet the food demands of the people while maintaining a sustainable environment.

Theoretically it would make sense to diversify the produce that is being grown in order to systemically stop the reign of monoculture. Intercropping involves two or more different crop species in the same bed, rather than just one crop for the entire span of the bed.[2] Historically this practice has been used almost since the dawn of the Neolithic revolution, however it's implementation has decreased due to the efficiency of monoculture. Despite this fall in popularity, there has been a substantial amount of academic support for the intercropping technique. One academic paper suggests that intercropping reduces the amount of nitrate leaching without lowering overall yield.[3] Another paper argues that small Latin American farms have seen increased revenue when adopting an intercropping system of maize and beans.[4] Finally, *Hallam 2001* states that there are increases in long term biomass production when perennial and annual crops are intercropped together.[5] These are just a few examples of the academic literature on the topic, however many scholarly papers do not focus on the overall financial validity of intercropping.

The experiment associated with this paper tries to address the lack of inclusion of dollar-valued arguments for intercropping by using economic strategies to account for external environmental costs within the samples. The focus of this experiment is to environmentally quantify the practice of intercropping, relative to a monoculture counterpart. Understanding the true impact of intercropping would require a long term, fully comprehensive study. Given the structure of the UW Farm's summer internship, temporal and spatial limits required a more constrained short term experiment. Beans and cucumbers were used in order to establish a single succession comparison experiment at the UW Farm's Mercer Court Apartment site. Raw scientific data was collected and then translated into dollar units in order to create fourteen different economic factors that would then be compiled into an environmentally driven

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[1] "It's Time to Rethink America's Corn System." Scientific American Global RSS. Accessed October 25, 2015. http://www.scientificamerican.com/article/time-to-rethink-corn/.
[2] McClure, Susan, and Sally Roth. *Companion Planting*. Emmaus, PA: Rodale Press, 1994.
[3] Whitmore, A.p., and J.j. Schröder. "Intercropping Reduces Nitrate Leaching from under Field Crops without Loss of Yield: A Modelling Study." *European Journal of Agronomy* 27, no. 1 (2007): 81-88. doi:10.1016/j.eja.2007.02.004.
[4] Francis, C.a., and J.h. Sanders. "Economic Analysis of Bean and Maize Systems: Monoculture versus Associated Cropping." *Field Crops Research* 1 (1978): 319-35. Accessed May 11, 2015. doi:10.1016/0378-4290(78)90034-5.
[5] Hallam, A., Anderson, I. C., & Buxton, D. R. (2001). Comparative economic analysis of perennial, annual, and intercrops for biomass production. Biomass and Bioenergy, 21(6), 407-424.

comparative cost-benefits analysis. The final results were formatted into four cost-benefit figures that take into account external environmental costs for an intercrop, a cucumber monoculture, a bean monoculture, and a total monoculture sample.

In order to signify that the bean-cucumber intercropping sample could truly be a more environmentally friendly system of agriculture, the net value of the cost-benefit analysis would have to be higher relative to the bean, cucumber and total monoculture samples' net revenue. A higher net revenue for the intercropping sample was the expected outcome before the final results of the experiment were calculated. This hypothesis was based on a handful of theoretical assumptions. First, the diversity of crops will also diversify the soil nutrient uptake, thereby resulting in lower fertilizer replacement costs and decreases in leaching effects. Secondly, each crop grows and structures itself in different ways, allowing a well designed intercropping set up to maximize the space necessary for each plant to grow. As mentioned before, there is a substantial amount of environmentally positive academic literature based on the intercropping process, thereby opening the doors for the potential to be a sustainable and economically viable farming operation.

Methodology

The design and structure of the experiment attempted to create similar environments for the intercropping and monoculture samples in order to accurately compare the results. Therefore, out of the five sample plots, two were designated for the growth of beans and cucumbers separately, while the other three beds were part of a specifically designed intercropping sample. There are many ways to create an intercropping sample of beans and cucumbers in a cumulative 210 ft^2 agricultural space, therefore the design had to acknowledge the surrounding area and the needs of crops being grown. For instance, it is recommended that when creating an intercropped design, the spacing of the plants should be the mean of the recommended spacing's of each plant involved in the process (beans 18in + cucumbers 38in = 56/2 = intercrop 28in).[6] The intercrop plots were set up with one furrow trellis structure, where every one cucumber start was planted for every two bean starts. Figure 1 in the appendix lays out the complete design of both the intercrop and monoculture samples involved, as well as the dimensions of each bed.

After the bean and cucumber starts were planted, I had to collect yield and soil nutrient data in order to understand the direct environmental impact the crops had on the environment. Harvesting methods differed depending on the plant. Cucumbers were harvested on average every week for almost three months, while beans were remained on the stalk until early November in order to let them naturally dry out. This discrepancy in harvest dates is actually a historically known social benefit to the community, in that one bed can produce food throughout the year instead of at one specific time like most monoculture systems. Soil nutrient tests were conducted prior to planting and after uprooting to fully understand the influence the crops had on the soil.[7] This allowed an estimation of the change in soil nutrient content throughout the duration of the experiment, which became useful in determining the economic factors involved in the translation process.

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[6] McClure, Susan, and Sally Roth. Rodale's Successful Organic Gardening: Companion Planting. New York: Distributed in the Book Trade by St. Martin's, 1994. Print.

[7] "Soil Sampling Instructions." *UMass Extension*. Accessed September 18, 2015. https://soiltest.umass.edu/sites/soiltest.umass.edu/files/fact-sheets/pdf/SPTTL_1%20Soil%20Sampling%20Instructions_1.pdf.

The next step in the experiment was taking all of this raw soil and yield data, and transforming it into dollar-specific values. An extensive literature review was the first key on creating reliable financial estimates, mainly due to the fact that environmental damage estimates are the most essential part of the numerical transformation. Table 1 in the appendix lists each scholarly source applicable to the process, as well as the variable(s) used and the associated economic factors involved. By combining the raw data collected, the damage estimates, produce prices, fertilizer costs, and a few simple mathematical conversions, I was able to estimate a financial value associated for each factor being evaluated in the experiment. Figure 2 in the appendix outlines the translation process for each economic factor examined, using example numbers to make the mathematical setup a bit easier to understand. Once all of the data was collected and translated each plot was assigned a representative variable in dollar units for each of the fourteen factors. The accumulation of the factors resulted in the final calculation of benefits, environmental costs, net revenues, and cost-benefit ratios for each sample.

Throughout the duration of this experiment, the collection and conversion of the data was the key aspect to the experiment. Scientific analysis of intercropping has been academically observed, however these results are difficult to apply to the economy. Standardizing all of the raw data by using dollar units is an important process, for both the experiment and generalized environmental business accounting.

