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Chapter 19
The Dollars and Cents of Soil Health

Charles M. Benbrook

Abstract Soil health is driven by a fluid and dynamic set of factors, many of which arise from above- and below-ground biodiversity and population dynamics. Unless soil depth, nutrients, water, or warmth/sunlight are dramatically limiting, plant health arises from interactions occurring at the root-soil-microorganism interface. In most cases, healthy soils make it far easier to grow healthy plants, while poor soil health makes it more difficult and costly to bring a crop to harvest. Accordingly, the ability to support healthy and profitable crop production is the core attribute of a healthy soil, and slippage in that ability is a direct consequence of declining soil health.

Soil and plant health, management skill, and net farm income are almost always intrinsically linked, especially in the medium to long term. The most significant, soil-health driven economic impacts on net returns per acre typically occur where high-value specialty crops (e.g., tomatoes, peppers, strawberries, celery) are grown and can vary from several hundred to $10,000 or more per acre. In the Pacific Northwest, astute soil-health investments and management can add or subtract several hundred to $2000 or more in profits per acre per year when replanting apple orchards, and also it is critical when converting rough, never-farmed dry land to irrigated vegetable production systems. In the Midwest, success in attaining and sustaining healthy soil can increase annual profits by an estimated $75–$145 per acre.

Keywords Soil health • Organic matter • Soil microbial biocontrol • Economic value soil

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19.1 The Soil Health Continuum

On any given field, crop production and profitability are determined by how skillfully farm managers take advantage of existing soil quality, along with the solar radiation and rainfall (and/or irrigation water) available to nourish a crop. Over several years, management decisions will trigger usually small, incremental changes in soil quality, while changes in soil health can occur more rapidly but also prove more fleeting.

Often, soil-health changes have their roots in shifting pest pressure and population dynamics. Such changes can be brought about because of the emergence of resistant populations, the establishment of a new, invasive species, or the loss of a previously effective pesticide.

Soil health exists along a continuum and is both cropping-system dependent and dynamic. Sometimes soil health alters the speed of water intake and water holding capacity, thereby changing yield outcomes. Likewise, macro- or micronutrient deficiencies, excesses, or imbalances linked to soil health, or big shifts in pH, can also drive profit margins up or down.

It is useful to analyze the typical impact of soil health on the performance and profitability of farming systems in three zones along the soil-health continuum:

- The “limited” zone where a problem or problems grounded in soil health are reducing yields and/or increasing costs relative to other nearby farmers producing a similar crop mix on similar soils
- The “moderate” zone in which soil health does not appear to be triggering any added costs or constraining yields compared to average conditions and cropping system performance in an area
- The “high” zone where enhancements in soil health make possible higher yields in years with ample rainfall; reduce the reduction in yield in dry years; increase N use efficiency, thereby lowering fertilizer costs; and, avoid significant pest-related costs or crop damage

Depending on the cropping system, location, and degree of differences in soil health, average expected net economic returns per acre on a typical field in the “high” zone might be 20–30 % higher, compared to a field in the “limited” zone. Differences in net returns along the soil-health continuum are typically greater in the case of high-value specialty crops, as well as when the performance of a soil in the top 10 % of fields along the continuum is compared to one in the bottom 10 %.

On a given field, soil health may be “moderate” or “limited” in support of the production of certain crops, but “high” if used to produce some other crop, or forages, trees, or vines. For example, raw land with sandy soils that is converted to intensive, irrigated production in the Columbia Basin requires significant compost, animal manure, and other soil-amendment inputs to produce commercially acceptable yields. Sometimes, significant quantities of viable weed seeds are brought onto such fields in improperly finished compost or raw animal manure. As a result, soil health on such fields would be seriously limited in the production of carrots, because of the limited options and high cost of weed management, but might well support a profitable potato or corn silage crop.

