



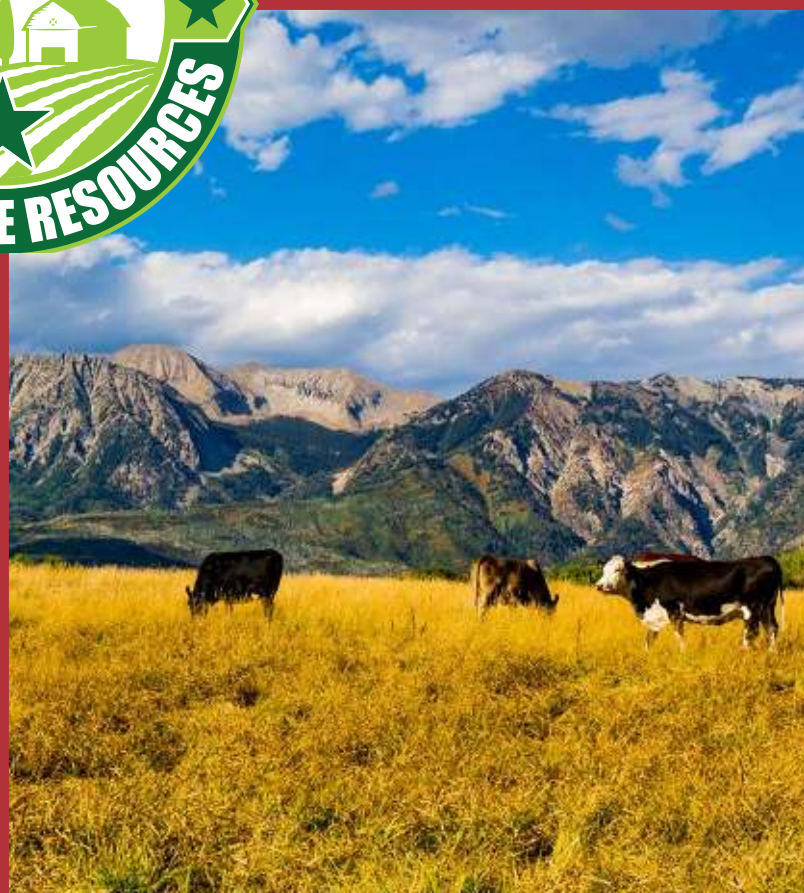
COLORADO
Department of Agriculture
Conservation Services Division

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COLORADO SOIL HEALTH FUNDAMENTALS





Dear Reader,

The Colorado Department of Agriculture is pleased to issue a series of soil health primers in partnership with Acres U.S.A. as part of the Colorado Soil Health Program. This primer is the first of 12 (see the guide to the right). The purpose of these primers, to be available multiple ways for growers in late 2022, is to provide resources for farmers and ranchers interested in improving their soil health. Providing opportunities for all farmers and ranchers to improve their soils is critical to maintaining the vibrancy and resilience of Colorado's agricultural community. The past two decades in the American West have been the driest in several centuries, and aridity and higher temperatures are expected to increase in the future. Market uncertainty will likely continue and food production will continue to face challenges. Helping Colorado farmers and ranchers improve the health of their soil is of utmost importance as soil health practices are affordable, scalable, immediately available, and critical to advancing diversity and productive capacity.

Healthy soils provide drought resilience because they retain more water and are less prone to erosion. Through soil health practices that help increase nutrient cycling, farmers can increase the productivity of land while also reducing labor and input costs. Colorado's producers have long been advocating in support of soil health. Nonetheless, barriers remain to adopting soil health practices and the goal of the Soil Health Program is to reduce these barriers through a voluntary and incentive based framework.

