FIELDPRINT CALCULATOR: A MEASUREMENT OF ENVIRONMENTAL AND ECONOMIC SUSTAINABILITY PERFORMANCE OF AGRICULTURAL SYSTEMS IN THE SOUTHERN HIGH PLAINS

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Abstract

The emerging initiatives to evaluate sustainability in agricultural production has allowed for new opportunities in research and marketing to improve productivity in the agricultural industry. Tools such as the Fieldprint Calculator provide a framework for sustainability measurements in order to quantify and create goals to improve environmental and economic progress. The purpose of this study was to provide a comprehensive evaluation of the effects of the sustainability metrics produced by the Fieldprint Calculator on management decisions utilized by growers in the Texas Alliance for Water Conservation (TAWC) project located in the Southern High Plains (SHP) of Texas. A sustainability index was created for six of the metrics utilized in the study and a profitability index was added in order to capture the economic effects relative to sustainability. The study was conducted over a period from 2007-2016. Spidergrams were also developed to quantify a producer's sustainability "footprint." Results showed the importance of a producer's management of resources and the type of systems used in an operation. Currently the Fieldprint Calculator does not evaluate profitability, therefore the strong relationship between the profitability metric and the land use metric implies that the land use metric can be used to evaluate economic performance for cotton. In order to be confident about the relationship between the land use metric and the profitability metric further research should develop a panel data set to analyze the metrics interactions.

Introduction

Today, sustainability in agriculture is playing a vital role with stakeholders throughout the agricultural industry. Companies are beginning to encourage producers to employ a variety of practices that contribute to sustainable agricultural production without jeopardizing economic viability of farming operations. Economic incentives and consumer demand will drive how farming operations adopt sustainable production practices. The profile for sustainability in agriculture will include a diverse set of incentives and trade-offs that will be made in order to find a balance between the economic, environmental, and social components of sustainability (Robertson 2105).

One of the key participants in the development of sustainable food, fiber, and fuel is the Field to Market program, which is creating a foundation for continuous improvement at all levels of agricultural production. Collaboration of Field to Market and several other partners have developed projects such as the Texas Cotton project, sponsored by the Cotton Foundation, which utilizes data gathered by the Texas Alliance for Water Conservation (TAWC) in the Southern High Plains(SHP) of Texas. With the alliance of industry and researchers, tools such as the Fieldprint Calculator have been developed for the evaluation of sustainability at the production level. Tracking performance over time can help producers in the decision-making process and identify inefficiencies in their operation. Sustainability metrics were developed based on the specifications of a producer's systems and the application of inputs in their fields. Field to Market has identified seven metrics of sustainable agricultural production. The first five indicators were developed to evaluate the efficiency of crop production: land use (acres/unit of production), irrigation water use (acre-inches of water applied/unit of production), energy use (gallons of diesel)/ unit of production), greenhouse gas emissions (lbs of carbon dioxide equivalent (CO_2)/unit of production), and soil conservation (tons of loss soil/ac/year). The soil carbon and water quality metric are comprised of several components and are expressed as indexes.

The objective of this paper is to provide insight on the values of the sustainability metrics for cotton production in the SHP. Specifically, developing a profitability metric to evaluate economic performance alongside environmental outcomes. By creating spidergrams with a unit-based measure, a producer's sustainability footprint can be quantitatively analyzed in order to compare it to other systems and across time.

Materials and Methods

The TAWC project gathers crop and livestock system information on producer operations located in the SHP of Texas. Evaluation of production practices and innovative technologies have allowed the creation of a database to compare management practices and methods over each crop year. The demonstration farms embody a range of management practices relating to tillage and irrigation systems. These include no-till, minimum-till, and conventional tillage practices in addition to irrigation management systems which include dryland, subsurface drip irrigation (SDI), center pivot irrigation (LESA, LEPA, MESA), and furrow irrigation. These systems vary by applications of inputs and output. This study represents extensive data collected over an 11-year period from, 2005-2016, and represents production systems to promote irrigation efficiency and maintain profitability. A total of 206 observations, from over 30 sites, and 17,000 acres are represented in this analysis. The TAWC site data was entered into the Fieldprint Calculator to evaluate the operation on a sustainability scale.