Results

The final results from the cost-benefit analysis were observed in two different ways. First, the net revenues and cost-benefit ratios were compared between plots in order to test the original hypothesis. Secondly, each final variable in the analysis was compared relative to its importance and position between the other plot variables. The data for the second perspective is marginalized by taking each dollar value and dividing it by the bed feet of the samples. The final results were significant, as well as opened the door for potential ways to address environmental problems on a larger scale.

Figure 3 in the appendix provides an accurate summary of the final results for the cucumber monoculture, bean monoculture, total monoculture, and intercrop samples. The intercrop plots yielded the highest benefits, the lowest environmental costs, and thus the highest net value of any of the other plots. Logically this signifies that the intercrop plot had the lowest cost to benefit ratio, implying that a lesser amount of environmental damage was done for every dollar theoretically earned relative to the monoculture plots. These results support the original hypothesis of the experiment as long as all constraints and assumptions are accepted. When looking at the monoculture plots by themselves, it is easy to see that growing solely beans provides a larger net revenue and lower cost-benefit ratio than growing solely cucumbers. Environmentally speaking this would be expected due to the legumes ability to fix nitrogen from the air into soil (a strictly natural way to get more nitrogen in the soil), thereby lowering any costs related to the use of nitrogen fertilizers. However, the bean monoculture plot still had the highest final value of total environmental costs, reflecting that the net revenue values probably had more to due with market prices rather than environmental damage.

It is understandable that the intercrop samples would support the hypothesis of having a higher net value considering the substantial differences in revenue earned. It was apparent by sight alone during the growing process that the intercropped plots were producing a substantially larger amount of produce relative to the monoculture plots. This observation was backed by the

final yield data, where the intercrop plot almost doubled the amount of money earned per bed foot than the summation of both monoculture plots. This large discrepancy in potential dollars earned per bed foot between the samples, as seen in Table 2, is most likely due to the spacing rule used when determining the design of the plot, as well as intercropping's ability to maximize bed space. Putting environmental degradation aside, intercropping could be used as a short term method for increasing the marketable revenue for farmers.

Five of the fourteen environmental factors that were apart of the analysis had to do with the change in nitrogen recommendation before and after the growing process. All of the nitrogen factors were structured using a replacement cost approach, where the estimations are based off the potential cost it would take to make up the loss of nitrogen using a standard fertilizer. Due to the incorporation of legumes in the experiment, the bean monoculture and the intercrop plots actually resulted in positive values; the post-growing soil test had a lesser recommendation of nitrogen relative to the before-planting soil test. This means that the bean monoculture and intercrop plots actually mitigated the environmental damage done by soil nitrogen, resulting in benefits rather than costs for these factors. However, the values for the bean monoculture were substantially higher than the intercrop plots, as seen in Table 2. It should be noted that the total monoculture resulted in negative values, therefore implying that the environmental costs of nitrogen for monoculture cucumbers outweighed the environmental benefits of nitrogen for monoculture beans. The nitrogen factors were expected to be costs before the final results were calculated, thereby implying that intercropping has the potential to not only mitigate environmental damage, but also reverse said damage (especially with the incorporation of legumes into the sample).

In contrast to the nitrogen based factors, the value of soil carbon was expected to be a benefit in the analysis. However, for every plot there was a loss in the amount of carbon stored in the ground. This result goes against the assumption that small scale farm operations are able to sequester carbon in the soil. However, there was not a large discrepancy in the dollar per bed foot lost between samples, making it difficult to assume that intercropping does a better job of sequestering carbon relative to the practice of monoculture. These results, as well as the methodology used to find these results, allows larger implications to be made about intercropping and agriculturally sourced environmental degradation.

Discussion

The environmental evaluation of intercropping, through financial values, allows for a more complete understanding of alternative agriculture, as well as has a large significance for the industry on the whole. In regards to the actual experiment, the hypothesis that the intercrop plots have a higher net value than the monoculture plots are accepted. This implies that the intercrop sample is not only less harmful to the environmental, but also brings in a substantially higher market revenue. If it is assumed that this would still be the case on a larger scale, than it can be noted that intercropping beans and cucumbers is a viable alternative to the standard monoculture practice of growing beans and cucumbers. In addition, due to the final values for the nitrogen factors (as well as some of the other fertilizer based factors) it can be assumed that incorporating legumes into an intercrop sample helps keep important elemental compounds in the ground. On a larger scale this could help mitigate problems such as fertilizer runoff and increased emissions in the production of fertilizer. The results of the experiment prove that intercropping is beneficial to both the environment and budgets of farmers.

Even though the experiment seems to be successful in regards to the potential outcomes of implementing an intercropping system, some inherent constraints and assumptions need to be noted. First, the costs calculated are solely based on the environmental effects of the plots. This means that labor costs were not a part of the analysis, which could presume to be higher for intercrop plots due to the complexity of harvesting and planting. Secondly, all of the damage estimates used in the economic translations were taken from scholarly sources, which has fundamental constraints and assumptions for each damage estimation. Precise damage estimates would provide more accurate financial figures for the experiment. Lastly, the experiment conducted is on a relatively small scale with little replication, which means that it might not be truly representative of the agricultural industry at large. That being said, the methodology used to calculate the final values has resounding effects for environmental accountability on any size farm.

Small scale, organic, biodynamic, local, diverse, and/or closed system farms are motivating a food movement that respects the environment. The economic translations performed in the experiment could potentially enhance this accountability with direct numbers that can be shared inside and outside the organization. That being said, it could be difficult for these farms to account for environmental costs in actual operational budgets, however most of the damage being done comes from large-scale, industrial farms. If these farms calculated and internalized the environmental costs of their actions, then massive strides could be made figuring out solutions to these problems. For instance, if farms understood the changes in soil nutrient composition through a dollar estimation, then environmental investment decisions could be made to mitigate soil nutrient depletion, as long as the investment was efficient over the long run.

Environmental accountability of this nature could ease in to the agricultural industry if political considerations are taken in to account. For instance, if a carbon tax was implemented in the future, then revenues from that tax could assist farmers and fight against climate change at the same time. If farmers can express the financial value of the carbon sequestered during a certain period of time, then carbon tax revenues could be given to these farmers. Additionally, if an environmentally based fertilizer tax is put into effect, then revenues from that tax could go to aquatic cleanup and restoration efforts. All of these theoretical policies require a way to financially account for the environmental damage being done. The methods used in this experiment could be a viable structure to calculating these costs.

