RODALE INSTITUTE

Farming Systems Trial

40-YEAR REPORT

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40-YEAR REPORT

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40 YEARS *and* COUNTING

A LETTER FROM OUR CEO

Rodale Institute's mission has always been to increase the number of organic farmers and acres under organic care. Our research is at the foundation of that effort. Through rigorous scientific examination, we're deepening the understanding of how and why organic methods work and we're gathering knowledge about the best practices that we can share with farmers. Research informs all of our other efforts, from our workshops and webinars to our nationwide network of consultants to our advocacy for public policies that support the expansion of the organic community.

The Farming Systems Trial (FST) is one of our most significant research projects. In fact, with FST's now 40 years of accumulated data and findings, it is fair to say that it is the most consequential study of organic agriculture anywhere. Its value comes from its real-world context. FST research takes place in the field, using the common practices of both organic and conventional farmers. As those strategies have evolved over the last 40 years, so has the FST. Today, the conventional research plots are planted with the latest GMO seeds that have come to dominate industrial-scale agriculture, and they are treated with herbicides recommended to farmers in our region. As you'll see in this report, the results show that those practices cause damage to our soils and inhibit their long-term viability. Meanwhile, the soil in the organic plots is growing healthier year by year, the costs are lower, and the crops' net returns are higher.

We refer to the Farming Systems Trial as one research project, but in fact it is producing several distinct but interconnected streams of valuable information. As you turn the pages of this report, you'll see what we're learning about fertility, soil biodiversity, weed management, water quality, comparative yields, economic impact, and more. Each is meaningful on its own; together this information is producing a clear picture of the power of organic systems to support the health of the land, people, communities, and the planet.

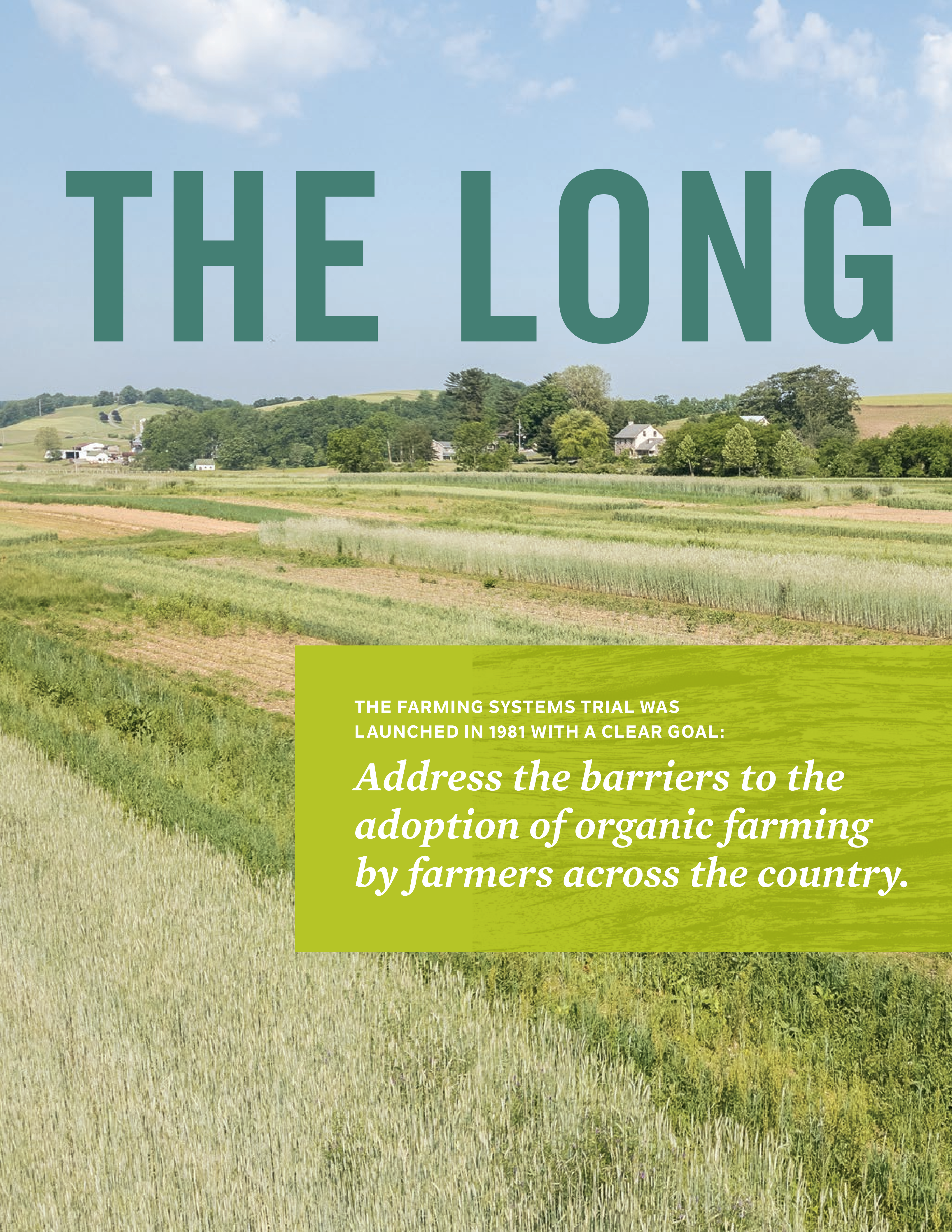
We are taking a moment now to celebrate four decades of discoveries, but the research continues to dig deeper and grow in new directions. In 2015, we launched the Vegetable Systems Trial to track the degradation of soil, and the impact that it has on human health, by comparing the nutrient density of organic and conventional produce. Our Industrial Hemp Trial is investigating the potential of grain and fiber hemp as a rotational crop in organic systems, specifically researching its impact on soil health. We've also joined with other scientists to study the effects of agricultural practices on the local watershed. At our regional resource centers in the South, Midwest, West, and Europe, researchers are building on the knowledge gleaned from the FST to help farmers to apply it in their conditions.

While this report looks back at the last 40 years, our attention is on the future. Ahead we see regenerative organic agriculture as the solution to many environmental, economic, and social problems facing the world. The Farming Systems Trial will be a guide to sustainable food production that benefits all of us, and this report documents why.

Sincerely,

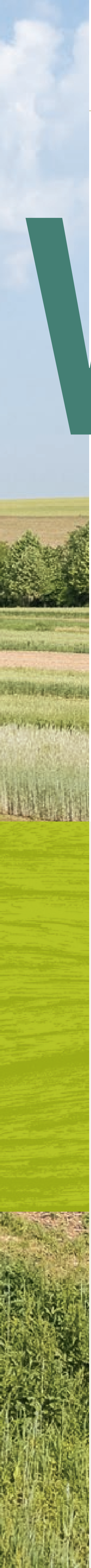
JEFF MOYER
Chief Executive Officer, Rodale Institute

THE LONG



THE FARMING SYSTEMS TRIAL WAS LAUNCHED IN 1981 WITH A CLEAR GOAL:

Address the barriers to the adoption of organic farming by farmers across the country.



VIEW

THE HISTORY AND CURRENT STATUS OF THE FARMING SYSTEMS TRIAL

To fulfill our mission, we created a study that would use the most credible analytic methods to compare the side-by-side results of organic and conventional farming practices from a variety of perspectives and planned to share that knowledge with farmers, scientists, and policymakers. Over the last 40 years, the research has evolved and broadened, building a deeper body of information with each passing season. The study tracks the impact of different practices on the farm's economic viability and energy usage, the nutritional quality of the food produced, the health of the soil, and the water that flows through the systems; it also measures the impact of these practices on the environment as a whole. As you'll see in the pages of this report, the research continues to demonstrate that organic farming strategies consistently match or outperform common conventional practices and yield a wide range of benefits for producers, consumers, and the world.

The Farming Systems Trial (FST) fields are located at Rodale Institute's Main Campus, a 386-acre certified organic farm in Kutztown, Pennsylvania (about 60 miles northwest of Philadelphia). The study comprises 72 different plots, which are carefully separated from each other by constructed buffer areas and other strategies to ensure that the data gathered from each one is unadulterated. While these plots have been studied continuously for 40 years, FST farming practices have changed as the common approaches of organic and conventional farmers have evolved.

THREE SYSTEMS, TWO WAYS

Grains like corn, soybeans, oats, and wheat are the raw materials of the U.S. food supply, and they fuel the engine of agriculture in this country. The FST is designed to mimic the real-world practices of farmers who raise these staples and to assess how their practices impact farmlands, farmers, and the communities around them. It sets up and compares three distinct farming systems. Two of the systems use organic methods but with different primary sources of nitrogen. The third system applies the conventional, or standard, production model, which relies on synthetic nitrogen sources and pesticides. This reflects the system used by the majority of grain producers across the U.S. All three systems are dynamic and continue to change over time to incorporate the latest technologies and practices.

Conventional

This system represents a typical U.S. grain operation. It relies on synthetic nitrogen for fertility, and weeds are controlled by synthetic herbicides that have been selected and applied at rates recommended by Penn State University Cooperative Extension and our project advisory board.

Organic Legume

This system represents the practices of an organic cash grain system. This low-input system is based on a mid-length rotation of annual grain crops and cover crops. The system's fertility comes from legumes, plants that extract nitrogen from the air and fix it in the soil. Crop rotation provides the principal line of defense against pests.

Organic Manure

This system represents the practices of an organic dairy or beef operation. It is based on a long rotation of annual grain crops and perennial forage crops. Fertility is provided by periodic applications of composted manure and by legume cover and forage crops in this rotation. In addition to providing fertility, a diverse crop rotation is the primary line of defense against pests.