Colorado has a robust legacy of soil conservation and soil stewardship. In the 1930s, Conservation Districts were created to tackle the Dust Bowl. Now, agriculture faces both new and similar environmental challenges, yet healthy soil remains a common denominator for tackling them. With that, in 2019, Colorado Commissioner of Agriculture Kate Greenberg and CDA staff helped launch the Colorado Collaborative for Healthy Soils, a stakeholder advisory group that has been integral to the development of shared soil health advancements. The collaborative successfully passed legislation in 2021, codifying the Soil Health Program in statute. Since then, CDA and its agricultural stakeholders continue to work hand-in-hand to implement and scale the Colorado Soil Health Program.

The Colorado Saving Tomorrow's Agricultural Resources (STAR) is the primary service currently offered under the Soil Health Program. STAR uses a five star rating system that allows farmers and ranchers to evaluate their current production system, identify areas for improvement, document their progress, and share their successes.

The evaluation system assigns points for management activities on an annual basis and scores are converted to a 1 to 5 STAR Rating, with 5 STARs indicating the most ambitious commitment to a suite of practices proven to improve soil health, water quality and water availability. In Colorado, as of 2022, STAR evaluates 11 different cropping systems and grazing lands for soil health. Any Colorado farmer and rancher can fill out a STAR field form on CDA's website to receive a STAR Rating and a free soil health test.

CDA has also launched the STAR Plus program, which works in partnership with Colorado's Conservation Districts to provide financial and technical assistance to farmers and ranchers across the state. In 2022, CDA is working with 130 farmers and ranchers and 17 conservation districts as they implement new practices on one field over three years and consider adopting them across their operation. Participants gain familiarity and expertise with new practices and an increased understanding of the environmental and economic outcomes associated with them.

The STAR program's financial incentives help farmers and ranchers absorb some of the risk of incorporating stewardship practices into their work. By supporting ag producers financially, the STAR program creates a new group of soil health champions in Colorado, who can help spread the word about the effectiveness and ease of implementing stewardship practices in traditional ag operations. Additionally, the STAR seal opens up new market possibilities for producers, by recruiting supply chain partners who recognize the importance of regenerative agricultural practices and who invest in Colorado producers tackling climate change. It also allows consumers to make choices based on the producers' commitment to addressing climate change through thoughtful, intentional action.

STAR Plus also provides significant capacity support, equipment grants, training and other support to conservation districts and eligible entities so they can provide technical assistance to landowners where and when they need it. These partners provide the trusted local support and knowledge to ensure producer success. We hope that you find these primers useful as you learn more about soil health and Colorado's STAR Program. We encourage you to participate in the Colorado Soil Health Program to better prepare for the climate challenges ahead of us.

Sincerely,

Commissioner Kate Greenberg

Summer 2022

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COLORADO SOIL HEALTH FUNDAMENTALS

PRIMER 1: BASICS

PRIMER 1 SUMMARY

The goal of the first installment in the Colorado Soil Health Primer series is to demonstrate the core principles related to soil health management as practiced and researched within the boundaries of the State of Colorado. This project included the participation of Colorado scientists studying the effects of management practices, as well as many Colorado farmers and ranchers stimulating and measuring the changes on the land.

As a disclaimer, this series is not about showing you the exact tactics a farmer or rancher would need to improve soil health. The individual tactics and strategies must change from property to property – or even field to field – depending on the goals of the land manager, and the available natural and financial resources. This primer series will give readers the resources to understand and evaluate practical and proven ideas to explore and adapt into a new or existing operation.

Most importantly, Colorado farmers and ranchers will share the soil health fundamentals – from cover crops to livestock integration – that are working for them. In this primer, we will hear from two different producers: Brendon Rockey, who owns Rockey Farms near Center, Colorado, and has used soil-health fundamentals in a circle-pivot system for more than a decade; and Daniel Fullmer, a vegetable market



▲ Colorado's agriculture industry is unique due to its geography, diversity of practices and range of climate zones (4-7). Source: Colorado Department of Agriculture

grower with river access who has successfully integrated chickens into his operation.

The reasons to change vary as widely as the tactics available to improve soil health. Most are economic. Some are environmental. Many are a combination of the two.

“We started out this way because we wanted to grow a better crop,” Rockey said. “At no point did we ever improve soil health for the sake of improving soil health.”

