Pasa 2019 SOIL HEALTH BENCHMARK STUDY

Example Farm

Thank you for participating in Pasa's 2019 Soil Health Benchmark Study. In 2019, 95 farms contributed to this citizen-science research project. Together, we are documenting that farmers in our region are forging new frontiers in the art and science of growing healthy soils. This report is a summary of your farm's 2019 soil health outcomes. If you have any questions about any aspect of this report or want to provide feedback or suggestions, please contact:

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HOW TO USE THIS REPORT

1. Review the "benchmark" tables and graphs to see what's typical, and possible, for soil health outcomes among your peer farmers.
2. Review the results of your Cornell Soil Health tests. These tests identify the strengths and constraints of your soils and also provide general management recommendations.
3. Connect with a learning community. This research will guide a series of Pasa field days, webinars, and conferences that will bring farmers together to share insights and develop new management ideas. The farmers contributing to this research are a tremendous resource, and through this project, Pasa can help connect you with a peer farmer who is tackling similar challenges.
4. Share the infographic marketing resources with your customers and help them understand the great work you are doing for soil health and sustainable farming.

REPORT CONTENTS

METHODS

This research draws from two data sources: 1) field soil samples and 2) farm management records. Our methods were developed with input from participating farmers and scientists at Pasa, the Rodale Institute, Penn State University, and Cornell University.

Pasa staff consulted with participating farmers to choose three study fields that spanned typical rotation practices on that farm. For instance, if a farmer practices a six-year crop rotation involving two years of corn silage, to one year of soybean, to 3 years of alfalfa, we would choose one field in 1st year corn, one field in soybean, and one field in 2nd year alfalfa. We also chose fields that represented typical soil types and topographic positions on each farm.

In October and November of 2019, Pasa staff and collaborating farmers collected soil samples from each field. For farms participating in the project for the first time, Pasa staff collected the sample. For most farms continuing with the study from previous years, farmers collected their own samples. We subsampled from five locations in each field, homogenized the samples, and submitted them to the Cornell Comprehensive Assessment of Soil Health. Cornell runs a battery of tests, evaluating ten different physical, biological, and chemical indicators of soil health.

Throughout the growing season, participating farmers maintained logs of farm operations in the selected fields, either using template excel spreadsheets provided by Pasa, farmOS software, or failsafe paper notebooks. Records included: 1) tillage, cultivation, and any farm operations involving soil disturbance or compaction; 2) planting and termination dates for crops and cover crops, and 3) application dates and quantities for all fertilizers and soil amendments.

Over the winter months, participating farmers shared their soil management records with Pasa. Pasa staff scientists organized these data and generated three additional management indicators: 1) days of living cover, 2) tillage intensity, and 3) organic inputs. These indicators provide a snapshot of some of the farm management practices that most influence soil health.

PARTICIPATING FARMS

As this study has grown since its inception in 2016, we have been increasing the number and diversity of farms participating in this project. The 2019 study includes contributions from three different farm cohorts: row crops (26 farms), pastured livestock (21 farms), and diversified vegetables (48 farms). Within these cohorts there is a great diversity of practices, including organic and conventional vegetable farms; no-til, reduced tillage, and organic row crop farms, and pastured livestock raising dairy cows, beef cattle, pigs, and poultry.

Diversified Vegetable Farms

• Dwight Alderfer, Detweiler Homestead Farm, Sellersville, PA • Amber Bahn, Leadership Education and Farming (LEAF), Landisburg, PA • Ellen Baird, Rivendale Farms, Bulger, PA • Brent Barnhart, Country Creek Produce Farm, Chambersburg, PA • Anais Beddard, Lady Moon Farms, Inc., Chambersburg, PA • Nina Berryman, Weavers Way Cooperative, Philadelphia, PA • Cleo Braver, Cottingham Farm LLC, Easton, MD • George Brittenburg, Taproot Farm, Shoemakersville, PA • Chris Brittenburg, Who Cooks for You Farm, New Bethlehem, PA • Will Brownback, Spiral Path Farm, Loysville, PA • Debra Brubaker, Village Acres Farm, Mifflintown, PA • Brian Campbell, Brian Campbell Farms, Berwick, PA • Scott Case, Patchwork Farm, Aaronsburg, PA • Jarrah Cernas, Chicano Sol, Blain, PA • Stanley Chepaitis, Uncle Henrys Garden, Indiana, PA • Emma Cunniff, Kneehigh Farm, Pottstown, PA • Jodi Danyo, Cherry Valley Organics, Burgettstown, PA • Katharine Dubansky, Backbone Food Farm, Oakland, MD • Lisa Duff, Oak Spring Farm, Freeland, MD • Sara Eckert, Healthy Harvest Farm, Bellefonte, PA • Trey Flemming, Two Gander Farm, Downingtown, PA • Jeffrey Frank, Liberty Gardens, Bethlehem, PA •

Jennifer Glenister, New Morning Farm, Hustontown, PA • John Good, The Good Farm, Germansville, PA • Emma Jagoz, Moon Valley Farm, Cockeysville, MD • Kip Kelley, Full Cellar Farm, Jefferson, MD • Art King, Harvest Valley Farms, Valencia, PA • Don Kretschmann, Kretschmann Farm LLC, Rochester, PA • Liz Krug, Fullers Overlook Farm, Waverly, PA • Dwayne Lebo, Oak Grove Farms, Mechanicsburg, PA • Gale Livingstone, Deep Roots Farm, Brandywine, MD • Kenneth Martin, Furman Farms, Northumberland, PA • Nolan Masser, Red Hill Farms Inc, Pitman, PA • Derek Mcgeehan, Anchor Run CSA, Newtown, PA • Tony Miga, Chatham University - Falk School of Sustainability, Gibsonia, PA • Tom Murtha, Blooming Glen Farm, Perkasie, PA • Will Nelson, Dickinson College Farm, Boiling Springs, PA • Eric Nordell, Beech Grove Farm, Trout Run, PA • Thomas Paduano, Flying Plow Farm, Rising Sun, MD • Jen Schneidman Partica, Bucknell University, Lewisburg, PA • Cameron Pedersen, Bending Bridge Farm, Fort Loudon, PA • Tara Rockacy, Churchview Farm LLC, Pittsburgh, PA • Yichao Rui, Rodale Institute, Kutztown, PA • Peter Scott, Fields 4 Valor Farms, Brandywine, MD • Lindsey Shapiro, Root Mass Farm, Oley, PA • Steven Tomlinson, Carversville Farm Foundation, Carversville, PA • Carrie Vaughn, Chesapeake Bay Foundation Claggett Farm, Old Marlboro, MD