COMMON PRACTICES

The FST is designed to replicate the standard methods and materials used by conventional and organic farmers across the U.S. In the last 15 years, the treatments for the FST research plots have evolved to incorporate these common practices.

GMOs: According to the USDA, over 90 percent of corn, cotton, and soybean acreage in the United States is planted with seeds that are genetically engineered to be herbicide-tolerant or express pesticides within the crop.[1] In 2008, genetically modified corn and soybean varieties (GMOs) were incorporated into all the FST conventional plots to represent current agricultural practices in the U.S.

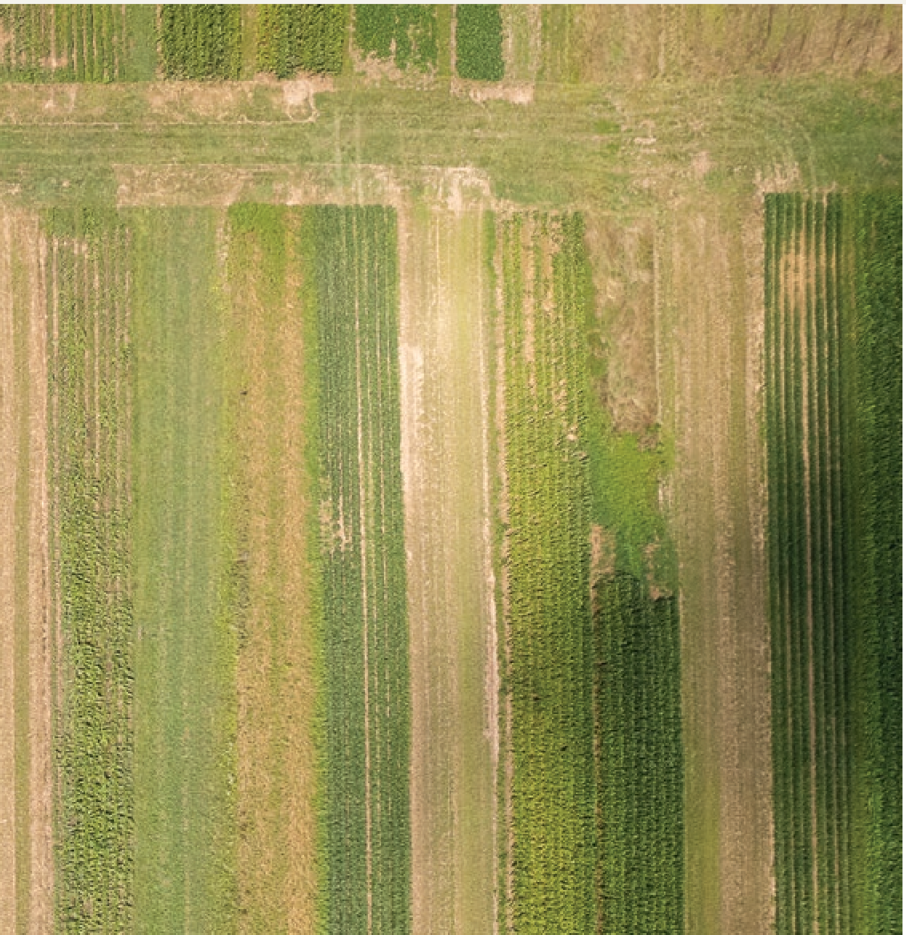
Tillage: For thousands of years, farmers have relied on turning the soil with tillage tools to prepare fields for planting crops and managing weeds. Disturbing the soil, however, can lead to soil erosion and damage the soil food web. The three systems of the FST were managed with full tillage until 2008, when each of them was divided into full-tillage (FT) and reduced-tillage (RT) plots. Herbicides are used in the conventional RT plots to control weeds and terminate cover crops when present. As a result, tillage is almost eliminated. In organic RT plots, the frequency

of tillage is reduced but not eliminated altogether. The ground is tilled strategically when appropriate within the crop rotation. In between, a roller-crimper is used to terminate cover crops and leave the residues to function as a weed-suppressing mulch and soil amendment as they decay.

Rotations: The crop rotations in the organic systems are more diverse than in the conventional system, including up to seven crops in eight years (compared to two conventional crops in three years). While this means that the conventional system produces more corn or soybeans within the cycle because those crops occur more often in the rotation, the organic systems produce a more diverse array of food and nutrients and are better positioned to mitigate system yield impacts in adverse conditions.

Cover Crops: The organic systems have relied on cover crops, or green manures, as forms of plant-based fertility from the inception of the research trial. In addition to providing fertility, cover crops have many other benefits, which include reducing erosion, preventing loss of nutrients to the environment, improving water infiltration, reducing weed pressure, enhancing soil biology, and adding carbon to the soil.

The adoption and use of cover crops by conventional and organic farmers across the nation continues to grow dramatically. In the latest USDA Agricultural Census, 25 percent of Pennsylvania farmland had cover crops planted.[2] For that reason, in 2015, one entry point of the conventional system now receives a cereal rye cover crop after the main crop is planted. This is the most common practice across temperate regions since cereal rye is cold-tolerant, effectively scavenges nitrogen, and produces high levels of plant biomass. These plots will allow measurement of the soil carbon sequestration and other benefits of cover crops in conventional till and no-till systems.



FARMING SYSTEMS TRIAL BY THE NUMBERS:

40 YEARS

12 ACRES

72 PLOTS

3 SYSTEMS

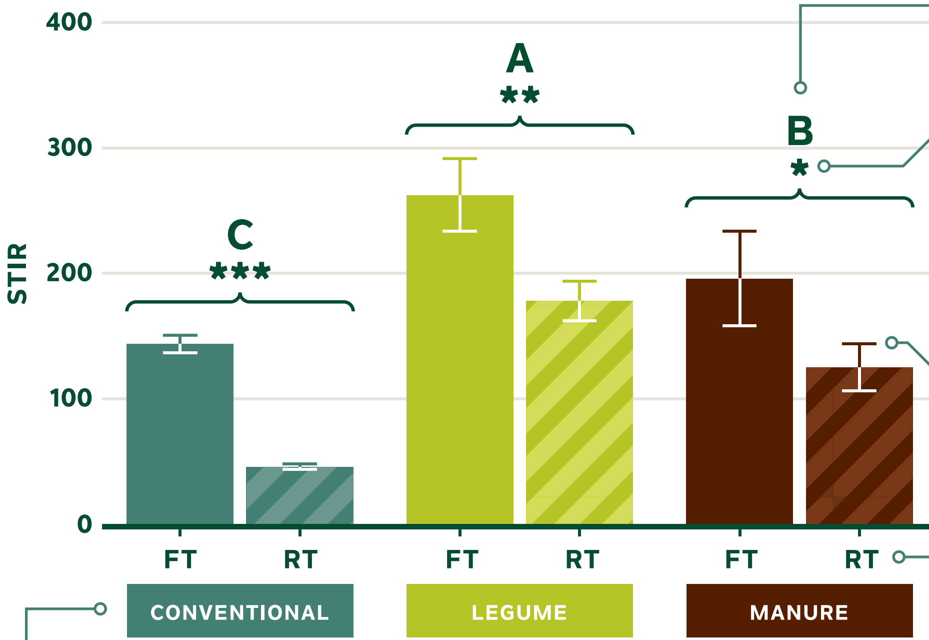
Annie Benson, Research Technician,
downloading and recording soil moisture data.

RESEARCH FINDINGS

RIGOROUS ANALYSIS ASSURES THAT THE FST RESULTS ARE SCIENTIFICALLY CREDIBLE.

The FST team gathers data each season from the research plots, capturing the results from the full-till and reduced-till practices separately. The information has been thoroughly analyzed using widely accepted scientific standards, and the findings are presented graphically in this report to make its conclusions simple to understand.

HOW TO READ THE CHARTS



LETTERS

Uppercase letters indicate significant differences (P<0.05) across systems.

STARS

Asterisks indicate significant differences between tillage treatments within each system.

* P<0.05
** P<0.01
*** P<0.001

BARS

Bars represent standard errors (SE) of the means.

FT/RT

Beginning in 2008, the FST established full-tillage (FT) and reduced-tillage (RT) plots in both the conventional and organic systems to assess the impact on yields, soil health, and economics of the three core systems.

CONVENTIONAL

This system represents a typical U.S. grain farm. It relies on synthetic nitrogen for fertility, and weeds are controlled by synthetic herbicides selected by and applied at rates recommended by Penn State University Cooperative Extension.

LEGUME

This system represents an organic cash grain system. It features a mid-length rotation consisting of annual grain crops and cover crops. The system's sole source of fertility is leguminous cover crops. Crop rotation provides the primary line of defense against pests.

MANURE

This system represents an organic dairy or beef operation. It features a long rotation of annual feed grain crops and perennial forage crops. Fertility is provided by leguminous cover crops and periodic applications of composted manure. A diverse crop rotation is the primary line of defense against pests.

TO TILL *or* NOT TO TILL?

THE EFFECTS OF COMMON SOIL AND WEED MANAGEMENT PRACTICES ON ORGANIC AND CONVENTIONAL FARMS

Farmers have long relied on mechanical cultivation, or tillage, to clear weeds from rows of field crops.

But growers and scientists have learned that frequent tilling adversely affects soil health, leaving soil vulnerable to erosion from wind and water and destroying important fungal networks underground. Tillage is also fuel- and labor-intensive. For these reasons, field-crop growers have explored ways to reduce or even eliminate it from their operations. Conventional farmers have implemented no-till practices by using chemicals to prepare weed-free seedbeds and control weeds in the system. Then they plant varieties that have been genetically engineered to withstand broad-spectrum herbicides so these herbicides can be applied directly to growing crops. Organic farmers do not use these chemicals or genetically modified varieties, so they have adopted different strategies for reducing tillage.