Conclusion

The results of this experiment show that intercropping could be a successful growing technique in that it maximizes bed space and provides biological benefits through increased biodiversity. However, before this theory is tested on a larger scale the agricultural industry will have to understand the environmental damage being done by their operations. Evaluating the environment in dollar units has potentially resonating effects for both small and large scale farms. Environmental costs could easily be incorporated in the already established budgets of said farms. Expanding on this idea is the fact that larger scale environmental problems associated with agriculture, such as global warming or fertilizer runoff, could be mitigated if we understand the damage being done in dollars rather than scientific units. Public policy addressing these large scale environmental problems could be the initial steps in making the agricultural industry a more environmentally friendly operation. Economic estimations of the environmental harm caused by agribusinesses are crucial to the sustainability of the industry.

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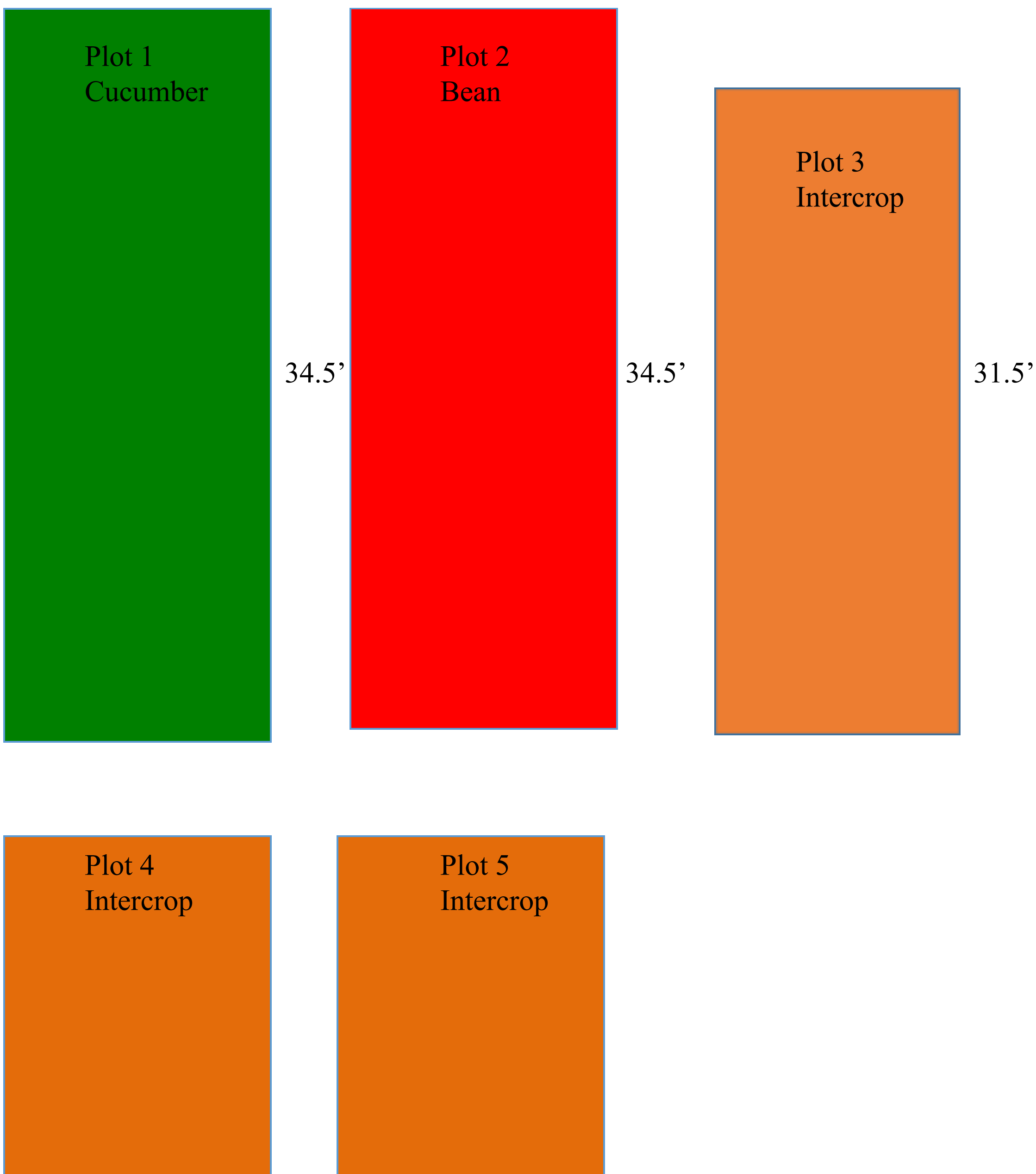
Velthof, G.l., J.p. Lesschen, J. Webb, S. Pietrzak, Z. Miatkowski, M. Pinto, J. Kros, and O. Oenema. "The Impact of the Nitrates Directive on Nitrogen Emissions from Agriculture in the EU-27 during 2000–2008."Science of The Total Environment 468-469 (2014): 1225-233. Accessed September 19, 2015. doi:10.1016/j.scitotenv.2013.04.058.

Appendix

Figure 1-Experimental Plot Overview: This simplistic map represents the spatial set up of the intercrop experiment, along with plot length dimensions. Plot width is three feet for each bed. Plot 1 and 2 represent the monoculture samples, where data is taken from each plot and then averaged to calculate the total monoculture variables in the cost-benefit analysis. The other 70 bed feet allotted to the experiment is split up into the intercrop plots 3,4, and 5. The average and summation of the data in these three intercrop plots represent the total intercrop variables in the cost-benefit analysis.



20.5’ 20.5’

Table 1: References and Associated Values Used for Intercropping Experiment: In order to translate the experimental raw data into environmentally based dollar value units, there needed to be an externally sourced financial estimate for each of the economic factors being addressed in the cost-benefit analysis. These estimates include vegetable/fertilizer prices, previous soil tests, and most importantly marginal damage estimates from environmental economic journals. This table clearly lays out the sources from the literature review in context to the financial estimates used from said source. In addition, the table includes which economic factors take into account the financial estimate from each specific source.

Source	**Associated Economic Factor(s)**	**Financial Estimate Used**
UW Farm Fresh Sheet	Revenue	*Cucumber ($/lbs.):* $.73 *Beans ($/lbs.):* $1.49
Raelani Kesler’s Senior Project	Value of Soil Carbon Sequestration; Replacement Cost of Fertilizer P_2O_5; Replacement Cost of Fertilizer K_2O; Cost of Fertilizer K_2O Production Emissions	*Bulk Density:* .483g/cm^3
"Soil Carbon Sequestration to Mitigate Climate Change" [8]	Value of Soil Carbon Sequestration	*Soil Organic Matter to Soil Organic Carbon Conversion Factor:* 1:1.72
"The Marginal Damage Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties" [9]	Value of Soil Carbon Sequestration; Cost of Fertilizer-N Production Emissions; Cost of Fertilizer P_20_5 Production Emissions; Cost of Fertilizer K_2O Production Emissions; Cost of Fertilizer $CaCO_3$ Production Emissions	*Marginal Damage of CO_2 Emissions:* $50/1tC

[8] Lal, R. "Soil Carbon Sequestration to Mitigate Climate Change." *Geoderma*123, no. 1-2 (November 2004): 1-22. Accessed September 19, 2015. doi:10.1016/j.geoderma.2004.01.032.