Row Crop Farms

• Teena Bailey, Red Cat Farm, LLC, Germansville, PA • Harlan Burkholder, Sacony Marsh Farms, Kutztown, PA • Tj Compagnola, Red Edge Farm, Bath, PA • Aaron Cooper, Cutfresh Organics, Eden, MD • Wendell Derstine, Alderfer Poultry Farm, Telford, PA • Charles Dotterer, Dotterer Farms, Mill Hall, PA • Andrew Frankenfield, Frankenfield Farm, Collegeville, PA • Ellen Gordon, Linden Farm - Sugarloaf Citizens Association, Dickerson, MD • Ryan Graham, Ryan Graham Household, Butler, PA • Perry Griffin, Profeta Farms, Readington, NJ • Steve Groff, Cedar Meadow Farm, Holtwood, PA • Jim Harbach, Schrack Farms, Loganton, PA • Jim Hershey, Pennsylvania No-Till Alliance, Elizabethtown, PA • Jamie Hicks, Hicks Brothers LLC, Kennett Square, PA • Dan Hunsicker, Little Lehigh Tree and Turf, Mertztown, PA • Ben Hushon, Woodside Vu Farm, Delta, PA • Dean James, Cotner Farms, Danville, PA • Dave Johnson, Provident Farms, Liberty, PA • Mike Mahalsky, Mahalsky Farm, Hillsborough, NJ • Dave Marshall, Marshall Farms, Halifax, PA • Dave Mclaughlin, Little Germany Farms, Elliottsburg, PA • Dan Miller, J & L Hay Farms LLC, Friedens, PA • Joel Steigman, Small Valley Milling, Halifax, PA • Doug Thomas, Banner Farm, Watsontown, PA • Andrew Weist, Steep Hill Dairy, Honesdale, PA • James Yatsonsky, Yatsonsky Farm, Honesdale, PA

Grazing Dairies

• Kim Albano, Ironstone Creamery & Farm, Pottstown, PA • Ted Barbour, Ted Barbour Farm, Cogan Station, PA • Matt Bomgardner, Blue Mt View Farm, Annville, PA • Deanne Boyer, Willow Run Farm - Boyer, Fleetwood, PA • Bill Callahan, Cow-a-Hen Farm, Mifflinburg, PA • Glen Cauffman, Glen Cauffman Farm, Millerstown, PA • Michael Cherry, Mike Cherry Dairy Farm, Tyrone, PA • William Elkins, Buck Run Land & Cattle Co. LLC, Coatesville, PA • Joshua Greene, Greene Kitchen Farm, Bloomsburg, PA • Neil Hertzler, Rock Hollow Dairy, Loysville, PA • Ron Holter, Holterholm Farms, Jefferson, MD • Andy Kline, Sandy Springs Farm, Newmanstown, PA • George Lake, Thistle Creek Farms, Tyrone, PA • John Meglich, Meglich Farm, Stevensville, PA • Brian Moyer, Moyers Dairy Farm, Towanda, PA • Keith Ohlinger, Porch View Farm, Woodbine, MD • Caroline Owens, Owens Farm, Sunbury, PA • Audrey Gay Rodgers, Hameau Farm in the Big Valley, Belleville, PA • Forrest Stricker, Spring Creek Farms, Wernersville, PA • Chris Ulrich, Ulrich Farms, Allenwood, PA • Lamar Wadel, Wadels Dairy, Shippensburg, PA

BENCHMARKS: Cornell Comprehensive Assessment of Soil Health Indicators

Table 1. Measurements and peer comparisons for the Cornell Soil Health Test Indicators. This table shows measured values for your fields, compared to the min, max, and median for peer row crop farms in the study.

	Your Fields			Peer Fields		
Soil Health Indicator	**119**	**125**	**129**	**Min**	**Median**	**Max**
Available Water Capacity (g/g)	0.2	0.3	0.3	0.2	0.2	0.3
Aggregate Stability (%)	40.2	46.9	30.8	10.1	34.8	79
Organic Matter (%)	4.9	5.2	4.8	0.9	3.9	6.7
Soil Protein Index	9	10.8	8.6	3.4	6.5	17.7
Respiration Index	0.3	0.3	0.3	0.3	0.7	1.7
Active Carbon (ppm)	928	1006	944	368	716	1180
pH	7.2	7	7.3	5.3	6.6	7.5
Phosphorous (ppm)	16.8	11.9	21.8	1.9	13.4	312
Potassium (ppm)	101	62.2	93	39.2	115	390
Magnesium (ppm)	113	114	120	38.4	133	409
Iron (ppm)	4.5	3	3.7	0.7	1.7	23.9
Manganese (ppm)	12.7	12.7	12	3.1	12.4	26
Zinc (ppm)	0.9	0.7	1.6	0.1	1.6	7.9

Table 2. Ratings and peer comparisons for the Cornell Soil Health Test Indicators. This table shows ratings for your fields, compared to the min, max, and median for peer row crop farms in the study.

	Your Fields			Peer Fields		
Soil Health Indicator	119	125	129	Min	Median	Max
Available Water Capacity	90	97	93	66	88	99
Aggregate Stability	69	81	49	12	57	99
Organic Matter	98	99	97	8	84	99
Soil Protein Index	77	90	74	16	50	99
Respiration Index	13	17	17	13	62	99
Active Carbon	98	99	99	23	87	99
pH	100	100	98	1	100	100
Phosphorous	100	100	94	0	74	100
Potassium	100	87	100	57	100	100
Minor Elements (Mg, Fe, Mn, & Zn)	100	100	100	56	100	100
Overall Score	85	87	82	50	78	97

OPTIMAL (80-100)
EXCELLENT (60-80)
AVERAGE (40-60)
LOW-LEVEL (20-40)
CONSTRAINED (0-20)

More detail on how each indicator is measured, and potential management approaches to remedy constraints, are included in your Cornell reports, which have been shared with you as a separate document. The Cornell Soil Health manual is also an excellent resource for deeper learning about this soil health test (https://soilhealth.cals.cornell.edu/training-manual/).