Beginning in 2008, the FST established full-tillage (FT) and reduced-tillage (RT) plots in both the conventional and organic systems to assess the impact on yields, soil health, and economics of the three core systems. The RT conventional system mimics large acres of conventional farms in the United States that have adopted no-till practices aided by synthetic herbicides and genetically modified varieties. The RT organic systems represent the efforts of organic farmers and agricultural scientists who strive to reduce soil disturbance to further improve soil health.

ROLLER-CRIMPER SOLUTION

To reduce tillage frequency, organic farmers need another effective strategy for managing weeds and terminating cover crops. Rodale Institute began developing and refining the cover crop–based organic rotational no-till systems in the 1990s. For grain production, these systems use annual cover crops that are planted in early fall and then terminated at cash-crop planting time in the spring by a roller-crimper that was designed by Jeff Moyer, Chief Executive Officer of Rodale Institute and past Farm Manager. The roller-crimper is a cylinder with chevron-patterned blades that can be filled with water to add or reduce weight. The cylinder attaches to the front or rear of a tractor for a one- or two-pass system. As the tractor runs over cover crops, the roller-crimper knocks the plants down and creases their stems at approximately 7-inch intervals. This terminates the cover crops, which remain on the ground and form a thick mulch that suffocates and reduces weed germination before gradually decomposing into the soil.

While the cover crop is terminated by the front of the tractor, no-till equipment attached to the rear carves a row through the cover crop mulch, drops in seeds such as corn or soybeans, and covers them up to ensure soil contact. The termination of the cover crop, establishing the mulch mat, and planting can all happen in a single pass, saving vital time and energy for farmers. The large-seeded grain crop germinates and grows through the mulch while small-seeded weeds are suppressed from sprouting or penetrating the mulch.

The RT regimen was introduced to FST organic plots in 2008. The reduced-till organic system partners specific cover crops with specific grain crops based on whether the cover crops are legumes, and on their size, morphology, and time of flowering. Over time, the researchers have found that not all cover crops are equally well-suited to organic reduced-till practices. They have observed the most success with annual crops including crimson clover, winter rye, winter barley, spring barley, spring oats, buckwheat, foxtail millet, pearl millet, fava bean, sunn hemp, black oats, hairy vetch, field peas, and winter wheat. The roller-crimper is not effective at terminating perennials and biennials, such as alfalfa and certain clovers, and some types of annual crops, such as annual ryegrass.

After this major management modification, the FST now has both conventional and organic systems divided into FT and RT. The calculated Soil Tillage Intensity Rating (STIR) shows that tillage is almost eliminated in the conventional system and is reduced by around 30 percent in the two organic systems (Figure 1). Rigorous research has been conducted since 2008. This report highlights the effects of reduced tillage on soil health, crop yields, and farm profitability in side-by-side conventional and organic systems.

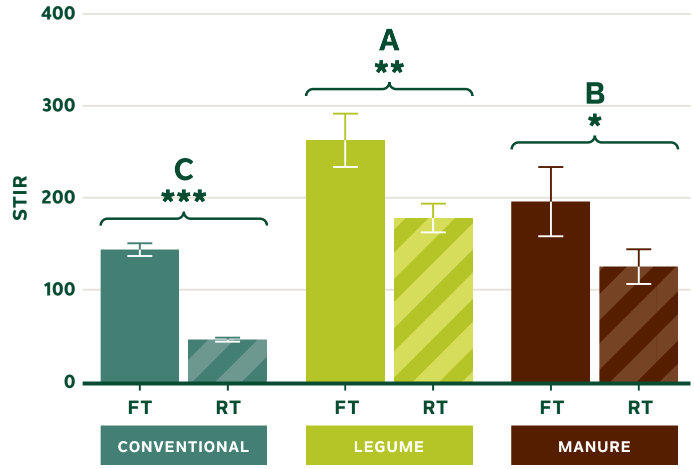


Figure 1 Average annual Soil Tillage Intensity Rating (STIR) of each of the systems in the Farming Systems Trial from 2008–2020. The STIR is a rating system created by USDA NRCS to measure overall soil disturbance. It accounts for tillage type, depth of tillage operation, operational speed of tillage equipment, and percentage of the soil surface area disturbed.

KEY TAKEAWAY

Certain annual cover crops, such as crimson clover, winter rye, barley, buckwheat, oats, and hairy vetch, are best-suited to organic reduced-till practices.

DIGGING IN *to* SOIL HEALTH

AN ASSESSMENT OF FERTILITY, VITALITY, AND BIOLOGICAL ACTIVITY IN EACH SYSTEM

Soil has always been the foundation of successful farming, so studying soil health is at the center of the Farming Systems Trial.

The health of the soil impacts the quantity and quality of the harvest and the long-term viability of the farm. In addition, soil is directly linked to the amount of carbon in the atmosphere and our changing climate. Evaluating the impact of different management practices on soil health benefits both farmers who can apply the results to their own operations and scientists looking at tools that sequester carbon. Helping farmers to continually renew the vitality of their soil also benefits the people who consume their food, the community around the farm, and the well-being of the environment we all depend on.

Over the last 40 years, FST researchers have laid the groundwork for the global conversation around soil health, advancing the understanding of what healthy soil is and the strategies for assessing it. Rodale Institute scientists, along with partner experts, have identified the critical factors that reveal the health of the soil, and the FST team has been gathering and analyzing data to understand the short- and long-term impact of different farm management practices, moving the conversation from soil quality to soil health.

SOIL ORGANIC MATTER

In healthy soils, carbon-containing organic matter can range from as low as 1 percent to as much as 10 percent of the soil's volume, depending on the soil type. However, it provides almost 100 percent of the food that nourishes the soil food web. Organic matter facilitates pore space formation, soil structure, and the ability of the soil to hold on to water, which helps increase aggregate stability and regulate moisture in the top soil layers. It is also a primary source of the carbon sequestered in the soil. A high level of organic matter in soil is a strong predictor of its health.

Research Says

After 40 years of management, the soil organic matter level was significantly higher in the organic manure system than in the conventional and the organic legume systems. Reducing tillage did not affect the soil organic matter level significantly in any of the organic or conventional systems. No-till management reduces soil disturbance and the oxidative loss of extant soil organic matter, but in order to enhance soil organic matter, especially the microbially derived, mineral-associated stable organic matter, an adequate amount of high-quality (lower carbon-to-nitrogen ratio) organic inputs that can stimulate microbial growth is necessary. In conventional corn and soybean systems, the diversity and quality of carbon inputs are often limited, leading to constrained soil microbial growth.

THE VALUE OF HEALTHY SOIL **Why is healthy soil so important?**

1. ***Peak Nutrition***
Soil is the foundation for food production and growing healthy, nutrient-rich food to sustain a growing population.

2. ***Drought Protection***
Healthy soil holds moisture until plants need it and creates symbiosis with fungi to extend the root network deeper into the soil.

3. ***Erosion Prevention***
The "aggregates" in healthy soil stick together and don't wash or blow away.

4. ***Disease Defense***
Active soil microbes ward off plant diseases.

5. ***Flood Resistance***
Heavy rainfall soaks into healthy soil, reducing flooding and runoff.

6. ***Carbon Capture***
Healthy soil holds carbon and keeps it out of the atmosphere.

However, in organic systems, which usually have much more diverse carbon inputs going into the soil, microbial biomass is significantly higher than in the conventional system, leading to higher soil organic matter over time. Reducing tillage in organic systems may further increase carbon content by protecting the accumulated soil organic matter from loss due to soil disturbance, although longer periods of time might be needed to detect a significant increase. Similarly, labile soil carbon and nitrogen pools (active C and soil protein) were larger in the organic manure system than in the conventional and the organic legume systems, indicating greater bioavailable carbon and nitrogen sources that would benefit soil microbial growth and activities as well as nutrient cycling.

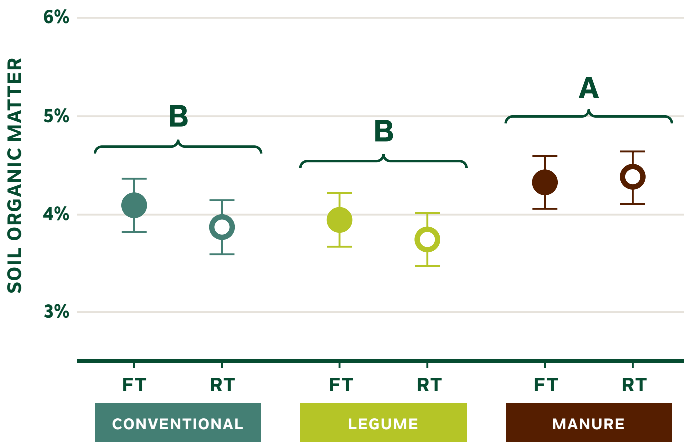
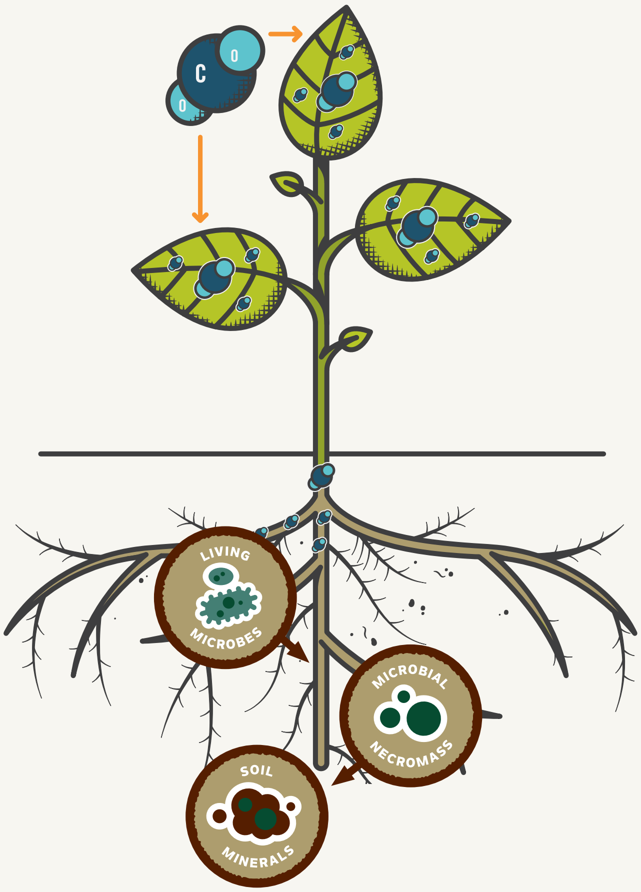


Figure 2 Average 0–20 cm soil organic matter content of each of the systems in the Farming Systems Trial in 2019 and 2020.