The Fieldprint calculator analyzes sustainability based on seven metrics to allow a producer to evaluate and quantify management methods. This gives producers the ability to enhance efficiency of their operation and allows for increased opportunities in the market place. The calculator requires input data based on the producers management decisions and timing of applications. The sustainability metrics are calculated based on the attributes of the field and the production practices used by the producer. Figure 1 is an example of how the metrics are plotted on a spidergram in order to represent a producer's sustainability performance. Smaller values indicate more efficient resource use and a lesser sustainability "footprint". The spidergram compares the footprint (shaded purple area) to the state (orange) and the national (green) averages

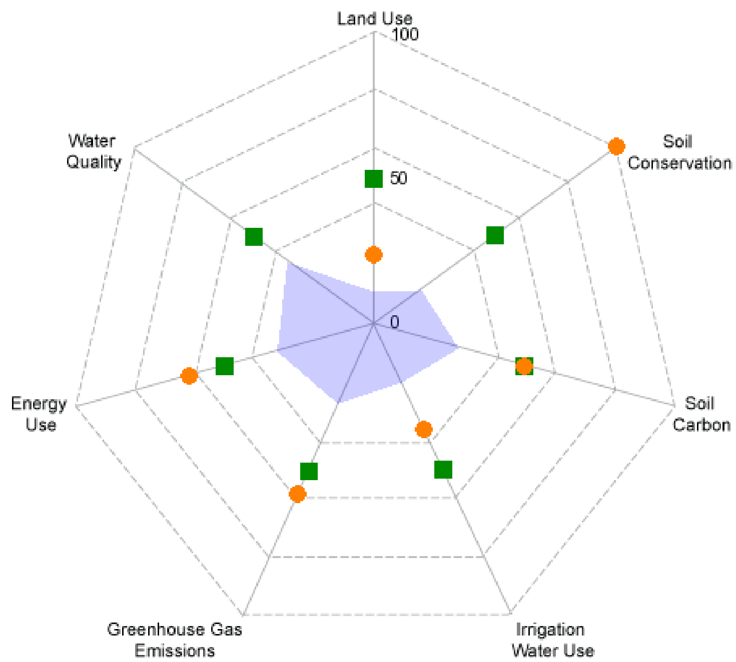

Figure 1. Spidergram representing a sustainability footprint TAWC cotton production site in 2013.

The Fieldprint calculator categorizes cotton as a commodity that produces joint products of lint and seed. Therefore, to account for the value of seed income, a lint equivalent calculation was developed. For cotton, the share of seed value and lint production was determined to be 83% of lint yield. A lint equivalent yield (LEY) is expressed in the calculations of the sustainability metrics.

Land use

The land use metric is dependent on crop yield and measures the efficiency of land utilization to produce a unit of crop production (acres/unit of production). This metric is part of understanding the sustainability of productivity and is improved by increased crop yields. The one data variable that is used to calculate the land use metric is the crop yield and is expressed with a high accuracy level.

Irrigation Water use

The irrigation water use metric measures the quaintly of water used to increase crop yields by one unit above the expected dryland production level (acre-inches of water applied/units of production less expected dryland yield). This metric measures the overall efficiency of irrigation water applied in crop production, which is directly controlled by the decisions of the producer.

Energy use

The energy use metric measures the energy used in all steps of production from pre-planting through the growing season and the transfer of the commodity from the field to the processor and is expressed as (gallons of diesel)/ unit of production). It includes all major energy-intensive production methods from direct energy use from farm equipment such as tillage practices, irrigation systems, and fuel used, and indirect energy use from the production of fertilizer and chemicals. The direct and indirect energy are field specific and is reliant on inputs used by the producer, therefore, a combination of the two energy types calculates the energy use metric.

Greenhouse Gas Emissions

The greenhouse gas emissions metric is calculated similar to the energy use metric, but the greenhouse gas emissions metric is expressed as (CO2)/unit of production). Greenhouse gas emissions are highly correlated to energy use**.**

Soil Conservation

The soil conservation metric estimates wind and water soil erosion for an acre (tons of loss soil/ac/year). Estimated soil erosion is based on several factors including soil type, tillage practices, irrigation methods, crop type and crop rotations. For this study, the soil conservation metric is expressed relative to the soil T value. The T value is soil loss tolerance, which is the maximum amount of soil in tons/acre/year that can be lost and still permit a sustainable level of crop productivity.

Soil Carbon

The soil carbon metric is an index that relates to reductions in overall greenhouse gas emissions and health of the soil. The outcome is crop specific and is in a range of +1.0 to -1.0, this states that as the number gets closer to 1.0 the management practices are likely to increase soil organic matter over time.