To help orient you to the tables, here is a quick summary of what each indicator measures and what it can tell you about your soil's health.

Physical Soil Health Indicators

Available water capacity is a measure of the amount of water accessible to plant roots relative to the total amount of water the soil can hold under saturated conditions. It is measured in units of grams of water per grams of dry soil.Soils with greater available water capacity allow plants to perform better under drought conditions.

Aggregate Stability is a measure of the extent to which soil structure can hold up to wind, rain, and other stresses. Aggregate stability is measured as the percentage of soil aggregates that hold together through a standardized rainfall simulation. Good aggregate stability helps promote germination and root growth.

Biological Soil Health Indicators

Organic matter is measured as the percent of total soil mass that contains carbon compounds derived from living or once-living biomass. Organic matter is a core measurement of soil health. Organic matter is the foundation of soil life, contributes to the formation of stable soil aggregates, helps to improve available water capacity, and provides a slow-release supply of nutrients.

The **Soil Protein Index** tells you the amount of protein contained in soil organic matter. Proteins contain a lot of nitrogen, and microbes in the soil can break down these proteins and make the nitrogen available to plants. Soil protein is measured as mg protein extracted per gram of soil.

Soil Respiration measures the abundance and activity of microbial life in the soil. Soil microbes work to break down plant residues in the soil and cycle nitrogen and other nutrients from organic matter into plant-available forms. As they break down organic matter, microbes release carbon dioxide (CO2), so microbial activity can be measured by capturing the carbon dioxide produced by soil microbes over a four-day incubation period in the lab. Respiration is expressed in units of mg CO2 per gram of soil.

Active Carbon is a measurement of the small portion of soil organic matter that can serve as an easily available food source for soil microbes, thus helping maintain a healthy soil food web. It is measured in parts per million (ppm). Active carbon is a good leading indicator of biological soil health and tends to respond to changes in management earlier than total organic matter content.

Chemical Soil Health Indicators

pH is a measurement of how acidic the soil is, which controls how available nutrients are to crops. If pH is too high, nutrients such as phosphorus, iron, manganese, copper and boron become unavailable to the crop. If pH is too low, calcium, magnesium, phosphorus, potassium and molybdenum become unavailable. The value is presented in standard pH units, and rated using a hump-shaped curve, with a pH between 6.2-6.8 optimal for most crops.

Phosphorus (P) is an essential plant nutrient and is used by plant cells to build DNA and regulate metabolic reactions. At high levels, P can become a risk to water quality and at very high levels it can interfere with plant uptake of micronutrients including iron and zinc. Note that Cornell scores P measurements using a hump-shaped curve, such that both low and high parts per million (ppm) values get ratings towards zero. Optimal ppm values for P vary based on the texture and geology of individual soil types, but ratings above 30ppm are typically considered excessive.

Potassium (K) is an essential plant macronutrient that contributes to heat and cold tolerance and promotes fruit development in horticultural crops. It is measured in parts per million by mass.

Minor Elements including Magnesium (Mg), iron (Fe), manganese (Mn), zinc (Zn) are essential for various plant biochemical reactions but are required in small quantities. If any minor elements are deficient, this will decrease yield and crop quality, but toxicities can also occur when concentrations are too high. Cornell provides individual measurements in ppm for each of these four minor elements, but aggregates all four into a composite minor element rating.

The **Overall Score** is a simple average of the ratings for the set of ten chemical, biological, and physical indicators in the Cornell Comprehensive Assessment of Soil Health. The overall score can be a useful general summary, but individual indicators will be more useful in identifying strengths or management challenges for a specific field.

BENCHMARKS: Pasa Management Indicators

How to Read These Graphs: We collated farm management records from participating farms to generate four key indicators of soil health management: days in living cover, days with cover crops, tillage intensity, and off-farm organic matter inputs.

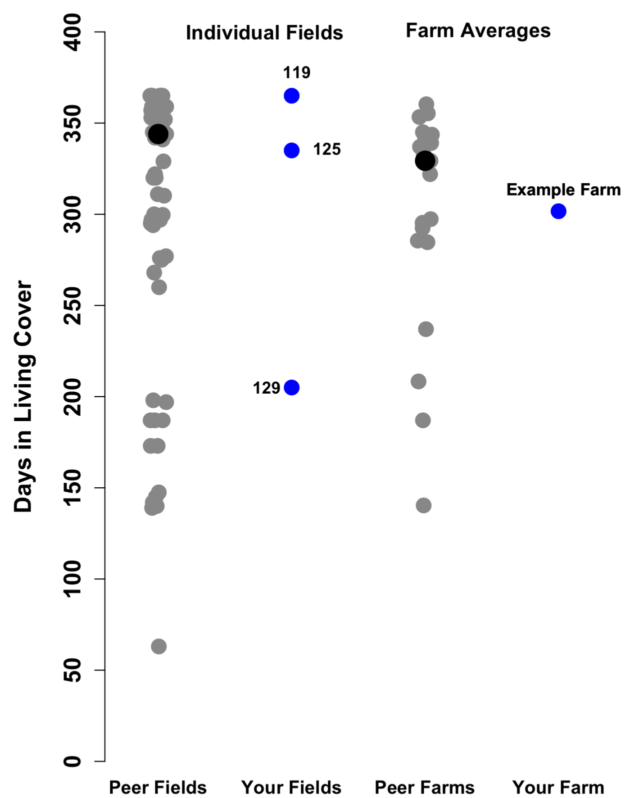
For each indicator, we've plotted results from your farm relative to results from peer farms. Because different phases of a row crop rotation often have very different management practices, we've plotted each indicator for the collection of individual fields, and for values for each farm averaged across the three study fields. In each figure, the **gray dots** show peer fields and farms, the large **black dot** shows the median values, and the **blue dots**, show your fields and farm. You can use these figures to think about the range of possible outcomes for separate phases of a row crops rotation and for a rotation as an integrated unit.