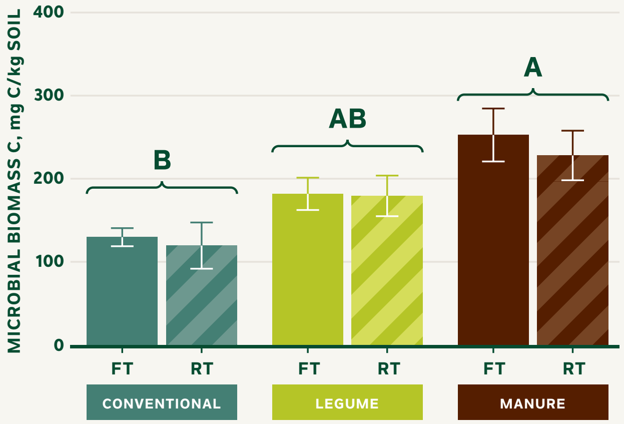


Figure 3 (Top) Recent conceptual development and empirical evidence suggest that soil organic matter formation and carbon accrual is largely a result of increased soil microbial biomass/necromass that can form close associations with soil minerals (silt and clay).

Figure 4 (Bottom) Soil microbial biomass carbon (average of 0–10, 10–20, and 20–30 cm depths) of each of the systems in the Farming Systems Trial in 2018. (Adapted from Littrell et al., 2021.)

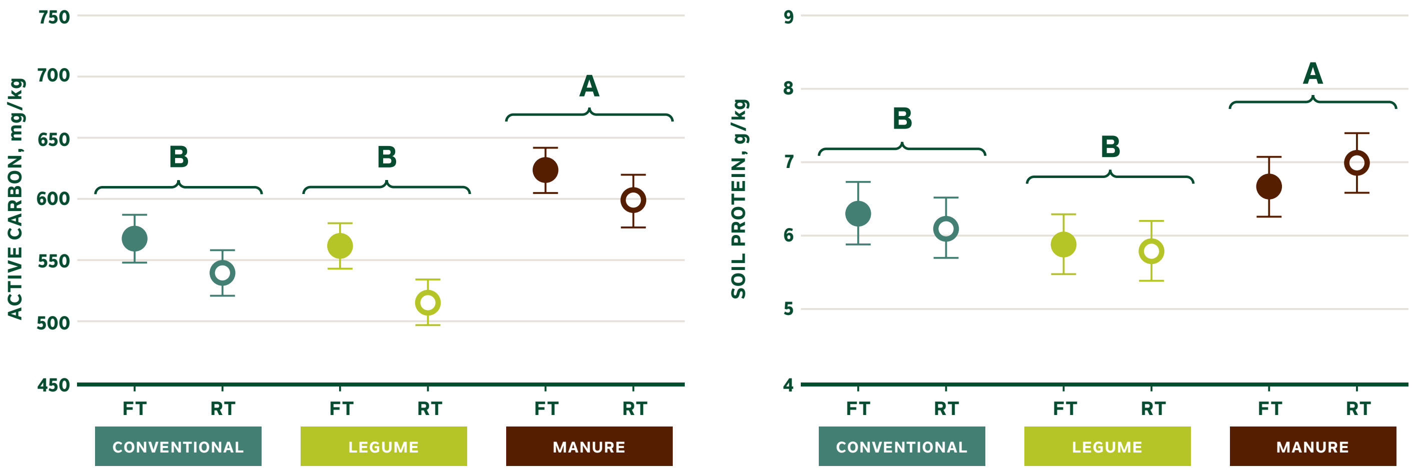


Figure 5 (Left) Average 0–20 cm soil active C (permanganate oxidizable C; POXC) and (Right) soil protein (autoclaved-citrate extractable protein) levels of each of the systems in the Farming Systems Trial in 2019 and 2020.

SOIL MICROBIOME DIVERSITY AND ACTIVITY

The soil food web is made up of many organisms, from microscopic bacteria and fungi to plump earthworms. Over 9 billion living organisms can be found in a single teaspoon of healthy soil. All of them play an essential role in maintaining the soil's ability to promote our own personal health and supporting the growth of crops by acquiring nutrients from available organic sources. Soil bacteria produce natural antibiotics that help plants resist disease. Fungi assist plants in absorbing water and nutrients. Together, they provide key functions that are essential to crop growth and ecosystem services.

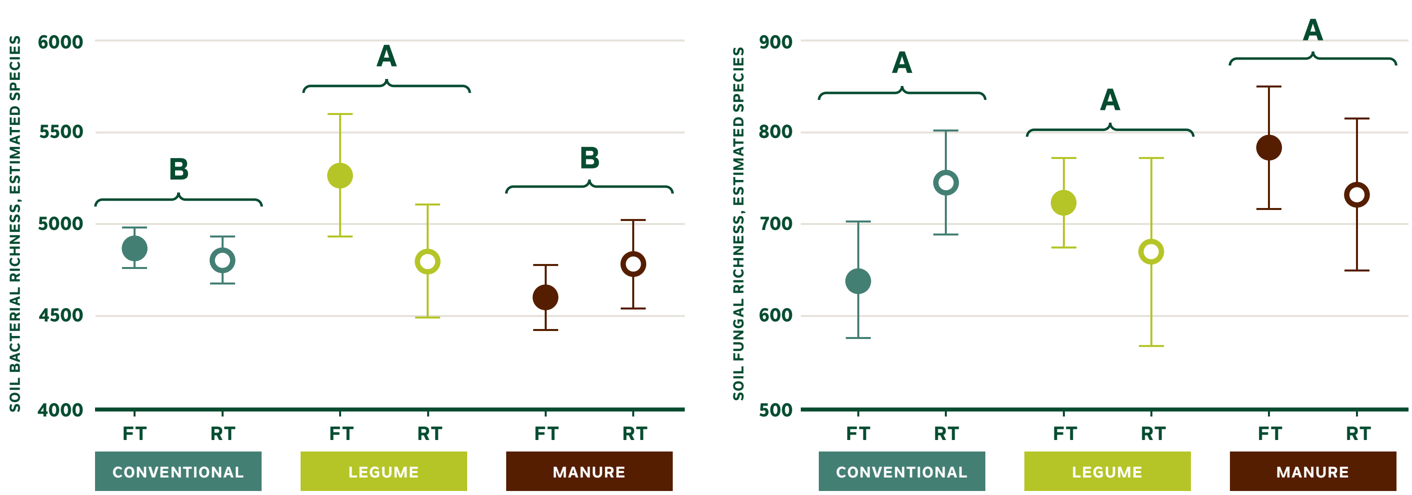


Figure 6 (Left) Soil (0–30 cm) bacterial richness and (Right) fungal richness of each of the systems in the Farming Systems Trial in 2019.

Research Says

The species diversity of some soil microbial groups collected down to a depth of 30 centimeters differed across management systems. Soil bacterial communities from the organic legume system had the highest diversity among all systems. Soil respiration, a measure of microbial activity in the soil, was significantly higher in the organic manure system than in the conventional or the organic legume system. **Reducing tillage increased soil respiration by 16 percent in the organic manure system and by 23 percent in the conventional system.**

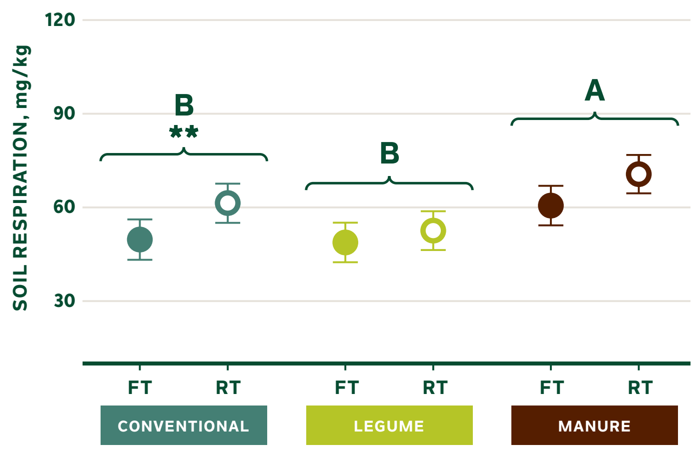


Figure 7 Average 0–20 cm soil microbial respiration of each of the systems in the Farming Systems Trial in 2019 and 2020.