[9] Tol, Richard S.j. "The Marginal Damage Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties." Energy Policy 33, no. 16 (June 5, 2004): 2064-074. Accessed September 14, 2015. doi:10.1016/j.enpol.2004.04.002.

"Factsheet on Soil Fertility and Nutrient Management"[10]	Replacement Cost of Fertilizer N; Replacement Cost of Fertilizer P_20_5; Cost of Fertilizer P_20_5 Production Emissions; Replacement Cost of Fertilizer K_2O; Cost of Fertilizer K_2O Production Emissions	*Price of N Fertilizer:* $.55/lbs. *Phosphorus to P_20_5 Conversion Factor:* 2.29:1 *Price of P_20_5 Fertilizer:* $.69/1lbs. *Potassium to K_2O Conversion Factor:* 1.21:1 *Price of K_20 Fertilizer:* $.48/1lbs.
"A Synthesis of Carbon Sequestration, Carbon Emissions, and Net Carbon Flux in Agriculture: Comparing Tillage Practices in the United States"[11]	Cost of Fertilizer-N Production Emissions; Cost of Fertilizer P_20_5 Production Emissions; Cost of Fertilizer K_2O Production Emissions; Cost of Fertilizer $CaCO_3$ Production Emissions	*Carbon Emissions from Production of Fertilizer-N:* 6.75Kg C/1Mg N *Carbon Emission from Production of Fertilizer P_20_5:* 5.10649078 Kg C/1 Mg P_20_5 *Carbon Emissions from Production of Fertilizer K_2O:* 4.789822 Kg C/1Mg K_2O *Carbon Emissions from Production of $CaCO_3$:* 3.5758 Kg C/1 Mg $CaCO_3$
"Nitrate Leaching from Agricultural Soils: Ecological Modeling under Different Economic Constraints"[12]	Environmental Cost of Nitrogen Leaching	*Environmental Tax Equivalent:* Varies depending on Nitrogen-N Recommendation

[10] Silva, George. "Factsheet on Soil Fertility and Nutrient Management." Accessed September 18, 2015. http://www.nine-esf.org/ENA-Book.

[11] West, Tristram O., and Gregg Marland. "A Synthesis of Carbon Sequestration, Carbon Emissions, and Net Carbon Flux in Agriculture: Comparing Tillage Practices in the United States." Agriculture, Ecosystems & Environment 91, no. 1-3 (2002): 217-32. Accessed September 16, 2015. doi:10.1016/s0167-8809(01)00233-x.

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"The Impact of the Nitrates Directive on Nitrogen Emissions from Agriculture in the EU-27 during 2000–2008" [13]	Social and Environmental Costs of N_20 Emissions; Social and Environmental Costs of NO_x Emissions	*N_20 Emission Factor for Applied Nitrogen-N:* 2% *NO_x Emission Factor for Applied Nitrogen-N:* .55%
"The European Nitrogen Assessment: Sources, Effects, and Policy Perspectives" [14]	Social and Environmental Cost of N_20 Emissions; Social and Environmental Costs of NO_x Emissions	*Environmental and Social Damage of N_20 Emissions:* 4.4 euro/1 Kg N_20 *Environmental and Social Damage of NO_x Emissions:* 2 euro/ 1 Kg NO_x
"Universal Soil Loss Equation (USLE)" [15]	Off-Site Cost of Soil Loss	*A Factor:* .1378 tonnes/1 hectare
"Maximizing the Environmental Benefits per Dollar Expended': An Economic Interpretation and Review of Agricultural Environmental Benefits and Costs" [16]	Off-Site Cost of Soil Loss	*Damage of Soil Loss:* $2.73/1ton

Figure 2: Step-by-Step Process for Each Economic Translation Examined: This figure outlines the mathematical procedures for each economic translation used in the analysis. In order to simplify the mathematical steps, example numbers are used for each translation that don't accurately represent what happened in a specific bed of the experiment. Each translation typically starts with a specific raw data value collected from the plots, and then ends with the final dollar amount of said cost or benefit. Outlining the process in this way allows easy replication for any future use.

- Revenue

Yield	**Price**	**Revenue (Yield * Price)**	**Comparison Factor**	**Final Revenue (Revenue * Comparison Factor)**	**Final Revenue/Bed Feet**
10 lbs.	$1	$10	3	$30	$.42
	1 lbs.				1 ft.

[13] Velthof, G.l., J.p. Lesschen, J. Webb, S. Pietrzak, Z. Miatkowski, M. Pinto, J. Kros, and O. Oenema. "The Impact of the Nitrates Directive on Nitrogen Emissions from Agriculture in the EU-27 during 2000–2008."Science of The Total Environment 468-469 (2014): 1225-233. Accessed September 19, 2015. doi:10.1016/j.scitotenv.2013.04.058.
[14] Sutton, Mark A. The European Nitrogen Assessment: Sources, Effects, and Policy Perspectives. Cambridge, UK: Cambridge University Press, 2011. Accessed September 16, 2015. http://www.nine-esf.org/ENA-Book.
[15] Stone, R.P., and D. Hilburn. "Universal Soil Loss Equation (USLE)."SpringerReference, 2011. Accessed September 21, 2015. doi:10.1007/springerreference_225394.
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Example Revenue - $30
Example Revenue/Bed Feet - $.42/ft.

- Value of Soil Carbon Sequestration

Soil Organic Matter	SOM to SOC Conversion Factor[17]	Soil Organic Carbon (SOM/SOM to SOC Conversion Factor)	Bulk Density[18]	Volume of Plot	Soil Carbon (SOC *Bulk Density * Volume of Plot)
5%		2.91%	.483 g	3958695.17 cm^3	55640.65 g
	1.72		1 cm^3		

Soil Carbon	Comparison Factor	Marginal Damage of CO_2 Emissions[19]	Value of Soil Carbon Sequestration (Soil Carbon * Comparison Factor * Marginal Damage of CO_2 Emissions)	Value of Soil Carbon Sequestration/Bed Feet
.05564065 tC	3	$50	$8.35	$.1193
		1 tC		1ft

Example Value of Soil Carbon Sequestration - $8.35
Example Value of Soil Carbon Sequestration/Bed Feet - $.1193/ft.