Water Quality

The water quality metric is also constructed as an index and is used to evaluate the influences of management practices on water quality by surface water runoff. The characteristics of this index are a combination of field makeup, soil type, nutrient management, tillage practices, chemical and fertilizer applications, irrigation management, and any other impactful conservation practices that formulate one output with weighting criteria. The NRCS WQI output ranges from 1-10 and allows an individual grower to compare practices to other potential practices that are more likely to benefit water quality. The closer the output is to 0 the more likely the practices are beneficial to water quality.

Index Calculation

In order for sites to be compared across management practices, an index was constructed based on the maximum of the raw values produced by the Fieldprint Calculator for all observations. Raw values were made relative to the maximum in order to develop a consistent scale of 0-100 and keeping the interpretation of the smaller value indicates increased sustainability. Table 1 gives an example for how five of the seven metrics were calculated. A lower index value has positive effects on environmental performance and represents a producer's sustainability performance.

Metric Calculation

$$Land\ Use\ Index\ = \frac{Raw\ Number}{Maximum\ Value} * 100$$

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Table 1. Example of land use index calculation.

Land use	Site D - Field 8 - 2013	Site D - Field 5 - 2014
Lint Equivalent (ac/lb)	0.00049025 (2039 lbs/ac LEY)	0.00060895 (1642 lbs/ac LEY)
Index Calculation	$= \frac{0.0049025_{Raw\ Number}}{0.0022074_{Max}} * 100$	$= \frac{0.00060895_{Raw\ Number}}{0.0022074_{Max}} * 100$
Land Use Index	22	28

For this analysis, a profitability index was developed incorporate an economic component into the sustainability footprint. Since the metric was created to allow for negative gross margins, it is calculated by taking into account the vertical distance of all observations and the distance of the raw values from the maximum. The index is interpreted similar to the other metrics; therefore, a lower profitability index represents a better economic performance. The soil carbon index was also calculated in this manner. Due to the lack of relevance of the water quality metric in this region, it was not included in the study.

Metric Calculation

$$Profitability\ Index = \frac{(Maximum\ value - Raw\ number)}{(Total\ Vertical\ Distance)} * 100$$

Table 2. Example of profitability index calculation.

Profitability Index	Site D - Field 8 - 2013	Site D - Field 5 - 2014
Gross Margin/Lint Equivalent ($/lb)	0.30729 (626.81 $/ac)	0.1865 (306.28 $/ac)
Index Calculation	$= \frac{0.6419_{Max} - 0.30729_{raw\ number}}{1.60838_{Total\ Vertical\ Distance}} * 100$	$= \frac{0.6419_{Max} - 0.1865_{raw\ number}}{1.60838_{Total\ Vertical\ Distance}} * 100$
Profitability Index	21	28

Results and Discussion

For this study, the indexes were reevaluated on a scale from 0-100 and were consistent across all sites and years. A profitability metric was added in order to capture the economic performance of each site relative to the how resource efficient the site was. Based on the TAWC data there were 29 sites evaluated with 194 observations. Individual sites were compared based on the type of irrigation system used and how they performed based on each individual metric. If a site had multiple fields, each field was weighted to the appropriate acres in order to create one observation for a site per year. After analyzing the sites overall, three sites were chosen for comparison based on the amount of observations, relative location, soil type (Pullman clay loam), and the irrigation system that was used (LESA, LEPA, and SDI). Sites D, A, and S were analyzed based on their sustainability metrics and spidergrams were constructed that include land use, irrigation use, energy use, greenhouse gas emissions, soil conservation, and profitability. Tables 3 through 5 show the overall average index for all sites and how the producer performed on each index for each year of production. The years 2008, 2010, and 2015 are highlighted in order to compare the indexes over time

Site D used a center pivot LESA irrigation system over an 8 year period from 2007-2015. This site had 20 observations with an average LEY of 1765 lbs/ac, an average irrigation rate of 14.5 in/ac, and a water use efficiency of 120 lbs/ac inch. The average overall index for this site was 22 and was 3% above the average footprint. Based on the average indexes per year this site showed to be above the average for 2011, and 2015. In the year 2015, the site had above average index values except for soil conservation, this is assumed to have been the result of higher irrigation levels and lower profitability.

Table 3. Average indexes by year and index for Site D.