SOIL COMPACTION

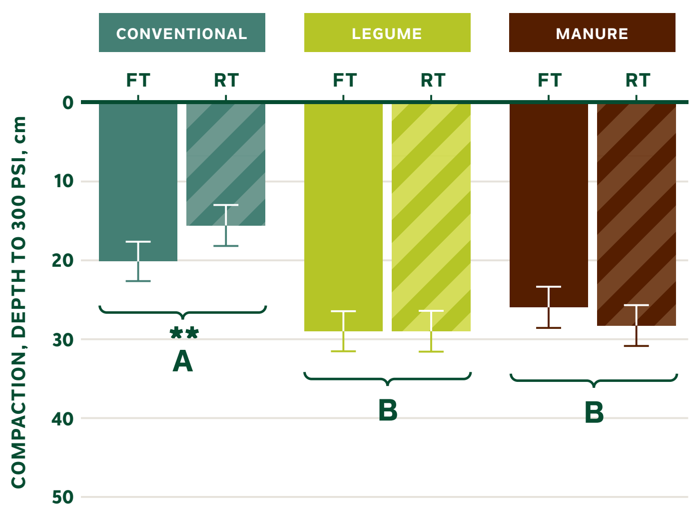
About half the volume of soil is composed of pore spaces that hold air and moisture necessary to the survival of plants and the soil food web. In compacted soil, the pore spaces are reduced or eliminated, and plants' roots are limited in their capacity to spread out and gather up water and nutrients. In compacted soil, crops are more vulnerable to drought and flooding and may suffer from stunted growth.

Research Says

FST researchers measured the depth to the compaction layer as the depth where soil pressure reached 300 pounds per square inch (psi), the pressure that is known to affect root penetration and thus plant growth.

An analysis of the soil conditions in each plot after many years of production revealed that the organic systems, legume- or manure-based, were significantly less compacted than the conventional system. Compaction was not significantly affected by reduced tillage in the organic manure and organic legume systems, but the soil was even more compacted in the reduced-tillage conventional plots. These results suggest that no-till management in chemical-intensive systems can cause severe compaction, which may further limit root and microbial activities due to constrained soil pore structure.

Figure 8 Average soil compaction layer (penetration depth at 300 psi) of each of the systems in the Farming Systems Trial in 2019 and 2020.



KEY TAKEAWAY

Organic no-till practices maintain or improve soil quality and vitality. Chemical-based conventional no-till practices can cause more soil compaction.

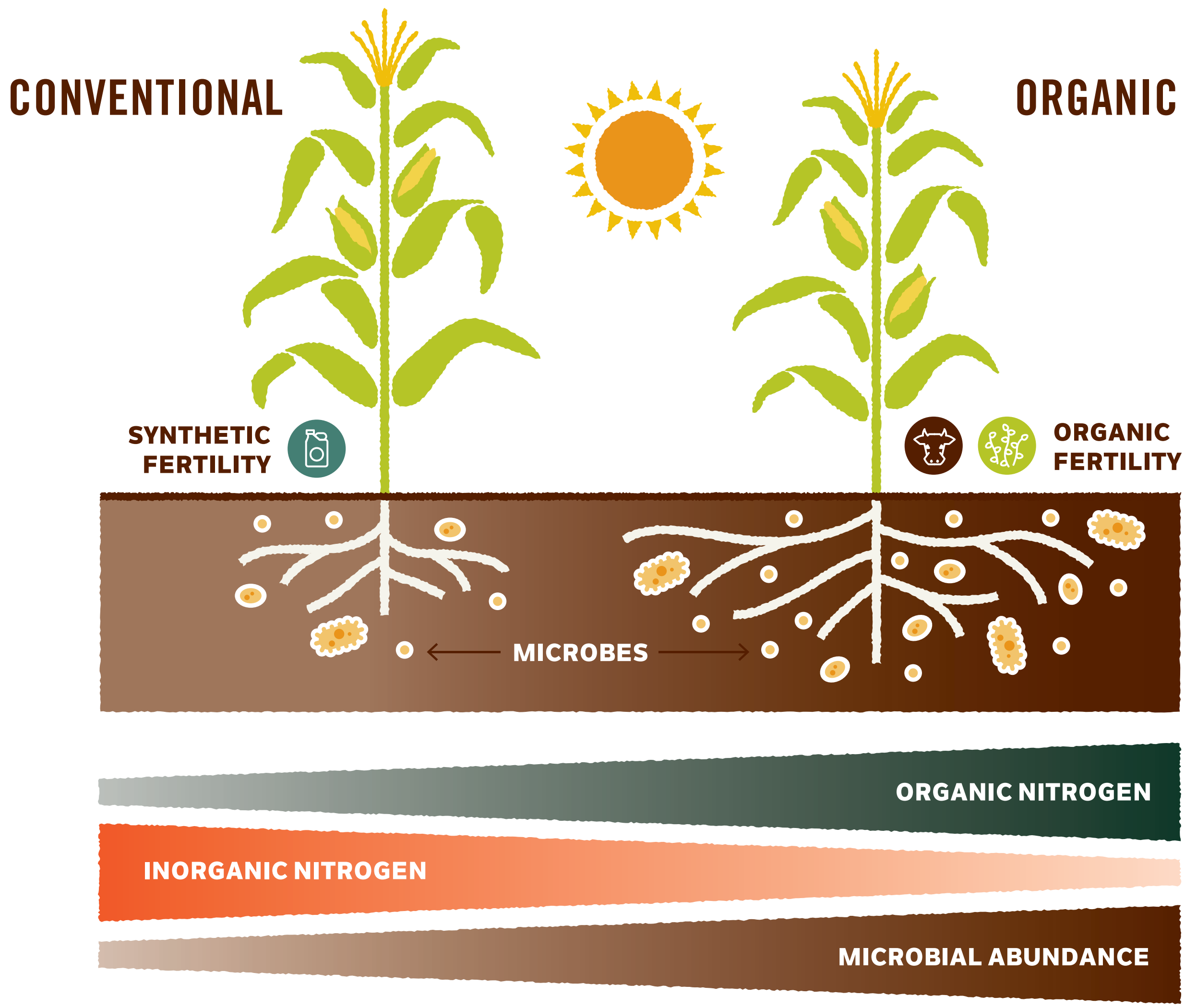


Figure 9 Different fertility sources for conventional and organic systems. Regenerative agricultural practices maintain belowground fluxes of plant surplus carbon that support soil microbes and generate soil organic matter. (Adapted from Prescott et al., 2021.)[3]

SOIL NUTRIENT AVAILABILITY

Practices that reduce the frequency and intensity of tillage benefit the soil in many ways; however, **tillage frequency affects organic and conventional systems differently.** One significant distinction is the availability of key soil nutrients. This is important because the inorganic sources of fertilizers that are typically used in conventional row-cropping are highly prone to leaching into groundwater and to loss as greenhouse gases. Organic sources of fertilizer tend to be more slow-release and less prone to loss into the environment.

Research Says

In the conventional system, soil inorganic nitrogen (ammonium and nitrate) concentrations were higher than in the organic systems. These forms of inorganic nitrogen tend to leach into groundwater or are lost as the greenhouse gas nitrous oxide. Organic nitrogen that is readily available for plant use, namely the potentially mineralizable nitrogen, was greater in the organic systems. In contrast to conventional crop production, organic production relies on soil organic matter and biologically supplied organic amendments (animal manure and leguminous cover crops) to provide nitrogen. These organic materials provide a higher level of diverse, complex, and slow-release sources of nitrogen, which can encourage greater abundance and activity of nitrogen-cycling soil microbes, increasing overall nitrogen-use efficiency on organic farms and decreasing nitrogen-related pollution.

Although full-till and reduced-till practices have not resulted in consistent differences in soil inorganic or organic nitrogen concentrations, reducing tillage may help improve soil nutrient availability in the long run by reducing soil organic matter decomposition.

Soil from a conventional, tilled research plot (Left) and from an organic, manure compost, reduced-till research plot (Right).

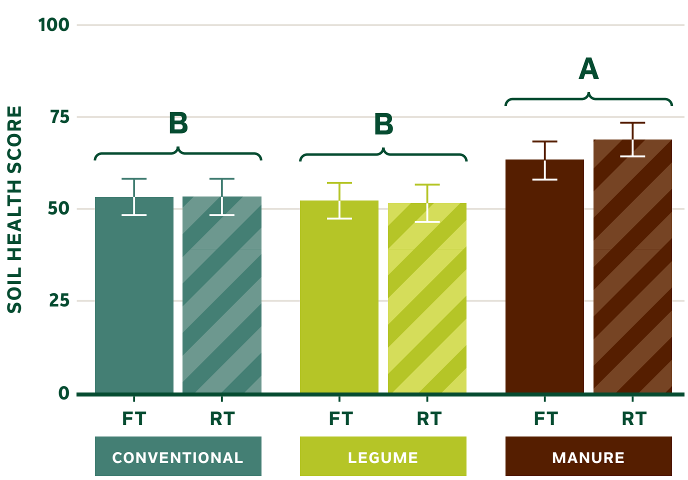


Figure 10 Cornell comprehensive assessment of soil health (CASH) score of each of the systems in the Farming Systems Trial in 2019 and 2020.

KEY TAKEAWAY

Organic practices increase soil organic matter and microbial biomass, diversity, and activity while reducing soil compaction—the key metrics for evaluating soil health. Chemical-based no-till practices degrade soil health.