A secondary goal of the primer will be to build a common vocabulary and understanding of the soil health terms being used across our state's agriculture

industry. Terms like “soil health” can be defined very loosely, and so can the components within the subject.

In this series, the key terms were defined and localized by set of experts, including farmers and Megan Machmuller, who researches soil health and data with Colorado State University, and her colleague, Jim Ippolito, an associate professor of soil health and environmental quality.

“It's not easy to know what we mean when we say ‘soil health,’” Ippolito said. “But we are talking about the broad over-arching concepts that allow us to maximize a soil's physical, biological, and chemical attributes.”

COMMON TERMS

Cover Crops: The act of keeping the ground covered and maintaining living roots are two principles of soil management, and cover crops are a key tool to help farmers transition and measure the gains.

Pasture: Fields for grazing, wildlife passage or soil remediation are common across the state of Colorado.

Soil Biology: The life in the soil, from the smallest microbes to earthworms and dung beetles. The biology is responsible for helping break down organic matter and turning it into available nutrients for your crops.

Soil Chemistry: The ratios of elements in the soil are important and go beyond N-P-K.

Soil Health: The concept of maximizing an ecosystem's ability to feed soil microorganisms, leading to efficient nutrient cycling and turnover, which creates more nutrient availability for plants, increases soil water storage, and improves ecosystem sustainability and resiliency.

Soil Testing: The process of quantifying certain attributes of soil, including macro- and micro-nutrients, soil organic matter, cation exchange capacity, soil biology, water and/or air.

Source: Jim Ippolito & Megan Machmuller, Colorado State University



NACD Soil Management Principles

1. Limit disturbance
2. Keep soil covered
3. Strive for biodiversity
4. Maintain living roots
5. Integrate animals

Increasing drought pressure, a changing agriculture industry and research breakthroughs are powerful forces working together to create a need for better soil health management practices in the state of Colorado.

The drought is one of the biggest reasons, which is turning water into an expensive but essential resource to our state agriculture industry. According to research published in 2022, the previous 22-year stretch was the driest period since at least 800 AD, and both researchers and farmers are seeing the impact directly. As water sources dry up, costs increase dramatically, and yield numbers lag behind historic averages.¹

For the state, water retention and management is at the core of the goals for its farmers and ranchers.

“The push in Colorado is to increase the amount of water being stored in soils,” said Jim Ippolito, an associate professor of soil health and environmental quality at Colorado State University. “That’s the soil health spin. We live in an area of prolonged drought. We want to make every drop of water go a little bit farther, and right now, you do that by putting it in a bank.”

And that bank is our soil. By increasing soil organic matter through management practices and sequestering elements like carbon, Ippolito explained, it allows the ground under our feet to absorb and store more water. How much more? Other arid states – like California – that have studied the effect estimate 10% to 30% water savings if common practices were adopted uniformly.²

Composting, livestock integration, poly-cropping, and cover cropping are the most common ways to create more organic matter, according to the researchers at Colorado State University. The result? More soil organic matter feeds the soil’s insect, invertebrate and microbial life, each of whose real job is to convert the nutrients into available elements for the plant’s rhizosphere to intake and use. The biological population is also important in maintaining the fungal networks, which are also vital in delivering nutrients to cash crops and prairie grasses and everything in between.

It’s not as simple as ensuring that



▲ Colorado’s water for agriculture is fed by four major river systems that are connected to the more than 4,000 lakes and reservoirs: The Platte River (northern Front Range); the Arkansas River (southern Front Range); the Rio Grande River (southern); and the Colorado River (Western Slope). A water system in Delta County is pictured. Source: Colorado Department of Agriculture

biology helps make the chemistry available. Water, or the lack thereof, was the reason farmers in the San Luis Valley, which is surrounded by mountains and sand dunes, began to rapidly move to cover crops, said Brendon Rockey, who operates Rockey Farms near Center. His farm runs an annual rotation of potatoes and cover crops, and like others in his valley, he said once he adopted the practice, he saw his water expenses decrease. When he was just planting barley between seasons, he would use 18 to 20 inches of water for the barley. Now, with his cover crop, he uses only 6 inches annually, and his water usage for his cash potato crop has decreased as well.