This is an example of why soil health is situation dependent. The crop to be grown in the next production cycle; the recent crop rotational pattern, whether a cover crop was planted or crop residues removed the season before; recent soil-amendment applications; and, several other factors *all* play a role in determining the ability of soil to grow a profitable crop in the next production cycle.

Intrinsic, physical, and chemical soil quality characteristics on a given piece of land, like soil type, pH, slope, and bulk density, tend to change slowly, if at all. Routine farm management decisions can either negatively or positively impact soil health, in turn altering crop production, input costs, and net farm income.

Farmers tend to be most acutely aware of changes in soil health when production problems, higher costs, or both undercut per acre profits. These circumstances also increase the odds that farmers will reassess long-standing practices and pencil out changes in management likely to address the underlying cause or causes of soil-health problems.

While slipping yields and profits are bound to attract the attention of farm managers, owners, and bankers, improvements in soil health are infrequently given credit when yields and gross income do better than typically expected.

19.2 Soil-Health and Pest Management Case Studies

In any given year, specialty crop growers must navigate through multiple sources of uncertainty and manage multiple risks that can drive net farm income dramatically up or down. In several years out of 10, specialty crop profit per acre is several thousand dollars lower or higher than projected, and often for reasons at least partially beyond the control of the grower.

While farmers cannot control the weather nor predict demand-supply dynamics, they are responsible for crafting responses to biotic stressors like weeds, nematodes, plant viruses, and recurring insects, any of which can significantly reduce yields and/or crop quality or drive pesticide costs sharply upward.

Over the long term, growers that respond cost-effectively to unforeseen, exogenous stresses in their production fields will make more money than growers who delay responses, respond inappropriately (e.g., adding N when pH, or a micronutrient imbalance is the issue), or overrespond by, for example, replanting a field when other options could have saved a crop.

The following case studies place into perspective the sizable economic consequences that can follow slippage in soil health or accompany sustained enhancement of soil health.

19.2.1 Orange Production in South Australia

Citrus growers in the Riverland-Sunraysia region of Southern Australia have suffered serious losses in fruit quality from Kelly's citrus thrips (KCT), *Pezothrips kellyanus* (Bagnall), feeding from the early 1990s (Crisp 2014). This insect causes scurfing of the surface of citrus and bleaching of the rind, reducing by 20–40 % the packout of export-quality, high-dollar fruit, as well as making some fruit unmarketable.

Depending on weather and population dynamics, one to five applications of organophosphate (OP) insecticides have been used over the last two decades in an effort to control KCT, but efficacy has slipped incrementally as the level of resistance in target populations rose. The industry recognized it was on an insecticide treadmill that would leave no producer standing.

Scientists led by Dr. Peter Crisp at the South Australia Research and Development Institute convinced growers to try a new approach grounded in the biology of KCTs. Composted soil amendments made from animal manures, grape mark, and other plant materials were applied at commercially common rates ranging from 40 kg/ha of animal manure to 200 kg/ha of composted green wastes plus animal manure, to increase soil carbon levels, one proven tactic to support progress along the soil-health continuum.

Emergence of KCTs was reduced more than 50 % in the plots treated with soil amendments in 2006 (Crisp 2014). Other results were dramatic and sustained and included:

- Higher soil moisture levels in treated plots for at least 6 years post application.
- Increased populations of a variety of fungivorous and detritivorous arthropods.
- Twofold to almost sixfold increases in predatory mite levels in the top 2.5 cm of soil.
- Plant-available nitrogen (total Kjeldahl % N) was three to six times higher.
- The percent soil carbon at 0–5 cm rose from 2.8 % to over 7 % and as high as 21.3 % in the 200 cubic meter/ha treatment with grape mark.
- Soil carbon increases in the 5–15 cm layer were about one-half of those in the top 0–5 cm layer.
- Increases in yield averaging over 20 %, and as high as 60 %, persisted for up to 4 years (end of study).
- Fruit size and density (i.e., soluble solids) increased.