Averages Site D						
Year	**Land Use**	**Irrigation**	**Energy**	**GHG**	**SC**	**Profitability**
Overall Average	30.76	17.18	21.62	17.95	17.95	25.78
2007	18.60	8.32	11.85	9.70	16.45	22.44
2008	22.41	16.52	19.19	14.97	11.21	29.61
2009	30.32	10.49	15.55	12.50	15.79	27.65
2010	31.62	11.27	26.63	29.29	12.60	21.88
2011	39.50	35.50	35.39	28.59	17.03	19.43
2013	22.21	20.79	22.56	18.76	12.17	20.80
2014	27.59	12.74	17.64	15.40	16.41	28.31
2015	33.36	28.33	40.49	32.73	12.00	35.92

Site A utilized a center pivot LEPA irrigation system over an 8 year period from 2007-2015 with 10 observations. This site had an average LEY of 1320 lbs/ac, an average irrigation rate of 10.6 in/ac, and a water use efficiency of 124 lbs/ac in. The average overall index for this site was 21 and was 6% below the average footprint. Based on the average indexes per year this site showed to be above average in 2011, which is assumed to have been the result of the extreme draught conditions experienced in that year.

Table 4. Average indexes by year and index for Site A.

Averages Site A						
Year	**Land Use**	**Irrigation**	**Energy**	**GHG**	**SC**	**Profitability**
Overall Average	30.76	17.18	21.62	17.95	17.95	25.78
2007	27.89	9.06	16.52	15.94	10.51	28.49
2008	38.37	11.97	19.85	16.68	11.02	30.91
2009	39.54	11.64	17.02	13.63	10.60	32.87
2010	34.43	9.56	14.88	12.06	9.49	18.04
2011	39.41	42.12	38.80	31.77	9.60	24.64
2013	37.98	23.44	26.60	21.00	9.56	8.46
2014	30.20	15.01	18.49	14.35	9.56	17.52
2015	32.84	11.56	17.24	12.89	9.47	29.65

Site S transitioned from a furrow irrigation system to a subsurface drip system (SDI) in 2008. This site had 11 observations under the SDI system from 2008-2015. This site had an average LEY of 1955lbs/ac, an average irrigation rate of 12.7 in/ac, and a water use efficiency of 153 lbs/ac in. The average overall index for this site was 17 and was 37% below the average footprint. Based on the average indexes per year this showed to be below average for all years including 2011.

Table 5. Average indexes by year and index for Site S.

Averages Site S						
Year	**Land Use**	**Irrigation**	**Energy**	**GHG**	**SC**	**Profitability**
Overall Average	30.76	17.18	21.62	17.95	17.95	25.78
2008	20.02	6.95	12.35	9.87	13.41	26.99
2009	19.79	21.07	23.84	17.69	12.90	28.15
2010	28.22	4.66	11.63	9.56	8.24	14.19
2011	23.54	18.14	22.37	17.86	9.05	10.98
2013	16.77	12.27	17.30	14.95	12.77	16.19
2014	25.46	15.98	19.47	15.32	12.77	28.43
2015	31.86	9.24	20.92	19.02	14.17	29.37

From the index values, spidergrams were developed in order to have a visual representation of a grower's sustainability footprint. Each metric is represented on the diagram to create the complete footprint. The spidergram analysis is measured on a scale from 0 to 100 based on how the producer performed on the metric analysis and then the area of the footprint is calculated and compared to the overall average footprint. This was developed in order to quantify the sustainability footprint. Figures 2 through 4, display the spidergrams for each of the three comparable sites. Each of the diagrams shows the footprints of the overall average index for the years 2008, 2010, and 2015 in order to compare the performance of each producer's footprint over time. An area is then calculated and compared back to the overall average in order to create a percentage of the average measurement. This allows for a quantitative measurement of the footprint to give a representation of an overall sustainability performance score for a single year. Tables 6 through 8, give the percentage of the area in each year of the spidergrams.