Note that if your farm was unable to share complete management records for 2019 you will not see blue dots in these figures for your farm's statistics. However, you may still find it useful to scan the range of outcomes on peer farms.

Days of Living Cover

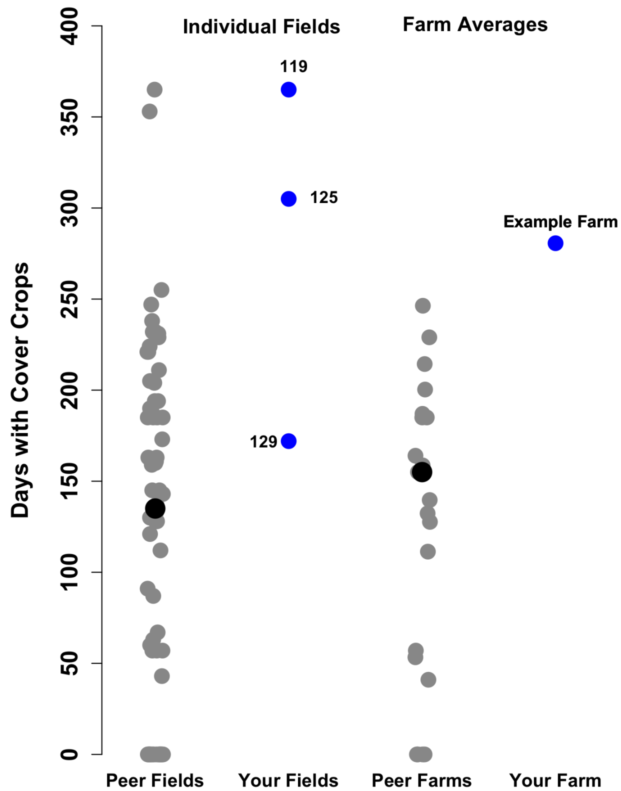
Living vegetation protects soil from wind and water erosion while also supplying the soil with fresh organic matter. Linking together crops and cover crops to maximize days of living cover is a fundamental soil building practice. The "Days of Living Cover" score is the days between crop or cover crop seeding (or transplant) and termination (or winter kill). For each field, we weighted the days of living cover for different crops and cover crops by the area planted and then summed over all the crops and cover crops.

Figure 1. 2019 Days of Living Cover on row crops farms. Your farm averaged **302 days**, while the median value for peer row crops farms was **329 days**.



Days with Cover Crops New this year, we also added an index of the days each field was planted to a cover crop. From a soil health perspective, cover crops have unique benefits because biomass and nutrients are not harvested from the crop, but are returned to the soil. The "Days with Cover Crops" score is the days between all cover crop or cover crop mixture seeding dates and the corresponding termination or estimated winter kill date. For each field, we weighted the days for each cover crop or cover crop mixutre by the area planted and then summed over all the cover crop plantings in that field.

Figure 2. 2019 Days with Cover Crops on row crops farms. Your farm averaged **281 days**, while the median value for peer row crops farms was **155 days**.



Tillage Intensity Index
Tillage can degrade soil structure and organic matter, but it can also be a valuable tool for weed management and incorporating cover crops. The tillage intensity index uses data from a Natural Resources Conservation Service soil erosion model to assign a soil disturbance score to all farm operations that can compact or disturb soil (Table 3). We weighted the cores for each machinery operation based on the area covered and then summed over the season. For context, NRCS assigns a single pass with a moldboard plow a score of 65, a disc harrow gets a score of 19.5, and a grain drill gets a score of 2.4. Below the figures, you can see a table of the implements and tillage scores we assigned for your fields.

Figure 3 2019 Tillage Intensity Index on row crops farms. Your farm averaged **77.8** units on the NRCS tillage intensity scale, while the median value for peer row crops farms was **6.9** units.

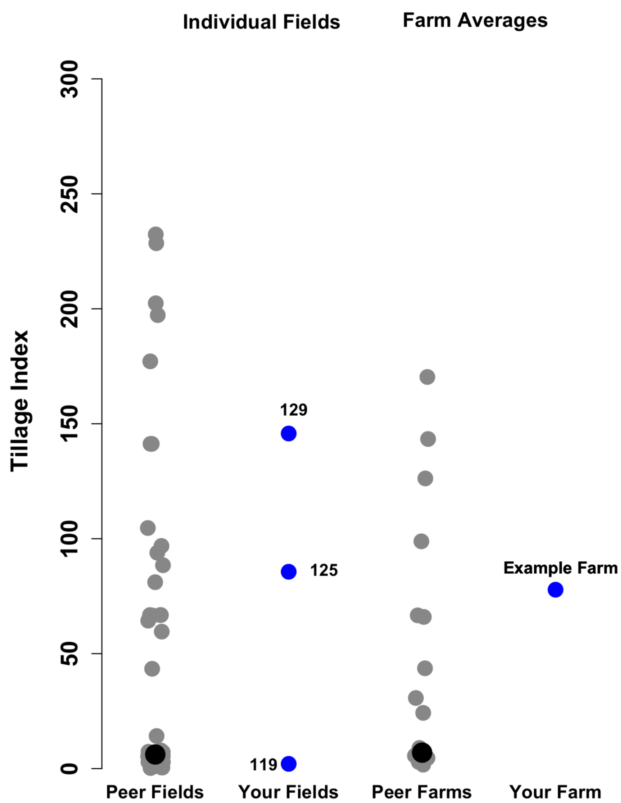


Table 3. Field operations and tillage intensity values. This table lists the field operations and implements you listed for each of your fields, along with the closest matching operation we could find in the NRCS tillage intensity index tables, and the corresponding tillage intensity value.