- Replacement Cost of Fertilizer N

Nitrogen-N Recommendation	Plot Size	Adjusted Nitrogen-N recommendation (Nitrogen-N Recommendation * Plot Size)	Price of N Fertilizer[20]	Comparison Factor
100 lbs.	.00160698 acres	.160698 lbs.	$.55	3
1 acre			1 lbs.	

[17] Lal, R. "Soil Carbon Sequestration to Mitigate Climate Change." *Geoderma*123, no. 1-2 (November 2004): 1-22. Accessed September 19, 2015. doi:10.1016/j.geoderma.2004.01.032.

[18] This figure was obtained through a UW Farm member's student project on soil analysis from all of the UW Farm sites. –Raelani Kesler

[19] Tol, Richard S.j. "The Marginal Damage Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties." Energy Policy 33, no. 16 (June 5, 2004): 2064-074. Accessed September 14, 2015. doi:10.1016/j.enpol.2004.04.002.

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Replacement Cost of Fertilizer N (Adjusted Nitrogen-N Recommendation * Price of N Fertilizer * Comparison Factor)	**Replacement Cost of Fertilizer N/Bed Feet**
$.2651517	$.003787881
	1 ft.

Example Replacement Cost of Fertilizer N - $.2651517
Example Replacement Cost of Fertilizer N/Bed Feet - $.003787881/ft.

- <u>Cost of Fertilizer-N Production Emissions</u>

Nitrogen-N Recommendation	**Adjusted Nitrogen-N Recommendation**	**Lbs. to Mega grams Conversion**	**Adjusted Nitrogen-N Recommendation**	**Carbon Emissions From Production of Fertilizer-N[21]**
100 lbs.	.160698 lbs.	.00045359237 Mg	.000072891Mg	6.75 Kg C
1 acre		1 lbs.		1 Mg N

Carbon Emissions from Nitrogen Replacement (Adjusted Nitrogen-N Recommendation * Carbon Emissions From Production of Fertilizer-N)	**Carbon Emissions from Nitrogen Replacement**	**Marginal Damage of CO_2 Emissions[22]**	**Comparison Factor**
.000492017 Kg	4.92017E-7 tC	$50	3
		1 tC	

Cost of Fertilizer-N Production Emissions (Carbon Emissions from Nitrogen Replacement * Marginal Damage of CO_2 Emissions * Comparison Factor)	**Cost of Fertilizer-N Production Emissions/Bed Feet**
$.000073803	1.054*10^-6
	1 ft.

Example Cost of Fertilizer-N Production Emissions - $.000073803
Example Cost of Fertilizer-N Production Emissions - $1.054E-6/ft.

- <u>Environmental Cost of Nitrogen Leaching</u>

Nitrogen-N Recommendation	**Lbs. to Grams Conversion**	**Nitrogen-N Recommendation**	**Acre to M^2 Conversion**	**Nitrogen-N Recommendation**
100 lbs.	453.59 g	45359 g	1 acre	11.208 g
1 acre	1 lbs.	1 acre	4046.86 M^2	M^2

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[21] West, Tristram O., and Gregg Marland. "A Synthesis of Carbon Sequestration, Carbon Emissions, and Net Carbon Flux in Agriculture: Comparing Tillage Practices in the United States." Agriculture, Ecosystems & Environment 91, no. 1-3 (2002): 217-32. Accessed September 16, 2015. doi:10.1016/s0167-8809(01)00233-x.

[22] Tol, Richard S.j. "The Marginal Damage Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties." Energy Policy 33, no. 16 (June 5, 2004): 2064-074. Accessed September 14, 2015. doi:10.1016/j.enpol.2004.04.002.

Environmental Tax Equivalent[23]	Replacement Cost of Fertilizer N	Environmental Cost of Nitrogen Leaching (Social Tax Equivalent * Replacement Cost of Fertilizer N)	Environmental Cost of Nitrogen Leaching/Bed Feet
80%	$.2651517	$.21212136	$.003030305
			1 ft.

Example Environmental Cost of Nitrogen Leaching - $.21212136
Example Environmental Cost of Nitrogen Leaching - $.003030305/ft.

- Social and Environmental Costs of N_2O Emissions

Nitrogen-N Recommendation	Adjusted Nitrogen-N Recommendation	N_2O Emission Factor for Applied Nitrogen-N [24]	N_2O Emissions (Adjusted Nitrogen-N Recommendation * N_2O Emission Factor for Applied Nitrogen-N)	Lbs. to Kilogram Conversion
100 lbs.	.160698 lbs.	2%	0.00321396 lbs.	0.453592 Kg
1 acre				1 lbs.

N_2O Emissions	Environmental and Social Damage of N_2O Emissions[25]	Environmental and Social Cost of N_2O Emissions (N_2O Emissions * Environmental and Social Damage of N_2O Emission)	Euro to $ Conversion Factor	Comparison Factor
0.00145782 Kg	4.4 Euro	.0064144 Euro	$1.13	3
	1 Kg N_2O		1 Euro	

Final Environmental and Social Cost of N_2O Emission (Environmental and Social Cost of N_2O Emission * Euro to $ Conversion Factor * Comparison Factor)	Final Environmental and Social Cost of N_2O Emission/Bed Feet
$.021744843	$.000310641
	1 ft.

Example Environmental and Social Cost of N_2O Emission - $.021744843
Example Environmental and Social Cost of N_2O Emission/Bed Feet - $.000310641/ft.

- Social and Environmental Costs of NO_x Emissions

Nitrogen-N Recommendation	Adjusted Nitrogen-N Recommendation	NO_x Emission Factor for Applied	NO_x Emissions (Adjusted Nitrogen-N Recommendation * NO_x Emission Factor for Applied Nitrogen-N)	Lbs. to Kilogram Conversion

[23] Botterweg, Peter, Lars Bakken, and Eirik Romstad. "Nitrate Leaching from Agricultural Soils: Ecological Modelling under Different Economic Constraints." Ecological Modelling 75-76 (1994): 359-69. Accessed September 18, 2015. doi:10.1016/0304-3800(94)90032-9
[24] *Velthof, G.l., J.p. Lesschen, J. Webb, S. Pietrzak, Z. Miatkowski, M. Pinto, J. Kros, and O. Oenema. "The Impact of the Nitrates Directive on Nitrogen Emissions from Agriculture in the EU-27 during 2000–2008."Science of The Total Environment 468-469 (2014): 1225-233. Accessed September 19, 2015. doi:10.1016/j.scitotenv.2013.04.058.*
[25] *Sutton, Mark A. The European Nitrogen Assessment: Sources, Effects, and Policy Perspectives. Cambridge, UK: Cambridge University Press, 2011. Accessed September 16, 2015. http://www.nine-esf.org/ENA-Book.*

		Nitrogen-N[26]		
100 lbs.	.160698 lbs.	.55%	0.0008838839lbs.	0.453592 Kg
1 acre				1 lbs.