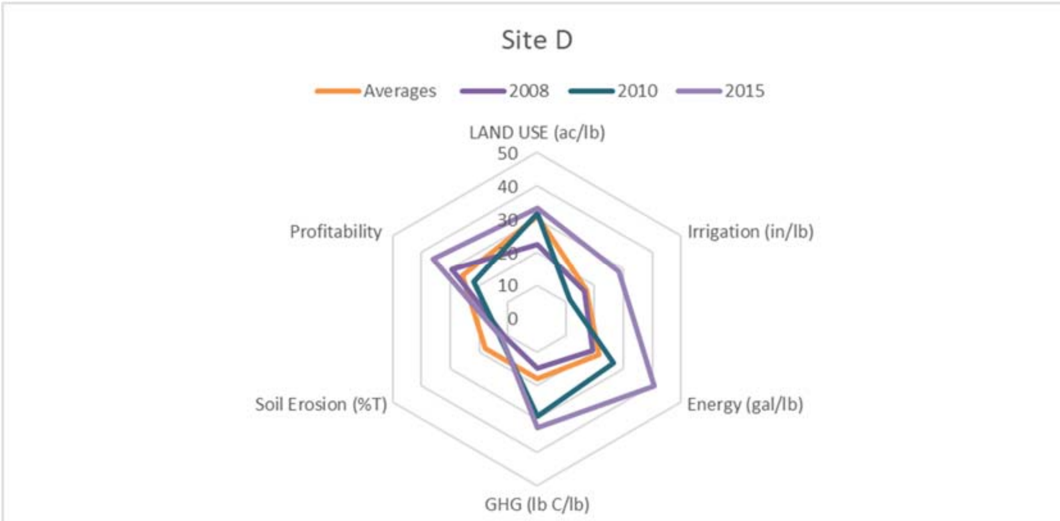

Figure 2. Spidergram evaluation for Site D.

Yearly Averages	Area Percentage
2007	46%
2008	75%
2009	75%
2010	97%
2011	183%
2013	80%
2014	82%
2015	190%

Table 6. Percentage of the average sustainability scores for Site D.

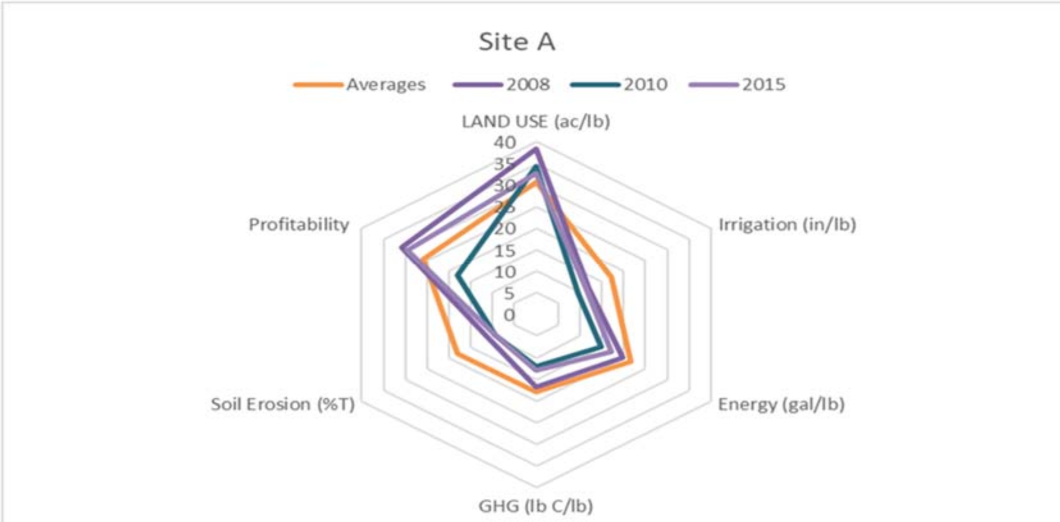

Figure 3. Spidergram evaluation for Site A.

Yearly Averages	Area Percentage
2007	67%
2008	96%
2009	94%
2010	54%
2011	211%
2013	93%
2014	64%
2015	76%