Field	Operation	NRCS Match	Tillage Index
119	Tractor and hay rake	Rake or windrower	1
119	Tractor and sprayer, 30 ft	Sprayer, kill crop	0.2
119	Swather, 18 ft	Mower, swather, windrower	0.2
119	Combine	Harvest, corn grain and cobs	0.2
119	Tractor and baler	Bale straw or residue	0.2
119	Tractor and mower	Shredder, rotary mower	0.2
119	Tractor and bale wrapper	Bale straw or residue	0.2
125	Plow - kverneland 3 furrow rollover	Plow, moldboard 6-7 inch depth	48.8
125	Speed disc - Kline speedtiller	Disc, tandem light finishing	19.5
125	Tractor and row crop cultivator	Cultivator, row 1 in ridge	14.6
125	Planter - white 6100, 6 row, 30 in	Planter, double disk opnr	2.4
125	Tractor and spin seeder	Planting, broadcast seeder	0.2
125	Combine - Gleaner R52, 6 row	Harvest, corn grain and cobs	0.2
129	Disc chisel - sunflower	Chisel plow, disk, st. pts.	65
129	Field cultivator - Brillion 19 ft	Cultivator, field with spike points	31.2
129	Speed disc - Kline speedtiller	Disc, tandem light finishing	19.5
129	Row crop cultivator - Sukup	Cultivator, row 1 in ridge	14.6
129	Phillips Harrow 15 ft	Harrow, rotary	10.2
129	Planter - white 6100, 6 row, 3 in	Planter, double disk opnr	2.4
129	No till drill, 13 ft	Drill or air seeder single disk openers 7-10 in spac.	2.4
129	Tractor and spin seeder	Planting, broadcast seeder	0.2
129	Combine	Harvest, corn grain and cobs	0.2

Organic Matter Inputs

Organic matter inputs including composts, manures, and straw mulches can jump-start the formation of soil organic matter, add microbiology to the soil, and supply macro and micro nutrients. However, continuous inputs can also contribute to soil health challenges, such as excessive phosphorus levels. This organic input score shows the total organic inputs (composts, manures, and mulches) into each field, in units of tons of dry matter (dm) per acre. We standardized organic amendments to a percent dry matter basis, based on amendment analysis submitted by farmers or taken from published estimates. This indicator only looks at inputs from "outside" the study field, and doesn't include manure deposited by animals grazing in that field or biomass generated by crops and cover crops.

Figure 4 2019 Organic Matter Inputs on row crops farms. Your farm averaged **0 T dm/A**, while the median value for peer row crop farms was **0.4 T dm/A**.

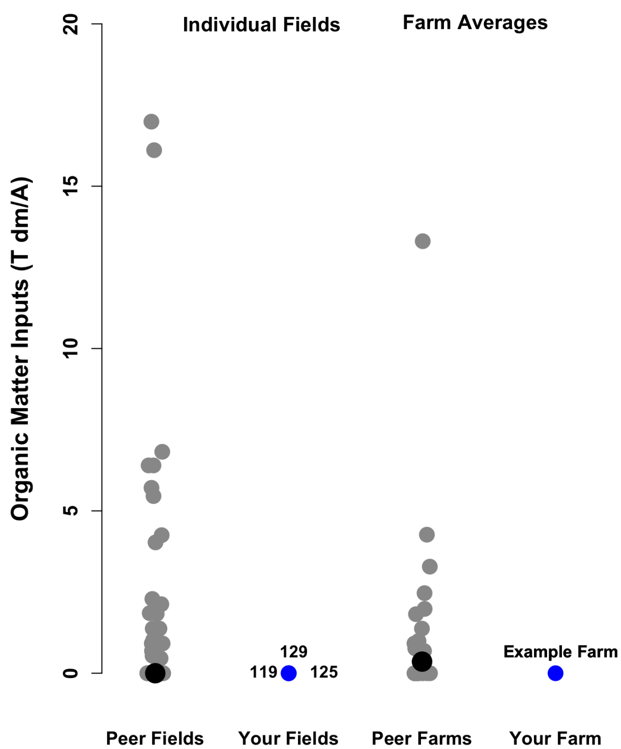


Table 4. Pasa management indicators, 2019. This table shows the values for your fields, compared to the min, max, and median for peer row crop farms in the study.

	Your Fields			Peer Fields		
Management Indicator	119	125	129	Min	Median	Max
Days of Living Cover	365	335	205	63	344	365
Cover Crop Days	365	305	172	0	143	365
Tillage Index	2.1	85.6	145.8	0.3	6.4	232.3
Organic Matter Inputs (T dm/A)	0	0	0	0	0	17

2017-2019 TRENDS

In this section, we share year-on-year changes in Cornell Soil Health Test and Pasa managment indicators for fields and farms in the study.

Table 5. 2017, 2019, and 2019 measurements for the Cornell Soil Health Test indicators for your study fields. For farms new to the project in 2019, we have not included year-over-year comparisons.

	Your Fields								
Soil Health Indicator	**4 , 2017**	**4 , 2018**	**4 , 2019**	**6 , 2017**	**6 , 2018**	**6 , 2019**	**7 , 2017**	**7 , 2018**	**7 , 2019**
Available Water Capacity (g/g)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Aggregate Stability (%)	45.3	15.8	27	37.9	12.3	25	38	12.6	24.6
Organic Matter (%)	4.2	3.8	4.1	4.1	3.4	3.9	3.9	3.3	3.8
Soil Protein Index	4	4.3	5.7	4.7	4.5	5.8	4	4.2	5.2
Respiration Index	0.6	0.4	0.4	0.8	0.4	0.4	0.8	0.4	0.5
Active Carbon (ppm)	433.1	498.8	581	500.8	500.6	676.9	477.1	452.1	619.4
pH	6.2	6.5	6.2	6.7	7.1	6.8	6.8	7.1	6.7
Phosphorous (ppm)	29.8	14.5	17.7	61.2	14.6	23	32	13.1	15.7
Potassium (ppm)	162	121.4	109.8	92.9	67.3	73	95.1	65	64.8
Magnesium (ppm)	97.7	85.8	92.5	146.8	138	155.9	172.2	159.4	164.1
Iron (ppm)	1.3	1.4	2.8	0.8	0.8	1.4	0.8	0.8	1.4
Manganese (ppm)	11.6	2.8	8	11	3	6.9	12.1	3.2	7.7
Zinc (ppm)	1.6	1.4	1.8	1.3	0.8	0.9	1	0.7	0.9

Because 2018 was the first year we had all three of our primary cohorts involved in the study (row crops, pastured livestock, and vegetable farms), we can compare changes in soil health indicators across cohorts for 2018-2019 (Table 6). For row crops, these data showed a consistent improvement in aggregate stability and active carbon levels. Most row crop farms also showed general (and occassionally substantial) increases in nutrient concentrations for phosphorus, iron, manganese, and zinc. We also observed broadly similar changes in the pastured livestock and vegetable cohorts, although because most pastured livestock farms already had high measurements for aggregate stabitliy, organic matter, and other biological indicators, we did not observe much change in these indicators on pastured livestock farms between 2018 and 2019. Possible explanations for the improvements in aggregate stability are discussed in the "Insights" section (page 15). Trends in nutrient concentrations varied considerably from farm to farm, and it's not possible to draw clear explanations for these changes from our data.