NO_x Emissions	Environmental and Social Damage of NO_x Emissions[27]	Environmental and Social Cost of NO_x Emissions (NO_x Emissions * Environmental and Social Damage of NO_x Emission)	Euro to $ Conversion Factor	Comparison Factor
0.000400922Kg	2 Euro	.000801844 Euro	$1.13	3
	1 Kg NO_x		1 Euro	

Final Environmental and Social Cost of NO_x Emission (Environmental and Social Cost of NO_x Emission * Euro to $ Conversion Factor * Comparison Factor)	Final Environmental and Social Cost of NO_x Emission/Bed Feet
$.002718251	$3.788322E-05
	1ft.

Example Environmental and Social Cost of NO_x Emission - $.002718251
Example Environmental and Social Cost of NO_x Emission/Bed Feet - $3.788322E-05/ft.

- Replacement Cost of Fertilizer P_2O_5

Phosphorus-P PM	Bulk Density	Volume of Plot	Phosphorus ((20 * Bulk Density * Volume of Plot) / 1,000,000)	Phosphorus to P_2O_5 Conversion Factor[28]	P_2O_5 (Phosphorous *Phosphorous to P_2O_5 Conversion Factor)
20	.483 g	3958695.17 cm^3	38.24 g	2.29	87.57 g
1,000,000	1 cm^3				

P_2O_5	Price of P_2O_5 Fertilizer[29]	Comparison Factor	Replacement Cost of Fertilizer P_2O_5 (P_2O_5 * Price of P_2O_5 Fertilizer * Comparison Factor)	Replacement Cost of Fertilizer P_2O_5/Bed Feet
.1930588 lbs.	$.69	3	$.399631716	$.00570925
	1 lbs.			1 ft.

Example Replacement Cost of Fertilizer P_2O_5 - $.399631716
Example Replacement Cost of Fertilizer P_2O_5/Bed Feet - $.00570925/ft.

[26] *Velthof, G.l., J.p. Lesschen, J. Webb, S. Pietrzak, Z. Miatkowski, M. Pinto, J. Kros, and O. Oenema. "The Impact of the Nitrates Directive on Nitrogen Emissions from Agriculture in the EU-27 during 2000–2008."Science of The Total Environment 468-469 (2014): 1225-233. Accessed September 19, 2015. doi:10.1016/j.scitotenv.2013.04.058.*
[27] *Sutton, Mark A. The European Nitrogen Assessment: Sources, Effects, and Policy Perspectives. Cambridge, UK: Cambridge University Press, 2011. Accessed September 16, 2015. http://www.nine-esf.org/ENA-Book.*
[28] Silva, George. "Factsheet on Soil Fertility and Nutrient Management." Accessed September 18, 2015. http://www.nine-esf.org/ENA-Book.
[29] Silva, George. "Factsheet on Soil Fertility and Nutrient Management." Accessed September 18, 2015. http://www.nine-esf.org/ENA-Book.

- <u>Cost of Fertilizer P_2O_5 Production Emissions</u>

Phosphorus-PPM	**Bulk Density**	**Volume of Plot**	**Phosphorus ((20 * Bulk Density * Volume of Plot) / 1,000,000)**	**Phosphorus**	**Phosphorous to P_2O_5 Conversion Factor**[30]
20	.483 g	3958695.17 cm^3	38.24 g	.00038241 Mg	2.29
1,000,000	1 cm^3				

Carbon Emission from Production of Fertilizer P_2O_5[31]	**Carbon Emission from Production of Fertilizer P_2O_5 (Phosphorous *Phosphorous to P_2O_5 Conversion Factor * Carbon Emission from Production of Fertilizer P_2O_5)**	**Carbon Emission from Production of Fertilizer P_2O_5**	**Marginal Damage of Carbon Emissions**[32]	**Comparison Factor**
5.10649078 Kg C	4.47185*10^-06 Kg	4.47185*10^-9 tC	$50	3
1 Mg P_2O_5			1 tC	

Cost of Fertilizer P_2O_5 Production Emissions (Carbon Emissions from Production of Fertilizer P_2O_5 * Marginal Damage of Carbon Emissions * Comparison Factor)	**Cost of Fertilizer P_2O_5 Production Emissions/Bed Feet**
$6.71*10^-07	$9.58*10^-09
	1 ft.

*Example Cost of Fertilizer P_2O_5 Production Emissions - $6.71*10^-07*
*Example Cost of Fertilizer P_2O_5 Production Emissions/Bed Feet - $9.85*10^-09/ft.*

- <u>Replacement Cost of Fertilizer K_2O</u>

Potassium-PPM	**Bulk Density**	**Volume of Plot**	**Potassium ((20 * Bulk Density * Volume of Plot) / 1,000,000)**	**Potassium to K_2O Conversion Factor**[33]	**K_2O (Potassium *Potassium to K_2O Conversion Factor)**
20	.483 g	3958695.17 cm^3	38.24 g	1.21	46.2716 g

[30] Silva, George. "Factsheet on Soil Fertility and Nutrient Management." Accessed September 18, 2015. http://www.nine-esf.org/ENA-Book.
[31] West, Tristram O., and Gregg Marland. "A Synthesis of Carbon Sequestration, Carbon Emissions, and Net Carbon Flux in Agriculture: Comparing Tillage Practices in the United States." Agriculture, Ecosystems & Environment 91, no. 1-3 (2002): 217-32. Accessed September 16, 2015. doi:10.1016/s0167-8809(01)00233-x.
[32] Tol, Richard S.j. "The Marginal Damage Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties." Energy Policy 33, no. 16 (June 5, 2004): 2064-074. Accessed September 14, 2015. doi:10.1016/j.enpol.2004.04.002.
[33] Silva, George. "Factsheet on Soil Fertility and Nutrient Management." Accessed September 18, 2015. http://www.nine-esf.org/ENA-Book.

1,000,000	1 cm^3				

K_2O	**Price of K_2O Fertilizer[34]**	**Comparison Factor**	**Replacement Cost of Fertilizer K_2O (K_2O* Price of K_2O Fertilizer * Comparison Factor)**	**Replacement Cost of Fertilizer K_2O/Bed Feet**
.1020114161 lbs.	$.48	3	$.172964392	$.00247092
	1 lbs.			1 ft.

Example Replacement Cost of Fertilizer K_2O - $.172964392
Example Replacement Cost of Fertilizer K_2O/Bed Feet - $.00247092/ft.