MATCHING YIELDS, HIGHER PROFITS

COMPARISONS OF THE MOST CRITICAL OUTCOMES FOR DIFFERENT FARMING SYSTEMS

To meet the escalating demand for certified organic field crops and maintain economic viability, farmers need to maximize productivity while managing their resources for the long-term health of the soil and land. After 40 years of compiling and comparing the data gathered from the test plots, the Farming Systems Trial research demonstrates that the yields of cash crops from organic systems are consistently comparable to conventional production yields. In extreme weather conditions, such as drought, organic systems proved to be more resilient, sustaining good yields while production in the conventional plots declined. **An economic analysis shows that organic systems are more profitable for farmers than conventional agriculture is.**

TOTAL YIELD

The rotations among the various FST plots differ so that only periodically are they all growing the same crops. An assessment of the cash crop yields from 2008 to 2020 in the three FST systems presented a few clear findings.

Organic Manure Tilled and Conventional Tilled

These systems consistently met county average yields for the cash crops. The majority of farms in the county (Berks County, Pennsylvania) are following the conventional tilled model.

Organic Legume

Yields for cash crops in this system came in about 20 percent lower than county averages. The production costs in this system, however, are lower than in the others, which has a significant impact on the farmers' net profit.

Tillage Effect

Across all three systems, reducing tillage generated yields that were 6.7 percent lower than the county averages. Farmers may find this yield loss acceptable because their input and labor costs are lower.

Impact of Weather

The organic grains are surpassing conventional yields in years of drought or excess rainfall. This is likely due to the organic soil's healthier structure and enhanced water-holding capacity.

CORN COMPARISON

For livestock feed and processing into oil, sugar, and other ingredients, organic field corn is a high-value cash crop. The FST results over the last decade show that corn yields are statistically equal between the organic manure and conventional systems. That means organic growers can match the volume currently produced by conventional operations, ensuring a steady supply for U.S. markets. Corn grain protein contents were also higher in the organic systems than in the conventional system (2008–2020).

Research Says

In 2016, corn was in the rotations of both the conventional and organic plots at the same time. It was an especially dry summer in Berks County, Pennsylvania, with a total of 9 inches of rain from June 1 to August 31. Corn yields were significantly higher in the organic manure system than in the conventional system. Overall, organic corn yields have been 31 percent higher than conventional production in drought years.

GRAINS FOR SALE

Wheat ranks third in the U.S. behind corn and soybeans in planted acreage, production, and gross farm receipts. The USDA estimates that about 47.8 million acres of cropland in the U.S. was planted in wheat in 2018 and 2019.[4] The U.S. is consistently among the world's three top exporters of wheat.[5] But as is the case with corn and soybeans, certified organic wheat crops represent less than 1 percent of the total acreage.[6] And demand for certified organic wheat grown in the U.S. far exceeds the supply.

The market for oats is smaller, but oats can still be a cash crop opportunity for organic farmers. Overall oat production in 2020 is estimated to be 65.4 million bushels—with organic less than 1 percent of the total.[7] Along with their use in traditional cereal foods for livestock and people, oats are now used for producing nondairy milk and yogurt, cosmetics, and building materials. Oats are included in the organic system rotations because they provide an opportunity to increase use of cover crops that improve soil health and reduce weed pressure, and the harvested grain can be sold to farms and food processors. Oats are not in the rotations for the conventional plots since they are not widely grown by conventional farmers in the region.

Research Says

The wheat yields in the FST from 2008 to 2020 were not significantly different across systems. For oats, all of the organic systems exceeded county averages, with almost twice the yields of oats produced by local conventional growers in the area. The yields were 29 percent higher in the organic manure system versus the organic legume system. Low yields of oats in the conventional system may be because they are not widely grown in the region.

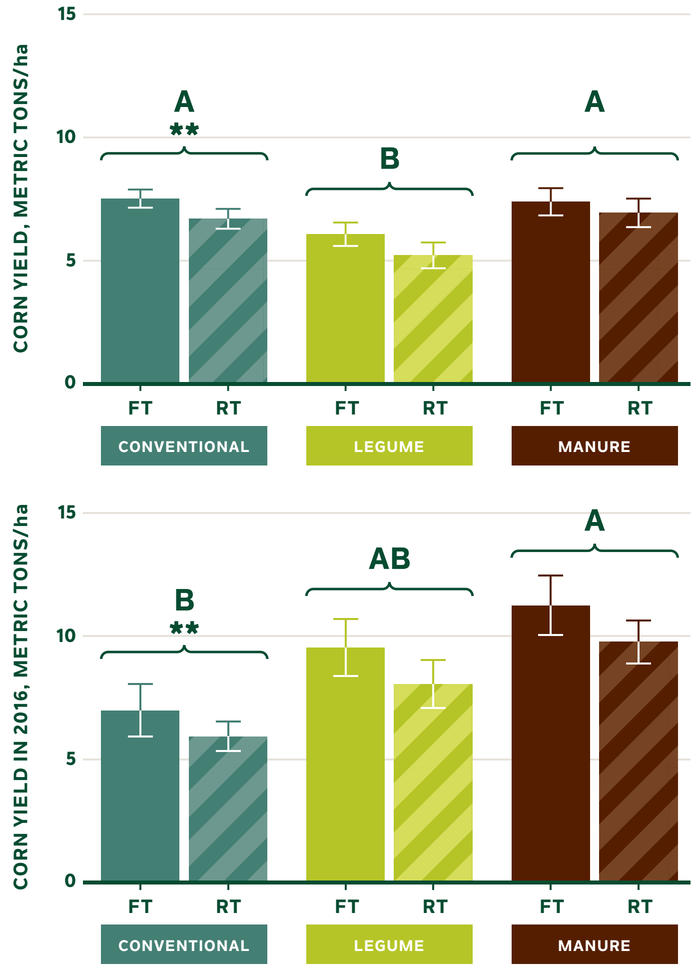


Figure 11 Average corn yield of each of the systems in the Farming Systems Trial from 2008–2020 (Top) and corn yield in 2016 (Bottom) which was an especially dry season.

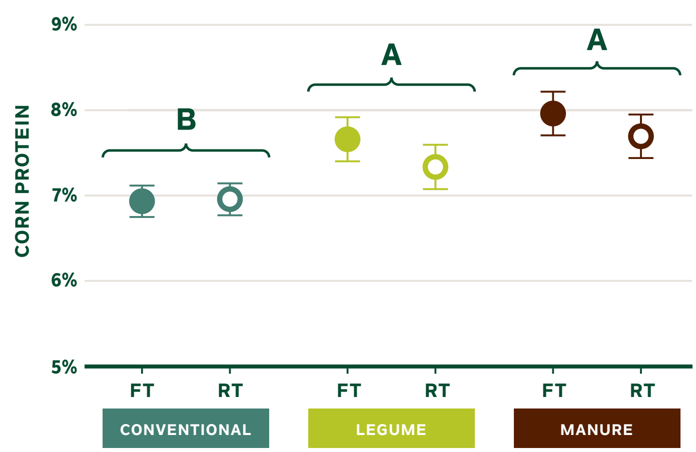


Figure 12 Average protein level of corn grain of each of the systems in the Farming Systems Trial from 2008–2020.

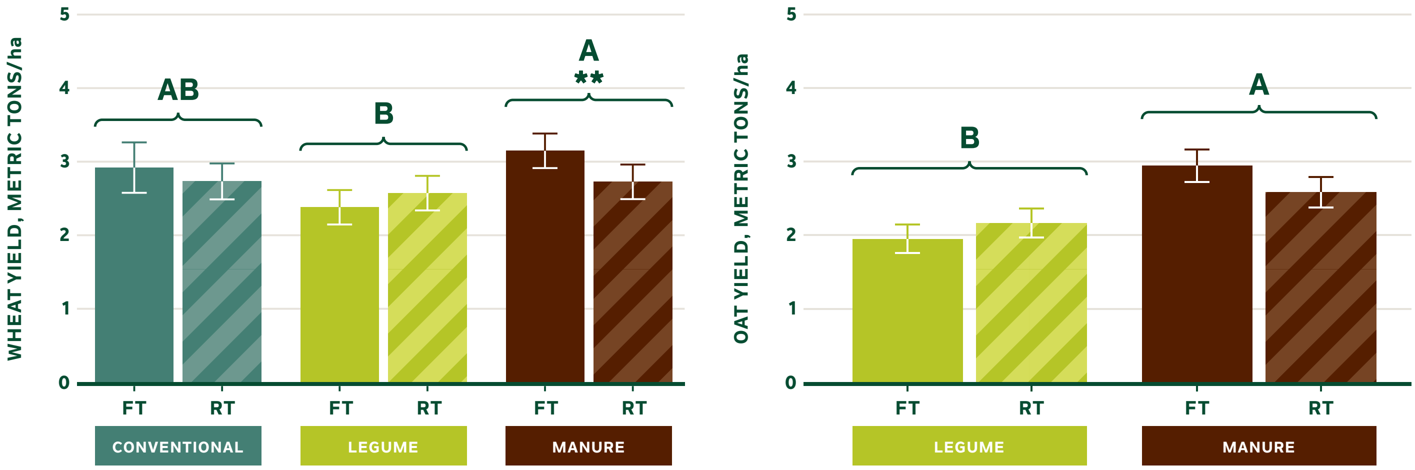


Figure 13 Average wheat (Left) and oat (Right) yields of each of the systems in the Farming Systems Trial from 2008–2020.

WEED RESISTANCE

Uncultivated and unwanted plants (weeds) growing in crop fields can reduce yields by siphoning off water and nutrients and attracting pest insects. Herbicide-resistant weeds continue to evolve even as more potent crop protection chemicals are used by conventional farmers. The progression of herbicide-resistant weeds has accelerated since the large-scale adoption of genetically modified herbicide-tolerant crops, leading to increased applications and use of herbicides, primarily glyphosate but also the highly volatile and mobile chemical dicamba. More than 92 percent of corn, 94 percent of soybean, and 92 percent of cotton crops planted in the U.S. are genetically modified. Meanwhile, the use of glyphosate has increased almost 15-fold since 1996, when glyphosate-resistant crops first hit the market.[8] Researchers and conventional farmers are observing that common weeds are developing resistance to these herbicides.