“That direct water savings is tremendous,” Rockey said. “That cover crop does so much to add carbon to the soil you end up using less water on the potatoes.”

There is an equal and important goal as well for Colorado soil health: improved economics. The rapid increase in synthetic fertilizer and pesticide costs, up to 700% in some areas in 2022, are prompting rapid changes, both at the producer and industry level. The growth in biological-based

fertilizers is expanding rapidly at a rate of 13.3% per year.³ And practices like cover cropping, which increased by 50% according to the last USDA Census of Agriculture, are now becoming standard operating procedures around the country.

According to the most recent natural cover crop survey, there is a direct correlation between cover cropping and increased yield in corn and soybeans.⁴

“Ultimately, it comes down to the bottom line on how it will affect their operations, and that’s the money,” said Megan Machmuller, a research scientist at Colorado State University. “How much they have to spend and how much they can potentially save, and what that means for the short and the long term.”

The organic food industry is one market signal on the growth of soil health practices, although organic certification and soil management are two unique concepts. The growth in organic agriculture practices has been on a steady trend since 2000, and increased in 2020 across all continents, according to the International Federation of Organic Agriculture Movements.⁵ While the United States does not rank in the

TABLE: Percent increase in yield for corn and soybeans following cover crops versus comparably managed fields with no cover crops

CROP YEAR	CORN	SOYBEANS
2012	9.6%	11.6%
2013	3.1%	4.3%
2014	2.1%	4.2%
2015	1.9%	2.8%
2016	1.3%	3.8%

▲ This chart shows the tested relationship between corn and soybean yields and the new introduction of cover crops to an operation. Source: Sustainable Agriculture Research and Education program. Source: SARE/CTIC National Cover Crop Surveys, 2012-2016.

top four in organic producers globally, the market domestically is the largest by far, making up 41 percent of all organic food sales around the world. The main effects the study highlighted:

- Consumers care more about health and wellness issues related to food supply;

- Supply chain issues will continue to challenge synthetic input production.

“My uncle was actually the one on my farm who sent me a new direction,” Rockey said. “When we made the biggest transition, the end goal was not soil health. We had no idea what soil health even meant. We didn’t know that term even existed. His deal was ... he didn’t want to have to use materials that required personal protection equipment, that was contaminating groundwater, and he would read the warning labels and he would ask, ‘Why are we using this?’ Those tools weren’t available to the previous generation and he didn’t understand why we were so dependent on those now. That said, we also really didn’t know what other step to take other than to remove some inputs. We had to put things together

one step at a time.”

Measuring What You Manage

Measuring what you want to manage is one of the core principles to adopt when transitioning to a more nuanced soil health management system.

While soil health itself is not a measurable term, there are components within a soil health management system that are measurable, including chemistry and biological features. These measurements are then connected to results like water retention and more fertile soils. Measurements can also look for organic matter, and cation exchange capacity, which helps determine the field’s yield potential. And measurements can look at the bottom line as well.

“Understanding how management affects the ecological and economic integrity of an operation is central to the adoption of soil health practices,” Macmuller said. “This requires a holistic approach that quantifies the diverse attributes of soil, how those change throughout time, and ultimately how they influence the bottom line.”

Her colleague Ippolito uses the concept of human health to teach the concept. He asks students to think about it this way: Most humans do not measure their own health with a single indicator; conversely, we use several to determine if we are healthy or if we are sick. What are we eating? How are we exercising? What is our temperature? What is our heart rate? What diseases are we genetically inclined to have?

It’s the same with soil health. There are a number of factors to be considered, and a number of ways to measure what you are doing. For Ippolito, soil organic matter is the place he starts because it adds and traps valuable carbon into the system, among other benefits.