Table 6. Percent change (2018-2019) in Cornell soil health indicators on your fields and on peer row crop, vegetable, and pastured livestock farms.

	Your Farm	All Veg			Row Crops	Livestock
Soil Health Indicator		Min	Median	Max	Median	Median
Available Water Capacity (g/g)	4%	-21%	0%	33%	-11%	21%
Aggregate Stability (%)	90%	-13%	39%	251%	39%	7%
Organic Matter (%)	13%	-11%	3%	55%	4%	7%
Soil Protein Index	28%	-21%	6%	98%	6%	12%
Respiration Index	9%	-58%	21%	75%	19%	1%
Active Carbon (ppm)	30%	2%	29%	68%	20%	34%
pH	-4%	-9%	-2%	4%	-2%	-3%
Phosphorous (ppm)	33%	-36%	51%	509%	26%	56%
Potassium (ppm)	0%	-44%	-13%	127%	-15%	-3%
Magnesium (ppm)	8%	-17%	8%	111%	6%	-3%
Iron (ppm)	84%	-39%	96%	1292%	54%	90%
Manganese (ppm)	151%	48%	238%	793%	197%	273%
Zinc (ppm)	26%	-31%	56%	469%	35%	46%

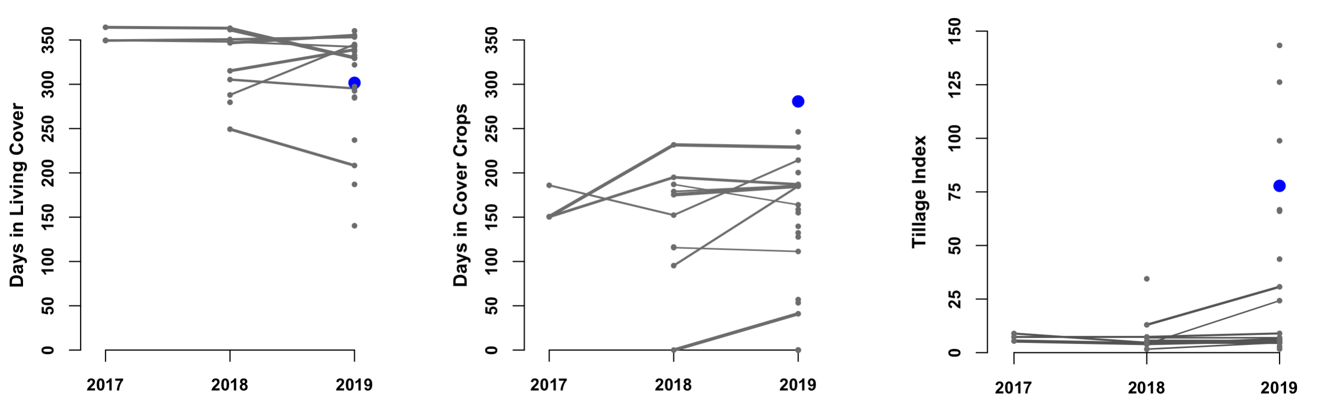
Table 7. 2017, 2019, and 2019 values for Pasa management indicators for your study fields. For farms new to the project in 2019, we have not included a year over year comparison.

	Your Fields								
Pasa Mgt. Indicator	4 , 2017	4 , 2018	4 , 2019	6 , 2017	6 , 2018	6 , 2019	7 , 2017	7 , 2018	7 , 2019
Days of Living Cover	246	278.9	247.8	256.6	269	274.1	293.4	301	219
Days of Cover Crop	205.4	205.2	98.8	209	171.8	80	203.4	234.7	101
Tillage Index	277.9	191.4	131.1	164.9	141.6	192.7	256.9	113.9	234.9
Organic Matter Inputs (T/A)	2.2	0	2	2.2	0	0	2.2	0	7.5

Over the course of this study, many farms have adjusted their management systems to changing weather conditions or adapted techniques and practices. Figure 5 shows 2 or 3 year trends for Days of Living Cover, Days with Cover Crops, and Tillage Intensity for the average of three study fields in each year. In each panel, year-to-year changes each peer farm is shown as a grey line, while your farm is show as a blue line.

Overall, most row crop farms held steady with Days of Living Cover and Days in Cover Crops, with several farms showing a significant increase in Day in Cover Crops in 2019, possibly due to better late summer and fall weather conditions in 2019. Most row crops farms have been consistent with the intensity of their tillage practices over 2017, 2018, 2019. In 2019, we welcomed several organic row crop farmers into the study, leading to some examples of higher-intensity tillage practices in the study. The "Insights" section on page 16 includes a discussion of the inter-relationships between tillage, organic matter inputs, and soil health.

Figure 5. Trends in Pasa management indicators on row crop farms, 2017-2019.