Research Says

The FST results show that organic practices are more effective than GMOs and toxic chemicals at helping farmers overcome the challenges of weed and pest management. The organic plots in the FST have tolerated much higher levels of weed competition than their conventional counterparts while producing equivalent yields. The researchers attribute the productivity of the organic plots to the increased health and fertility of the soil, which is supporting high yields in the crops and weed growth.

Yichao Rui, Ph.D., former FST research director, shows the development of herbicide-resistant weeds in conventional no-till plots of FST.

THE PROFIT PICTURE

The bottom line for farmers is the return they earn from the time, labor, and resources they invest in growing their crops. The FST research team conducted a comprehensive economic analysis to compare the profitability of the different systems.

Research Says

FST field activities, inputs, and crop yields from 2008 to 2020 were used to construct enterprise budgets for representative farms (54 hectares) for which cumulative labor costs, returns, and risks were assessed. The analysis shows that reducing tillage lowered crop yields and gross revenue in the conventional system and the organic legume system, but management costs were also lowered by reducing tillage. In the organic manure system, however, reducing tillage did not affect total revenues or net returns. Overall, regardless of tillage practices, the organic systems outperformed the conventional system; the organic systems were more profitable and lower risk due to lower total costs and high price premiums for organic grain and forages.

KEY TAKEAWAYS

In conventional systems, no-till practices do not always improve soil health or grain yields, and herbicide-resistant weeds have become more abundant and difficult to manage.

Total costs of operations are significantly lower in the organic systems than in conventional management. Without the price premiums paid for organic crops, the organic manure system is the most profitable, followed by the conventional system and the organic legume system. With organic price premiums, both organic systems are much more profitable than the conventional system.

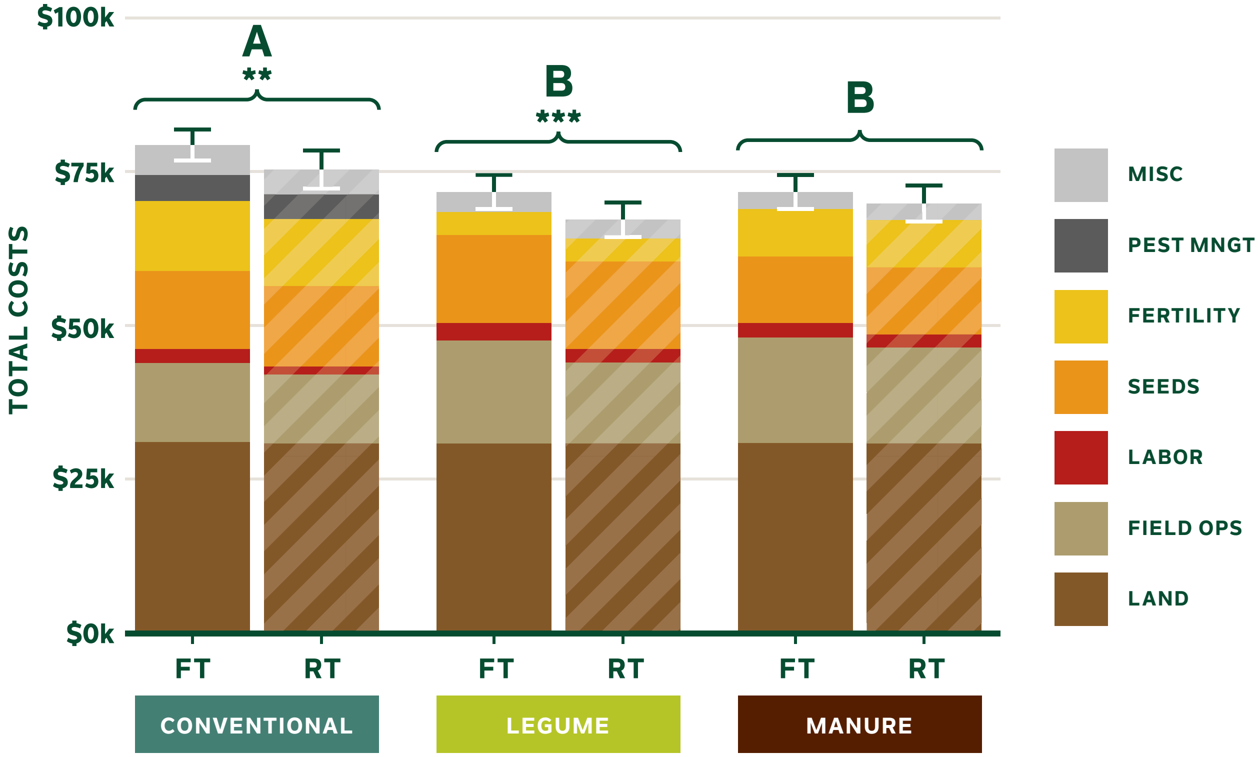


Figure 14 Total and individual costs of each of the systems in the Farming Systems Trial from 2008–2020. Budgets are for representative farms 54 hectares in size.

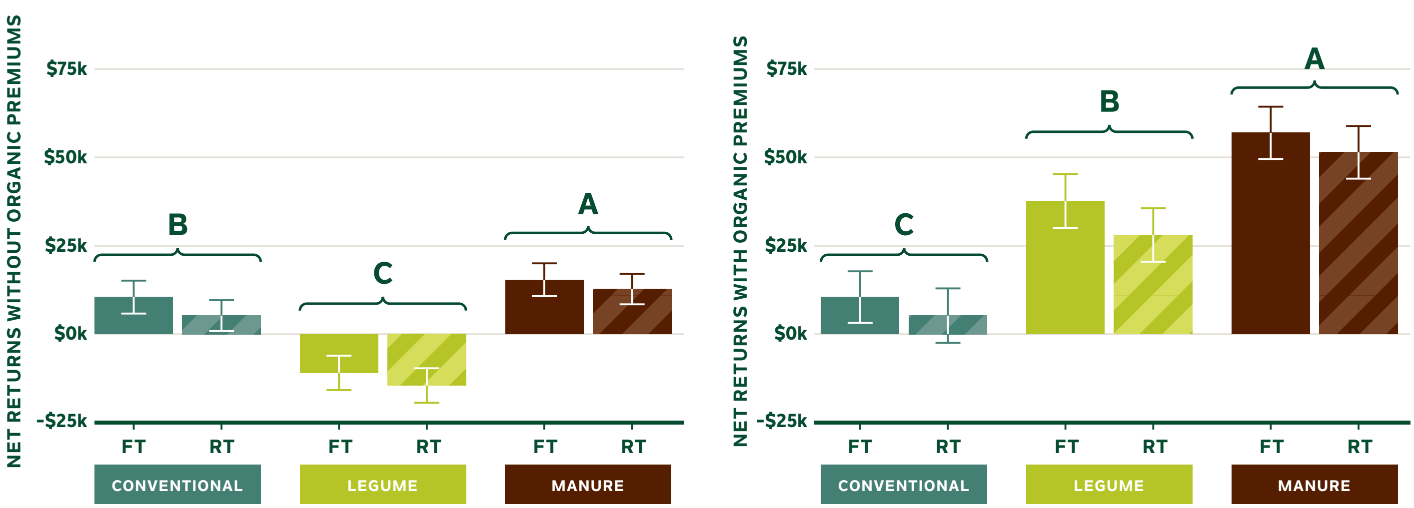


Figure 15 Net returns (Left, without organic price premiums; Right, with organic price premiums) of each of the systems in the Farming Systems Trial from 2008–2020. Budgets are for representative farms 54 hectares in size.

ENVIRONMENTAL PROTECTION

EVALUATING THE IMPACT OF FARMING SYSTEMS ON WATER QUALITY

While more than 70% of the earth's surface is covered in water, less than 1% is fresh water available for drinking, bathing, irrigation, and other life-sustaining purposes.

Increasing pollution from conventional agriculture threatens the freshwater supply. About 1 billion pounds of pesticides, 12 million tons of nitrogen, and 4 million tons of phosphorus fertilizer are applied annually to crops in the U.S., according to a report from the U.S. Geological Survey.[9] A portion of these chemicals soak into groundwater and run off from farmland into rivers and streams, eventually making their way downstream to lakes, estuaries, and bays. "Soil erosion, nutrient loss, bacteria from livestock manure, and pesticides constitute the primary stressors to water quality," says a U.S. Environmental Protection Agency report.

The residue of chronic herbicide use on conventional grain crops is showing up in the water supply. The most widely planted varieties of corn, soybeans, cotton, and other crops raised by conventional farmers have been genetically modified to tolerate glyphosate, a potent weed-killer that persists in the environment for years after it has been applied. A long-term, nationwide study by the U.S. Geological Survey found glyphosate in 40 percent of freshwater samples and 70 percent of rain samples. Glyphosate and other herbicides in groundwater and surface water disrupt the entire ecosystem, causing harm to soil biology, aquatic plants, wildlife of all kinds, and humans.

The FST now includes an assessment of the direct effects of farming practices on the water quality. Samples from organic and conventional full-till and reduced-till plots at Rodale Institute and Stroud Water Research Center are tested for water infiltration, which is linked to stormwater runoff and soil erosion, and for fertilizer contamination. In just a few years of study, the results already indicate that organic systems protect water quality and safely replenish the water farms rely on.

WATER QUALITY

The FST researchers have been comparing several indicators of how organic and conventional full-till and reduced-till systems impact the water supply and the soil.