- <u>Cost of Fertilizer K_2O Production Emissions</u>

Potassium-PPM	**Bulk Density**	**Volume of Plot**	**Potassium ((20 * Bulk Density * Volume of Plot) / 1,000,000)**	**Potassium**	**Potassium to K_2O Conversion Factor[35]**
20	.483 g	3958695.17 cm^3	38.24 g	.00003824Mg	1.21
1,000,000	1 cm^3				

Carbon Emission from Production of Fertilizer K_2O [36]	**Carbon Emission from Production of Fertilizer K_2O (Potassium * Potassium to K_2O Conversion Factor * Carbon Emission from Production of Fertilizer K_2O)**	**Carbon Emission from Production of Fertilizer K_2O**	**Marginal Damage of Carbon Emissions[37]**	**Comparison Factor**
4.789822 Kg C	.000221627 Kg	2.21627 *10^-07tC	$50	3
1 Mg K_2O			1 tC	

Cost of Fertilizer K_2O) Production Emissions (Carbon Emissions from Production of Fertilizer K_2O * Marginal Damage of Carbon Emissions * Comparison Factor)	**Cost of Fertilizer K_2O Production Emissions/Bed Feet**
$3.32*10^-05	$4.75*10^-07
	1 ft.

Example Cost of Fertilizer K_2O Production Emissions - $3.32*10^-05

[34] Silva, George. "Factsheet on Soil Fertility and Nutrient Management." Accessed September 18, 2015. http://www.nine-esf.org/ENA-Book.
[35] Silva, George. "Factsheet on Soil Fertility and Nutrient Management." Accessed September 18, 2015. http://www.nine-esf.org/ENA-Book.
[36] West, Tristram O., and Gregg Marland. "A Synthesis of Carbon Sequestration, Carbon Emissions, and Net Carbon Flux in Agriculture: Comparing Tillage Practices in the United States." Agriculture, Ecosystems & Environment 91, no. 1-3 (2002): 217-32. Accessed September 16, 2015. doi:10.1016/s0167-8809(01)00233-x.
[37] Tol, Richard S.j. "The Marginal Damage Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties." Energy Policy 33, no. 16 (June 5, 2004): 2064-074. Accessed September 14, 2015. doi:10.1016/j.enpol.2004.04.002.

Example Cost of Fertilizer K_2O Production Emissions/Bed Feet - $4.75*10^-07/ft.

- Replacement Cost of Fertilizer CaO_3

Limestone Recommendation	Plot Size	Adjusted Limestone Recommendation (Limestone Recommendation * Plot Size)	Price of $CaCO_3$ Fertilizer[38]	Comparison Factor
100 lbs.	.00160698 acres	.160698 lbs.	$1.816	3
1 acre			1 lbs.	

Replacement Cost of Fertilizer $CaCO_3$ (Adjusted Limestone Recommendation * Price of $CaCO_3$ Fertilizer * Comparison Factor)	Replacement Cost of Fertilizer $CaCO_3$/Bed Feet
$.875482704	$.012506896
	1 ft.

Example Replacement Cost of Fertilizer $CaCO_3$ - $.875482704
Example Replacement Cost of Fertilizer $CaCO_3$/Bed Feet - $.012506896/ft.

- Cost of Fertilizer CaO_3 Production Emissions

Limestone Recommendation	Adjusted Limestone Recommendation	Lbs. to Mega grams Conversion	Adjusted Limestone Recommendation	Carbon Emissions From Production of $CaCO_3$[39]
100 lbs.	.160698 lbs.	.00045359237 Mg	.000072891Mg	3.5759 Kg C
1 acre		1 lbs.		1 Mg $CaCO_3$

Carbon Emissions from $CaCO_3$ Replacement (Adjusted Limestone Recommendation * Carbon Emissions From Production of $CaCO_3$)	Carbon Emissions from $CaCO_3$ Replacement	Marginal Damage of Carbon Emissions[40]	Comparison Factor
.000260651 Kg	2.60222E-7 tC	$50	3
		1 tC	

Cost of Fertilizer $CaCO_3$ Production Emissions (Carbon Emissions from Limestone Replacement * Marginal Damage of CO_2 Emissions * Comparison Factor)	Cost of $CaCO_3$ Production Emissions/Bed Feet

[38] http://www.amazon.com/Pounds-Carbonate-Limestone-Amendment-Fertilizer/dp/B00G8ICE6G
[39] West, Tristram O., and Gregg Marland. "A Synthesis of Carbon Sequestration, Carbon Emissions, and Net Carbon Flux in Agriculture: Comparing Tillage Practices in the United States." Agriculture, Ecosystems & Environment 91, no. 1-3 (2002): 217-32. Accessed September 16, 2015. doi:10.1016/s0167-8809(01)00233-x.
[40] Tol, Richard S.j. "The Marginal Damage Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties." Energy Policy 33, no. 16 (June 5, 2004): 2064-074. Accessed September 14, 2015. doi:10.1016/j.enpol.2004.04.002.

$3.9033E-05	$5.57619E-07
	1 ft.

Example Cost of Fertilizer $CaCO_3$ Production Emissions - $3.9033E-05
Example Cost of Fertilizer $CaCO_3$ Production Emissions/Bed Feet - $5.57619E-07

- *Off-Site Cost of Soil Loss*

R Factor	**K Factor**	**LS Factor**	**C Factor**	**P Factor**	**A Factor (R * K * LS * C * P)[41]**	**Hectare to Acre Conversion**	**Soil Loss (A Factor * Hectare to Acre Conversion)**
70	*.45*	*.07*	*.125*	*.5*	*.1378 tonnes*	*1 hectare*	*.055789 tonnes*
					1 hectare	*2.47105 acre*	*1 acre*

Plot Size	**Adjusted Soil Loss (Soil Loss * Plot Size)**	**Tonnes to Tons**	**Final Soil Loss (Adjusted Soil Loss * Tonnes to Tons)**	**Damage of Soil Loss[42]**	**Comparison Factor**
.00160698 acres	.000089653 tonnes	1.10231 tons	.00009824 tons	$2.73	3
		1 tonne		1 ton	

Off-Site Cost of Soil Loss (Final Soil Loss * Damage of Soil Loss * Comparison Factor)	**Off-Site Cost of Soil Loss/Bed Feet**
$.000809369	$.000011562
	1 ft.

Off-Site Cost of Soil Loss – $.000809369
Off-Site Cost of Soil Loss/Bed Feet - $.000011562/ft.

Figure 3-Graph of Final Benefits, Environmental Costs, Net Revenues, and C:B Ratios for Each Plot: The green, red and blue bars on the graph respectively represent the total benefits, environmental costs, and net values for each of the plots, scaled by the values on the right axis. The numbers at the top of each bar represent the final dollar value. The large tan bars represent the ratio of environmental costs to benefits. This allows an understanding of what portion of the received benefits is neglected by the environmental damage being done. The values for the C:B ratio are represented on the left axis, and specifically on the top of each tan bar.