INSIGHTS: Rebuilding Aggregate Stability

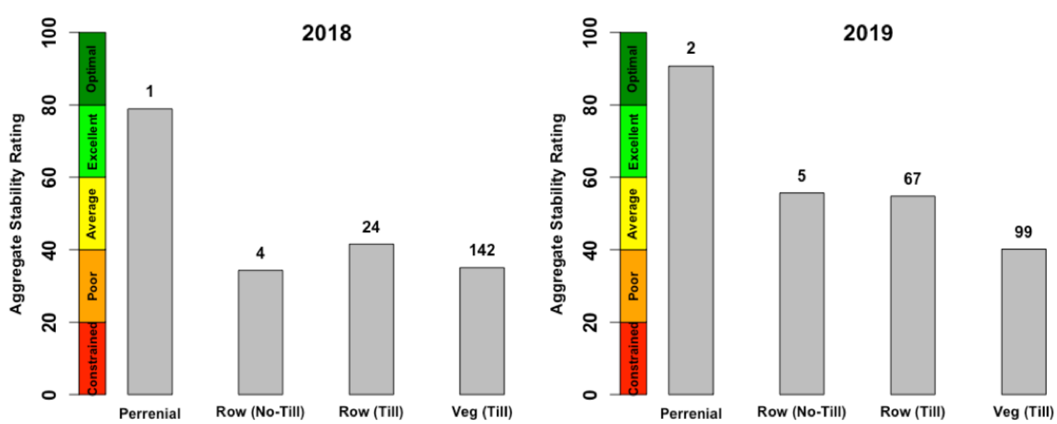
Climate change has arrived in Pennsylvania, and maintaining soil aggregate stability in the face of new weather patterns has emerged as a key challenge on many of our collaborating farms. Total annual precipitation in the northeast United States has increased over the past half century by about 10%, or five inches per year. But this gradual change is overshadowed by a much sharper increase: incidents of extreme precipitation (defined as more than 1 in. of rain in a 24 hour period) have increased 71% since 1950.

As many remember, 2018 was a particularly challenging year, with total rainfalls 50% above normal across much of Pennsylvania, and many locations experienced dozens of extreme rainfall events. Possibly as a result of this historic rainfall, we saw a crash in aggregate stability on many farms between 2017 and 2018. Fortunately, aggregate stability is a dynamic soil property, and previous research suggests that soil aggregates can be repaired through cover cropping and rotations that put living roots back in the soil. After a year of better growing and field work conditions in 2019, we observed a 64% and 53% rebound of aggregate stability on row crop and vegetable farms, respectively, on median.

The drop in aggregate stability occurred mainly in annual cropping systems; aggregate stability on pastured livestock farms remained high even after the fall deluges of 2018. Interestingly, despite achieving nearly year-round crop cover and drastically minimizing soil disturbance compared to vegetable farms, no-till row crop farms were not spared the 2017-2018 drop in aggregate stability (Figure 6). This trend suggests that even without tillage or cultivation, farmers can put substantial stress on soil structure by taking heavy planting, spraying, and harvesting equipment onto fields, especially during wet weather years. In 2018, many farmers reported that the difficult weather conditions often forced them to bring machinery into wet soils that weren't ready to be worked.

In 2019, we found that row crop farms, including both no-till and conventionally tilled farms, both rebounded their aggregate stability more than vegetable farms. Planting fibrous-rooted cover crops and successfully timing field operations may be a key to rebuilding soil aggregates after bad weather years. In general, we've found that row crop farmers in our study are more consistent cover croppers than most vegetable farmers, and vegetable farms have substantially more intense tillage practice than even organic or conventionally-tilled row crop farms.

Figure 6. Relationships between tillage systems, tillage intensity, and aggregate stability ratings on study farms in 2018 (left) and 2019 (right). Bars indicate the mean aggregate stability for each tillage system, while the numbers above each bar indicate the mean tillage index. For context, NRCS assigns a single pass with a moldboard plow a score of 65, a disc harrow gets a score of 19.5, and a grain drill gets a score of 2.4 (NRCS 2008).



INSIGHTS: Balancing Tillage and Soil Health

Discussions around soil health can often become entrenched around prescriptive extremes, with advocates arguing passionately for no-till farming, organic farming, grazing, or any number of systems defined by specific practices. Contrary to this more polarized conversation, our data point to a wide spectrum of management systems that can grow healthy soils.

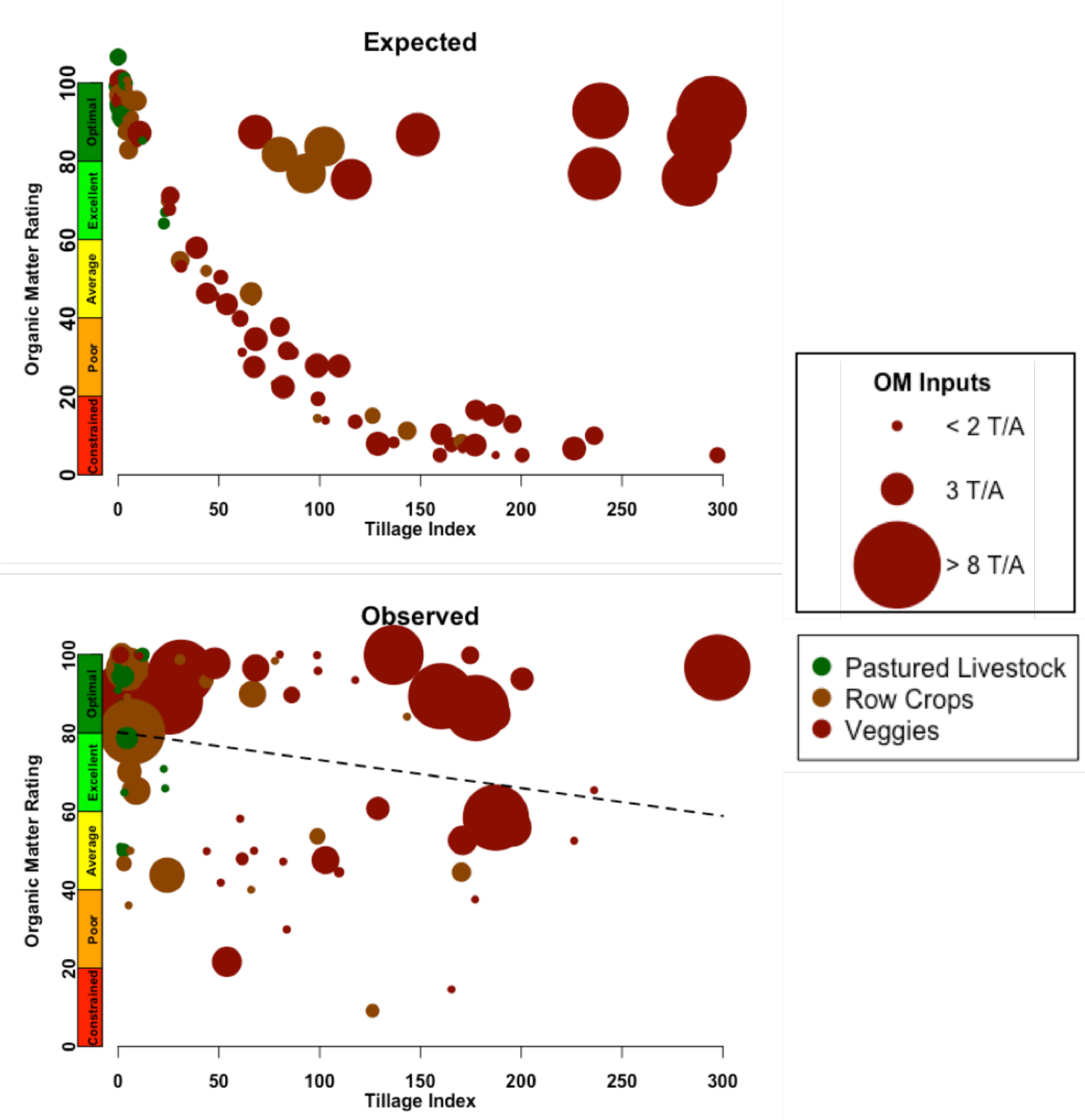
In many ways, organic matter is the central soil health indicator. Organic matter influences the formation of stable aggregates, provides long-term slow release soil fertility, and provides fuel and habitat for beneficial microorganisms. Viewed through the lens of soil organic matter, our data show that healthy soils can be achieved with a range of management systems and tillage practices.