Infiltration Through Soil: Whether rainwater soaks into the soil or runs off has an impact on farmers, the community around the farm, and the overall environment. When water infiltrates the soil, crops get more consistent moisture, the groundwater is replenished, and the water is filtered before it reaches the surface. Due to improved soil health, 15 to 20 percent more water percolates through the soil in organic systems.

Fertilizer Contamination: Conventional fertilizers are high in soluble nitrates and phosphates that can be lost to the environment through leaching and run off which declines water quality. Organic fertilizers (such as animal manure) are effective at building soil health, but overapplication could pose a huge risk for groundwater. The research shows that in the crops' rooting zone (20 to 30 centimeters deep), where plants can absorb nitrates, the levels are similar across the different management systems. Below the rooting zone, nitrates are six times higher in conventional plots. The conventional system poses the greatest groundwater contamination risk (even without considering pesticides).

Below the rooting zone, nitrates are six times higher in conventional plots.

Research Says

In the FST plots, water infiltration is significantly faster under long-term organic, compared to conventional, management practices. Higher soil water infiltration rates minimize waterlogging and surface runoff conditions that lead to soil erosion. Reduced-till management has tended to reduce water infiltration rates, although the effect has not been statistically significant when multiple years of data have been combined.

Water samples indicate that chloride and nitrates are percolated out at higher concentrations under the conventional system than in the organic systems. Collectively, these results suggest that the studied conventional system is leaching significantly higher concentrations of nitrogen compared to the organic systems, likely reflecting differences in the amount and type of fertilizer input and its retention in the soil, as well as differences in the volume and retention times of soil pore water.

KEY TAKEAWAY

Organic management increases water infiltration, replenishes the water table, and does not contribute to the accumulation of toxins in waterways caused by conventional agriculture.

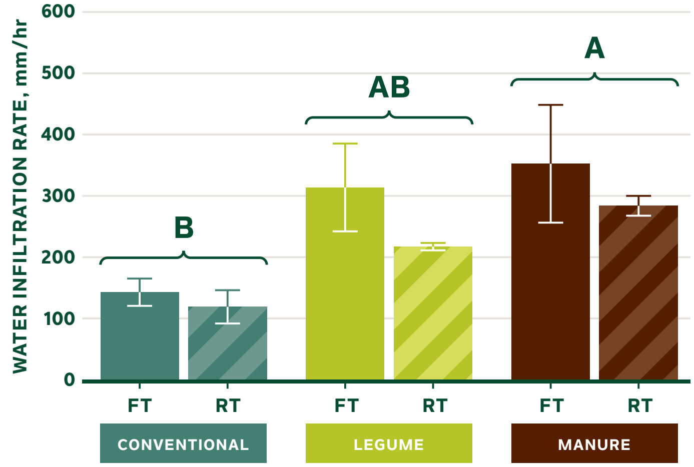


Figure 16 Average water infiltration rates in each of the systems in the Farming Systems Trial from 2019–2021.

Soil sampling from FST plots for physical and chemical analyses.

CLEAN WATER PARTNERSHIP

The Delaware River Watershed covers about 13,500 square miles and provides clean drinking water for about 5 percent of the U.S. population. With an annual economic value of $25 billion, it is a major recreational and industrial area for residents of New York, New Jersey, Pennsylvania, and Delaware. The Watershed Impact Trial (WIT), a partnership between Rodale Institute and Stroud Water Research Center, was launched in 2018 as a long-term research, education, and outreach project, aimed at addressing the barriers to adopting water conservation farming practices. Healthy soils and their associated ecosystems promote water infiltration and storage of rainwater and help minimize contaminants (sediments, nutrients, and pesticides) in underground aquifers and surface waterways that support humans and wildlife. This collaborative project focuses on quantifying and demonstrating how soil health influences the quantity, quality, and safety of fresh water under organic, conservation, and conventional management practices.

Rodale Institute and Stroud Water Research Center collaborated at the 2021 Stroud Field Day, with Yichao Rui, Ph.D., FST research director (top left), and Jinjun Kan, Ph.D., associate research scientist.

NATURAL LANDS STROUD PRESERVE

In 1990, Dr. Morris Stroud bequeathed his 332-acre farm to Natural Lands, a nonprofit organization that saves open space, cares for nature, and connects people to the outdoors. The land is now known as Stroud Preserve. Dr. Stroud's will stipulated that Stroud Preserve be available as a long-term study site for the Stroud Water Research Center. Scientists from the center have set up experiments on the preserve to evaluate how to create riparian forest buffers and other soil and water conservation practices that can filter out sediments, nitrogen, phosphorus, and other chemicals that threaten downstream waters. Because the Stroud researchers have permanent access to the preserve, they are able to conduct studies that last for years. **Learn more at natlands.org.**

WORKING TOGETHER

RODALE INSTITUTE RESEARCHERS COLLABORATE WITH OTHER SCIENTISTS AND FARMERS TO MAXIMIZE THE VALUE OF THE FARMING SYSTEMS TRIAL

The FST Advisory Board ensures that the research meets the highest scientific standards and remains current with real-world conditions. These experts are current or former of this committee.

Mary-Howell and Klaas Martens, Martens Farm and Lakeview Organic Grain, Penn Yan, New York

Mark Doudlah, Doudlah Farms Organics, Evansville, Wisconsin

Benjamin Banks-Dobson, Hudson Hemp, Hudson, New York

William Curran, Ph.D., Emeritus Professor of Weed Science, Penn State University

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Tom L. Richard, Ph.D., Professor of Agricultural and Biological Engineering, Penn State University

John Teasdale, Ph.D., Lead Scientist, USDA Sustainable Agricultural Systems Laboratory, Beltsville, Maryland

PARTNERS IN SCIENCE

Over the decades, Rodale Institute researchers have joined forces with many other scientific teams to broaden the types of information that can be gleaned from the trial. Listed below are just a few of these partnerships.

In 2019, Rodale Institute contributed to the "North American Project to Evaluate Soil Health Measurements," an effort by the Soil Health Institute to develop and test standardized soil health measurements that can be trusted by farmers, agronomists, and researchers.

Rodale Institute began working in 2018 with Stroud Water Research Center in Avondale, Pennsylvania, on the Watershed Impact Trial, which is studying the impact of organic and conventional agriculture on the water supply and will help encourage water conservation and protection by farmers. (Page 26)

Craig Chase, program manager in Iowa State University's Agriculture and Natural Resources department, has conducted an in-depth economic analysis of the costs and returns on investment for each of the farming systems. (Page 21)

Brad Heins, Ph.D., associate professor in the University of Minnesota Department of Animal Science, has studied and compared the nutritional quality of the food produced by each of the farming systems. (Figure 12 on Page 19)

A new project in partnership with collaborators from University of Delaware, Stroud Water Research Center, Pennsylvania State University, Iowa State University, West Virginia University, North Carolina State University, Dickinson College, USDA Agricultural Research Service, and farmers in different regions of the country will begin in-depth measurements of the nutrient density and protein quality of wheat grown under different management practices.

CORPORATE PARTNERS (IN ALPHABETICAL ORDER)

Blooming Prairie Foundation

Foundation for Food & Agriculture Research

The GIANT Company

Grantham Foundation

Organic Valley

Pennsylvania Department of Agriculture

Rockefeller Foundation

Towards Sustainability Foundation

U.S. Department of Agriculture

William Penn Foundation

Wyncote Foundation

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LOOKING A

So much has changed since the Farming Systems Trial was launched in 1981.

Rodale Institute researchers had already collected 20 years of data by the time the USDA began certifying organic products in 2001. Over the years, the acreage under organic care has been growing steadily, with more than 16,500 certified farms now in the U.S. Sales of organic products to consumers have reached $10 billion, and the demand for certified organic crops still exceeds the supply.

Meanwhile, conventional agriculture has become completely dependent on fertility from fossil fuels, crops genetically modified to withstand powerful herbicides, and pesticides known to be toxins. For four decades, the FST has been documenting the impact of those practices. **The results clearly and consistently demonstrate that organic management protects the health of soil, the crops, the environment, and farmers, while conventional practices inevitably lead to degradation of the soil and diminishing returns for farmers.**

As the longest-running side-by-side comparison of organic and conventional farm management systems in North America, the FST is providing a rare perspective on their short- and long-term effects. Even while collecting consistent data over four decades, the FST has evolved to keep up with changes in farming practices, incorporating reduced tillage for both conventional and organic plots and using cover crops in conventional plots to reflect what many farmers have begun to do. At the same time, the FST has been expanding the scope of its research with studies of water quality and human nutrition.

The many new and experienced farmers taking up organic methods need up-to-date information about how to most effectively grow their crops, manage their resources, and sustain their operations. Three new Rodale Institute Organic Centers—in California, Iowa, and Georgia—are now researching and sharing region-specific information for organic growers in those climates. Rodale Institute's Organic Farmer Consulting Service is helping growers around the country transition to organic practices, navigate the certification process, and apply the knowledge gleaned from the FST's 40 years of research.

The FST results point in one direction: Focusing on soil health and nutrition pays long-term benefits to farmers and consumers. Rodale Institute remains at the forefront of supporting farmers who are committed to improving soil health as well as meeting high standards for animal welfare and social equity. In 2018, Rodale Institute and its partners introduced a Regenerative Organic Certified™ label, which is overseen by the Regenerative Organic Alliance, a nonprofit made up of experts in farming, ranching, soil health, animal welfare, and farmer and worker fairness.

What hasn't changed is Rodale Institute's commitment to growing the organic movement through rigorous research, farmer training, and education. As the FST continues into its fifth decade, it becomes an ever more valuable resource for understanding why and how regenerative organic management is the pathway to securing a healthy future for people and our planet.

AHEAD

WILLIAM PENN FOUNDATION

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