Soil organic matter is the driver for soil health,” Ippolito said. “I’m not an organic-carbon specialist, nor do I claim to be one, but we need to increase soil organic carbon levels and do it correctly. We need to follow a logical, systems approach, as soil organic carbon feeds microorganisms, with those organisms enhancing nutrient cycling and turnover to feed the plants we grow for humans and animals.”

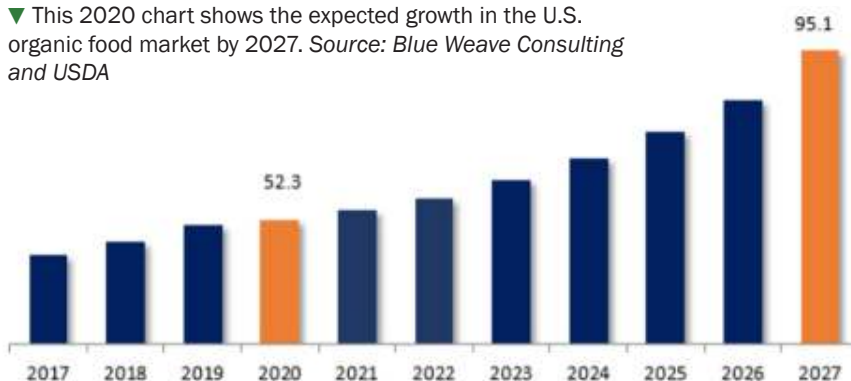
Testing methods can vary between labs. And the need for testing can vary widely between farms and fields. Some test monthly, while others test every few years. Yet, the coordinated nature of the research between farmers and ranchers in the state STAR program underlines the need for better connections between the practices involved with soil health and the proven economic and ecological benefits, both Machmuller and Ippolito agreed.

“In Colorado, we have a lot of farmers performing many practices, but we simply don’t have the research background to support changes they may be observing,” Ippolito said. “That’s why we’re building out a Western U.S. soil health program, to answer questions such as How do you ranch to improve soil health, and what metrics are needed to quantify those improvements?”

Colorado will be testing more than 140 operations that are participating in the STAR program, Machmuller detailed. “We will measure a suite of chemical, biological, and physical soil attributes in the first year and again 3-5 years later to understand how a variety of management practices affects soil function – including microbial activity,

CHART: U.S. Organic Food Market, By Value (USD Billion)

▼ This 2020 chart shows the expected growth in the U.S. organic food market by 2027. Source: Blue Weave Consulting and USDA



nutrient cycling, and water retention,” she explained. She said they will also have soil moisture sensors reporting back high-res data every hour and available to both the producer and the researchers.

“With our data we can show how a shift in management influences water retention. For example, you enhance soil water holding capacity by X percent, which translates into X amount of savings in irrigation water, or your soil holds onto X gallons more than the business-as-usual scenario,” Machmuller added. “Even if you’re not irrigating, your soil can hang onto water this much longer. It can hold X gallons more than the usual business scenario.”

For Rockey Farms’s managers, they are trying to figure out the best way to integrate buckwheat into their existing crops as a companion. While they know the crop helps mobilize phosphorous – a crucial element in photosynthesis and for freeing up calcium – they aren’t sure exactly at what point they will see diminishing returns.

“Can we quantify this?” Rockey asked. “If I had numbers on paper, that would be a great tool to help spread adoption of some of the practices. I know what I’m doing is positive ... but [other farmers] really need to see numbers on paper to believe everything.”