Farmers have traditionally cultivated soils to control weeds and prepare a seedbed for planting. Tillage and cultivation can severely deplete soil organic matter by disturbing soil structure and exposing soil to fresh air (oxygen stimulates microbes to metabolize or burn up organic materials). It would therefore be reasonable to predict that soil disturbance could have a severe and unavoidable negative impact on soil health. If this were true, we would expect a steep and consistent negative relationship between tillage intensity and organic matter (Figure 7, upper panel). Where cases of heavy tillage co-occurred with healthy organic matter levels on individual farms, we would expect to see consistent and heavy inputs of organic matter from outside the farm (e.g. manure, compost, or mulch) to counterbalance the negative effects of soil disturbance.

Our data do not support these predictions. Instead we find a shallow and weak correlation between tillage intensity and organic matter. We also observed a large number of row crop and vegetable farms that utilize primary tillage implements (tillage index > 50), and maintain "optimal" organic matter in the Cornell rating system (Figure 7, lower panel). Interestingly, many of these farms apply relatively small quantities of organic matter inputs to their fields annually.

These surprising insights point to the need for farmers to consider a balanced and holistic approach to soil management. Our data indicate that organic and conventional tillage farmers can balance the negative impacts of tillage with intensive cover cropping, diverse crop rotations, integrating livestock, and carefully timing field operations, along with judicious use of organic inputs. On the other hand, no-till farmers dealing with herbicide-resistant weeds or looking for ways to reduce their herbicide costs may find examples in our study for techniques to bring back some "steel-in-the-field" for weed management without compromising long-term soil health.

Figure 7. Relationship between tillage intensity, organic matter inputs, and organic matter rating on pastured livestock, row crop, and vegetable farms on study farms. The upper figure reflects the expected relationship between these variables, while the lower figure shows the observed results for 2019. Each data point reflects the average of three selected fields on a collaborating farm. In the right hand panel, the dashed line shows a linear regression model between tillage intensity and organic matter rating (p=0.01, r2=0.15). For context, NRCS assigns a single pass with a moldboard plow a score of 65, a disc harrow gets a score of 19.5, and a grain drill gets a score of 2.4.



MARKETING RESOURCES:

Healthy soils improve air and water quality, grow more nutritious products, and help ensure an abundant food supply for future generations. Farmers that practice excellent soil stewardship therefore deserve a better price and bigger markets for their products. We designed the customized infographic included with this report to help you tell your customers and stakeholders about the important work you are doing to improve and protect your soil resources. Each infographic has been tailored to your farm's soil health data for 2019, and shows your farm averages for three key statistics:

Cornell Soil Health Scores, compared to the average soil health score for all soils in the Cornell database, which is set to 50 in their scoring system.

% Organic Matter, compared to the % organic matter estimated by the NRCS Soil Survey for the soil types sampled on your farm.

Days of Living Cover, compared to a Pennsylvania benchmark for a corn and soybean rotation planted without cover crops. Estimates for corn and soybean days of living cover were taken from planting and harvest dates reported by the National Agricultural Statistics Service (NASS).

You can add these infographics to your farm's website, or share print copies with your wholesale buyers, at your farm stand, or in CSA boxes. These marketing resources are a new experiment for Pasa. If you do share your farm's infographics with your customers, please let us know if you have suggestions for how we can improve them or create additional resources to support you in marketing your soil health stewardship to your customers.

NEXT STEPS

As our project continues in 2020 and beyond, the data you and peer farms are contributing will provide an enormous resource for benchmarking trends in soil health and uncovering common challenges, and highlighting specific solutions. As the season winds down, we'll also be organizing conference calls and workshops to further explore the data and learn from the collective experience of our 106 contributing farmers. **In October, we'll be gearing up for another round of this project, so please check your email and mailboxes for information on collecting and submitting your 2020 soil samples and management records.** New this year, we'll also be collecteing water infilration data on a subset of 28 farms.

For vegetable farms, we've also begun enrolling a pilot cohort in the Real Food Campaign, to assess nutrient density in specialty crops and explore connections between soil health and produce quality. We will be enrolling more farms in 2021, so if you are interested in measuring nutrient density on your farm, please reach out to sarah@pasafarming.org!

Save the Date!

- November, **Cohort Conference Calls**

Join other vegetable farmers in this study to discuss these reports, unpack the the 2020 season, and explore changes and solutions for the year ahead.

- January 19 - February 6, **30th annual Pasa Conference**, Online on Everywhere. Our conference will be virtual this year and will include extensive soil health programming.

Event information is available at www.pasafarming.org/events or call 814-349-9856.