[41] Stone, R.P., and D. Hilburn. "Universal Soil Loss Equation (USLE)."SpringerReference, 2011. Accessed September 21, 2015. doi:10.1007/springerreference_225394.
[42] Poe, Gregory L. "Maximizing the Environmental Benefits per Dollar Expended": An Economic Interpretation and Review of Agricultural Environmental Benefits and Costs." Society & Natural Resources 12, no. 6 (1999): 571-98. Accessed September 21, 2015. doi:10.1080/089419299279452.

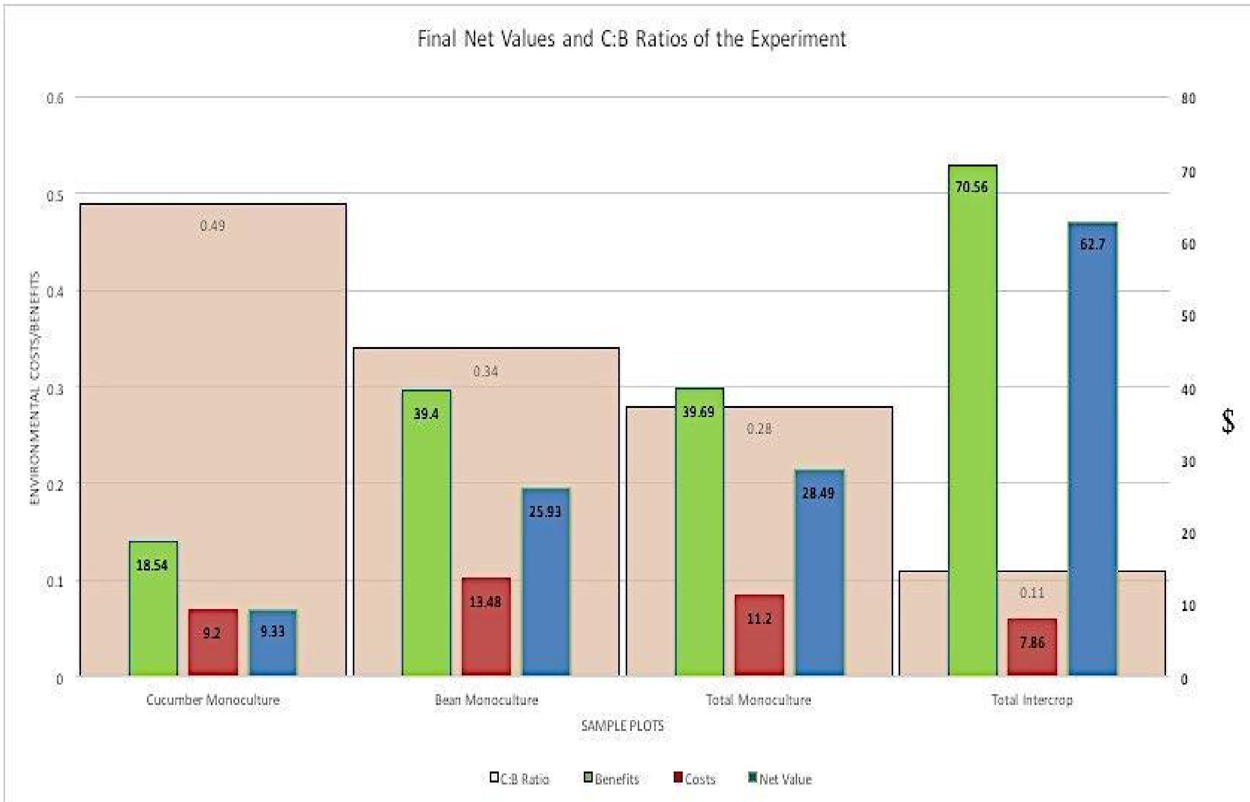

Table 2-Expanded Cost-Benefit Results with Dollar/Bed Foot Units: This is an adjusted final cost-benefit table, in that each of the values is marginalized by the bed feet of each plot. Each column represents the sample plots and each row is a specific economic translation that was performed. The economic translations are separated based on the type of environmental problem they are trying to represent. No totals are accounted for on this table mainly because the purpose is to compare the values within each individual translation.

	CUCUMBER MONO-CULTURE	BEANS MONO-CULTURE	TOTAL MONO-CULTURE	TOTAL INTERCROP
Fiscal Benefits				
REVENUE/BED FEET	0.26	0.30	0.57	1.00
Value of Soil Carbon				
VALUE OF SOIL CARBON SEQUESTRATION/BED FEET	-0.095	-0.119	-0.107	-0.095
Fertilizer Replacement Costs				
REPLACEMENT COST OF FERTILIZER N/BED FEET	-7.142E-04	1.857E-03	-1.857E-06	1.893E-06
REPLACEMENT COST OF FERTILIZER P_2O/BED FEET	-1.886E-03	-6.259E-03	-4.073E-03	-6.614E-03
REPLACEMENT COST OF FERTILIZER K_2O/BED FEET	-0.030	-0.067	-0.048	-0.009

REPLACEMENT COST OF FERTILIZER CaO_3/BED FEET	0	0.250	6.243E-05	-6.585E-04
Social and Environmental Cost of Fertilizer Emissions				
SOCIAL AND ENVIRONMENTAL COST OF N_2O EMISSIONS/BED FEET	-6.143E-05	1.543E-04	-1.560E-07	1.543E-07
SOCIAL AND ENVIRONMENTAL COST OF NO_x EMISSIONS/BED FEET	-7.757E-04	1.941E-03	-1.857E-06	1.929E-06
Environmental Costs of Fertilizer Production Emissions				
COST OF FERTILIZER-N PRODUCTION EMISSIONS/BED FEET	-2.110E-07	5.270E-07	-5.270E-10	5.207E-10
COST OF FERTILIZER P_2O_5 PRODUCTION EMISSIONS/BED FEET	-3.166E-05	-1.05E-04	-6.829E-05	-1.110E-04
COST OF FERTILIZER K_2O PRODUCTION EMISSIONS/BED FEET	-6.714E-05	-1.500E-04	-1.086E-04	-2.143E-05
COST OF FERTILIZER CaO_3 PRODUCTION EMISSIONS/BED FEET	0	1.113E-04	2.790E-07	-9.300E-07
Environmental Cost of Nitrogen Leaching				
ENVIRONMENTAL COST OF NITROGEN LEACHING/BED FEET	-2.500E-03	6.571E-03	-5.000E-06	5.000E-06
Environmental Cost of Natural Soil Loss				
OFF-SITE COST OF SOIL LOSS/BED FEET	-1.160E-05	-1.160E-05	-1.160E-05	-1.150E-05