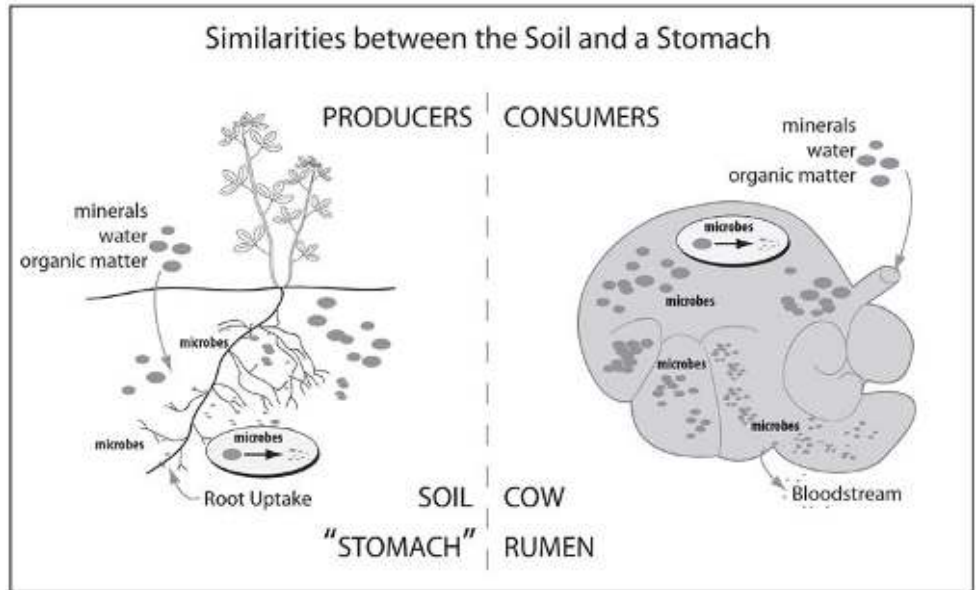
Measuring can go well beyond laboratory data. It can be as simple as using your five senses. Rockey says one of the big philosophical changes in approaching your fields from a soil health perspectives is the time needed in the fields to see, hear, smell, touch and taste what is changing. Walk the field with him and he will show you how to smell, see, and feel, the difference.

“How do you know something is changing if you’re not in your field?” Rockey said.

In his valley in southern Colorado, as farms transitioned to biodiverse cover crops, they also made an astounding discovery they would only make by walking the fields: the cover crops were fighting off parasitic nematodes, expanding the range of savings on time and pesticide applications each year.

Soil Biology & Chemistry

Measuring soil health can be an essential part of the process, but knowing



▲ Soil biology helps break down organic matter to make nutrients available to the plant, similar to the systems in human digestive systems and cow rumens. Source: *The Biological Farmer*

what to do with the data you collect is a different challenge. In areas where soil biology is minimal, or soil chemistry is imbalanced, farmers and ranchers will see other issues like erosion, poor crop quality, invasive species and compaction, Ippolito explained.

Often, one can determine problems with soil biology or chemistry without doing detailed lab work, and instead collect data by walking and observing the crop and soil quality.

“Does it stink like rotten eggs?” Machmuller asked. This often means there is not enough air in the soil and it is creating an anaerobic environment, which isn’t so healthy. Conversely, “Pick up the soil. Are you seeing a good aggregate? Does it smell good?” Machmuller asked.

She continued: “In terms of soil health, we often think of leading indicators versus lagging indicators. Leading indicators are often manifested above ground in your crops. Do they look stressed? Are you supporting more diversity of pasture grasses, or insects or birds? Oftentimes, those indicators are more obvious in the short term than the longer term. Soil can be quickly lost with disturbance, but to rebuild soil takes time and patience.”

With soil chemistry, it often comes from experience. And it can get more complicated than some operators are comfortable with.

“The whole system is tied together, and that’s hard for people,” Ippolito said. “The plant is driving the gradients in water availability, which delivers nutrients, which delivers gradients in nutrient distribution from high concentration to low concentration. And then you talk about microorganisms helping drive nutrients to the plants through mineral dissolution; it’s complicated. People talk about soil health like it’s so easy. It’s not that easy.”