Table 7. Percentage of the average sustainability scores for Site A

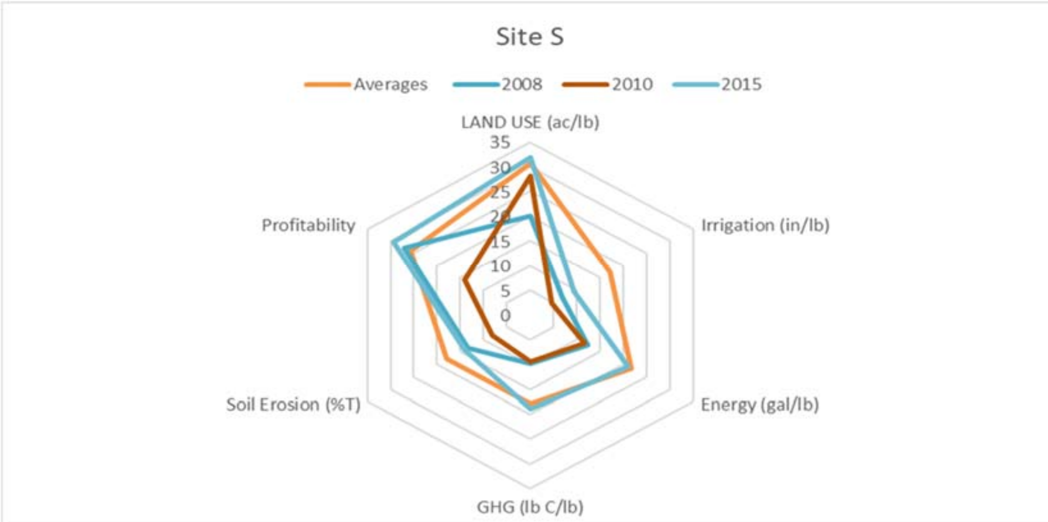

Figure 4. Spidergram evaluation for Site S.

Yearly Averages	Area Percentage
2008	48%
2009	87%
2010	31%
2011	61%
2013	47%
2014	80%
2015	87%

Table 8. Percentage of the average sustainability scores for Site S.

Land Use and Profitability Metric

An additional analysis was conducted to look at the relationship between the land use index and the profitability index for cotton. The profitability index allows each site to be evaluated on the efficient use of resources from an economic standpoint. In order to analyze the relationship between the two metrics, the profitability index was regressed on the land use index and nine dummies for years 2007-2015 in order to account for the variability in weather and prices. The model used 2016 as the base year. The data was transformed into a natural log function in order to interpret the elasticity effects. The result showed that there is a strong relationship between the indexes and that they are positively correlated. The equation indicates that a 1% decrease in the land use index is estimated to decrease the profitability index by approximately 0.638%, all else being equal.

Model

$$Ln\, profit\ index = \beta_0 + \beta_1\, ln(Land\ Use\ Index) + D_1\,(2007) + D_2\,(2008) + D_3\,(2009) + D_4\,(2010) + D_5\,(2011) + D_6\,(2012) + D_7\,(2013) + D_8\,(2014) + D_9\,(2015)$$

$R^2 = 0.56$

Variable	Parameter Estimate	t-Stat	P-Value
Intercept	1.262708033	4.928827468	1.78274E-06
Ln Land Use	0.63824661	9.16778724	7.50457E-17

Conclusions

The purpose of this study was to evaluate the sustainability metrics calculated by the Fieldprint Calculator on cotton production in the Southern High Plains and provide a method to index the raw numbers in order to create a standard scale in order to compare the effects of different management systems. A profitability metric was added to the analysis in order to give a measurement of economic performance for each site. In order for a producer to adopt sustainable practices, there must also be financial and economic benefits to the operation. The results of the index analysis show that if a site has similar location and soil types the irrigation system could have an impact on how the operation performs on an economic and environmental standpoint. The analysis showed that since the profitability index is not calculated in the Fieldprint Calculator, the positive correlation of the profitability metric and the land use metric would imply that the land use metric is a proxy for profitability in cotton production. In further research, in order to be confident about the relationship between the land use metric and the profitability metric a panel data set should be developed.

The study provided a different analysis of the spidergrams that allowed the sustainability footprints to be analyzed on a unit based measure of the metrics and highlighted the metrics that are relevant to the Southern High Plains. By calculating the areas of each footprint, a producer can determine a quantitative measure of sustainability. Impacts of years such as 2011 with extreme drought can be seen in the footprints where many producers were unable to produce a crop without excess use in resources. Based on the irrigation systems evaluated in the site comparison, the SDI system used in site S showed to be more sustainable overall. On an index comparison, the SDI system performed better in the following metrics land use, profitability, irrigation, energy, and greenhouse gases. The SDI site also remained below the average size sustainability footprint in all years, where the smaller size footprint indicates a positive impact on sustainability. The LEPA irrigation system utilized by site A performed best in the soil conservation metric and followed the SDI site in irrigation, energy, greenhouse gases, and profitability. The LEPA system had the second lowest overall average based on the sustainability metrics and was only above the average footprint in 2011. Although the LESA system from site D, performed better than the LEPA system in land use it was overall the less sustainable system evaluated by the metrics and spidergrams. The LESA system was above the average footprint in 2011 and in 2015. Based on this analysis a producer can, over time, isolate the quantitative impacts on a site's performance of adopted changes in management and/or new technologies.

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