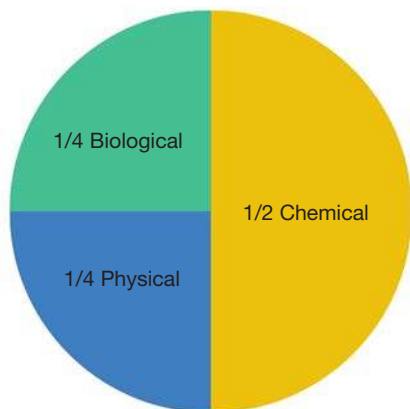
The first step most farmers take when they turn their attention to soil health management is not to focus on what each element does – that’s for agronomists and consultants – but rather to look beyond the traditional N-P-K systems. It takes a network of dozens of elements working together to ensure the plant has what it needs, when it needs it, to both grow and fight off disease. And no matter the chemistry, a healthy system still needs diverse biology, fresh air, and clean water to make it all work. Add a fungal network to the mix, and you have a functional ecosystem with plant-available nutrients, beneficial insects and maximum water storage.

“It’s a 10,000-piece puzzle,” Ippolito said.

Rockey agreed, saying that he saw major acceleration in his soil balancing, biology and chemistry when he started introducing biodiverse cover crops

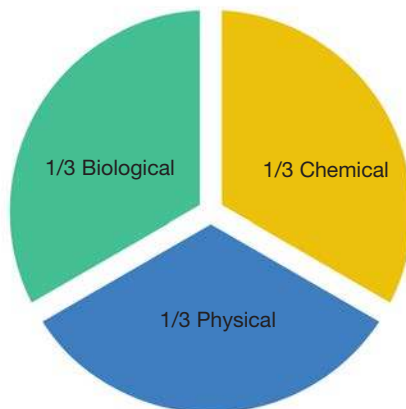
SOIL BALANCE

Chemical - Physical - Biological



SYMPTOMS

1. Harder, more compacted soil
2. Muddy soil that doesn't dry out
3. Small root systems
4. Drought-intolerant crops
5. Unhealthy plants / Poor nutrition for livestock
6. Weed and pest problems
7. Need for more fertilizers
8. More carbon escape



RESULTS

1. Soil easier to work
2. Improved crop quality
3. More efficient use of fertilizers
4. More opportunities for profits

▲ While there will be varieties in the symptoms you see, these are the general traits related to balanced (right) and unbalanced (left) soil. *Source: The Biological Farmer*

and companion crops into his potato rotations.

"Diversity is something I would really emphasize," Rockey said. "If you're already doing a cash crop, do a cover crop and bring in the diversity."

Livestock Integration

"You're either a livestock person, or you're not," is a common phrase in agriculture, and that may never change. Yet, there is a common misconception that goes along with it today, that implies livestock cannot be a part of a healthy ecosystem and healthy soil management system.

Livestock makes up 60% of the Colorado state agriculture economy, and includes more than 2.7 million head of cattle⁶. How livestock can be integrated into the soil health picture is not only an interesting question; the practice could be vital to make sure our state remains economically viable in the agriculture industry.

"Livestock can be positive if they are used long enough," Ippolito said. "We have a study in its sixth year looking at management-intensive graz-

ing and looking at the impacts of soil health. ... The animals are grazing on plants, with the output (i.e., manure) acting like a slow-release fertilizer that helps slowly feed the plants the animals are grazing on."

For Colorado farmer Daniel Fullmer, owner of the Tierra Vida Farm, passive work on his soil was not creating the changes he wanted. He inherited a field with heavy clay, a side effect from the benefits of his nearby access to the Florida River, part of the Lemon Reservoir water system. In his first few years, as he tried to break up the compaction, he used a bed lifter and regularly added a bunch of compost. He saw some gains, but they were slow.

He looked for another step to take and considered poultry, since it has a low cost of entry, low risk, and would help him diversify his market vegetable revenue.

"That was our ah-ha moment," Fullmer said. "I had been trying all sorts of purchased products, sprays and powders, nothing provided much of a benefit. On the other hand we saw tremendous productivity gains by combin-

ing chickens and cover crops."

He said he saw two immediate benefits: the chickens would eat the bugs he didn't want, and they would also provide a high nitrogen content into their fertilizer system. They run the chickens through their large, 30-by-100-foot greenhouses after bringing in ground cover like leaves. He's careful to say that it's not just as simple as adding chickens. It does take management, but he saw an immediate impact – within one year – on plant yield and food quality.

"If I just left the manure on top, it would pile up and get hot and it would be too much, so I brought in leaves from Durango residents, and the chickens would scratch that into the soil," Fullmer explained. "I still can't think of a better way to do it. It was such a remarkable change, we grew more product in that year per square foot than we ever thought was going to be possible."

Other livestock, including cattle, perform the same function of adding soil fertility and biological matter. Rockey has 90 head of cattle and 1,400 head of sheep grazing his fields every year. Insects like dung beetles are positive signs that the introduction of animal waste is improving the ecosystem, Ippolito said.

Inter-Cropping

Inter-cropping, or poly-cropping or companion cropping, means growing more than one species of plant together for beneficial reasons. Diversity in biology can help control pest outbreaks, as well as create a more beneficial root network in the soil.

Inter-cropping as a tool in your soil health system means instituting new practices and mindsets into the operation, including re-imaging what your field looks like. Farmers like Brendon Rockey and Daniel Fullmer will tell you their mindsets are a big part of their systems. A soil health manager thinks about the whole system, including biological life, macro- and micro-nutrients, soil structure, crop biology, wildlife and more. For Rockey, his fields often can look "messy" – his words – to the conventional eye, but those flowering plants sticking up in his potato fields have a distinct purpose. They are no accident.



▲ Walking your fields with your team to explore soil and crop conditions regularly is a recommended soil-health management practice. Source: Colorado Department of Agriculture

He works with a company that researches and designs beneficial cover crops and inter-cropping mixes for his farm. “There aren’t any excuses anymore,” he said. “They will help you by understanding what you want to accomplish and build the right mix.”

As researchers are increasingly coming to understand more and more, the key role of biology is in making nutrients available to the plant, and also in helping regulate disease and pathogen resistance, is partially influenced by the amount of natural, harmonic biology in the system. A 2022 study of high-altitude barley shows that when grown continuously and without biological diversity, two results become apparent:

- Nurture beats nature. Your practice choices matter. These results indicated

that the fungal community responds negatively to the continuous barley cropping but not to other environmental variables, such as temperature and precipitation.

- Diversity builds diversity, but the opposite is true too: Fungi thrive in diverse fields. Continuous barley cropping markedly reduced the fungal richness and phylogenetic diversity.⁷

“If you’re doing monoculture, it’s all or nothing,” Rockey said.

Fullmer agreed. He grows 50 to 60 different plant varieties on his farm. “There’s plenty of minerals in the soil, and if I create the right micro-climate in the soil, that makes them available and allows for good crop growth,” Fullmer said. “I’m assuming that the microbiology in the soil and the rhizosphere is

delivering what the plant needs. My job is to create the condition for it.”

And to create those conditions will require following the fundamentals of soil management and health, no matter how they are applied.

“Most of what I learned was from other farmers who didn’t grow potatoes,” Rockey summarized. “We were implementing the same fundamentals. Those fundamentals are universal.”

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Endnotes

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The biological farmer : a complete guide to the sustainable & profitable biological system of farming/ by Gary F. Zimmer and Leilani Zimmer-Durand. • 2nd ed. Greeley, CO, ACRES U.S.A., 2017. xviii, 518 pp., 28 cm.

The STAR program was originally developed by Champaign County Soil and Water Conservation District (CCSWCD) in Illinois and is now also administered in four other states: Colorado, Indiana, Iowa, and Missouri. The Colorado STAR Plus program grew out of a stakeholder process launched by the Colorado Department of Agriculture and other partners in 2019 that was facilitated by the Colorado Collaborative for Healthy Soils, involved more than 250 stakeholders and resulted in passage of HB21-1181 and SB21-235, which authorized and funded the launch of a state soil health program based around STAR. This state stimulus funding and additional grant funding received from the Gates Family Foundation, Colorado Department of Public Health and the Environment, Colorado Water Conservation Board, NFWF, and NRCS have enabled the launch of the first round of the STAR Plus program.