Crisp and colleagues reported an estimated 5:1 return over the cost of the soil-amendment treatment. The direct economic benefits of the soil-amendment treatments included an average annual (Crisp et al. 2013):

- Reduction of around two OP sprays annually, at an average cost of approximately $75–$100 (US $$) per hectare for the active ingredient and application
- Substantial reductions in fertilizer and other pest management costs over the useful life of the soil-amendment treatment, after taking into account the cost of the treatment

- Increased gross income on the order of \$1800 per hectare, given the expected ~20 % average increase in marketable fruit, increased packout of export-quality fruit, and average, pretreatment gross income from sale of citrus fruit of about \$9000/ha
- Unquantified environmental footprint benefits arising from lessened OP use and improved water quality and nutrient cycling in the soil

Accordingly, the total, annual economic benefits can be roughly estimated to be ~\$2000 (US \$\$) per hectare (\$810/acre) in a typical year. In years when weather conditions worsen KCT pressure or place trees under moisture stress, the benefits would likely be at least 2-X higher. In years with exceptional well-timed rains and low pest pressure, the benefits/ha would likely be 50–75 % lower.

19.2.2 Vegetables in Florida

In South Florida's fresh market tomato and pepper production systems, gross income per acre generally ranges from \$20,000 (US \$) to \$25,000 per acre. Production costs vary between \$15,000 and \$22,000 per acre in "typical" years. Two factors, above all else, can dramatically alter end-of-the-season net economic outcomes:

- Market price levels and demand when the early season and main crop comes in, as well as whether harvest operations can be prolonged until late in the season when prices typically rise sharply
- Costs and efficacy of control of soil-borne pathogens and especially nematodes that can increase costs by hundreds of dollars per acre and reduce yields by 15–50 % or more

For many years, Florida vegetable growers and their IPM consultants avoided nematode feeding damage in high-value crops by fumigating with methyl bromide and/or chloropicrin. In 2004, 81 % of Florida's 42,000 acres of fresh market tomatoes were treated with both methyl bromide (69 lb active ingredient/acre) and chloropicrin (151 lb/acre), for a total of over 7.5 million pounds of active ingredients (USDA-NASS 2005).

Efforts to reduce agricultural emissions of greenhouse gasses were incorporated in the Montreal protocols, resulting in a negotiated phase-out of methyl bromide use in agriculture. Fumigant use on FLA tomatoes fell to 48 % of acres surveyed in 2006, with a combination of fumigants including dibromochloropropane (1,2-D), metam sodium, and chloropicrin. Reliance fell further in 2010 to 38 % of surveyed acres treated with 1.5 million pounds of a variety of fumigants, an 80 % drop since 2004.

Concern over airborne exposures to farm and field workers, and rural neighbors, led the Florida Department of Agriculture to further tighten already-strict limits on fumigant use. As a result, only about 20 % of tomato acres are now treated with a fumigant, opening up a biological vacuum nematodes have sometimes exploited.

Most Florida vegetable growers are no longer confident they can afford to spray their way through nematode problems, because the chemical tools are either too expensive, only partially effective, or pose unacceptable risks. Just as the case with Kelly's citrus thrips in Australia, the most promising management solution is building soil health and microbial activity to the point where nematode populations are usually kept below damage thresholds.

Microbial biocontrol can be elegant, safe, and profitable when everything falls into place, but efficacy is dependent on a host of factors not under the farmer's control. As a result, farmers moving toward prevention-based, biointensive integrated pest management (IPM) solutions need a broader toolkit of tactics, practices, and inputs to draw upon quickly when nematode populations threaten to spike, despite a promising degree of microbial biocontrol.

Many growers are now nurturing soil and plant health as their primary line of defense and managing biological interactions in ways that target nematodes when and where they are vulnerable. Fortunately, highly selective bio-insecticides are also now available that target a major nematode weakness – their chitin-based outer skins.

Over evolutionary time in the never-ending quest for a solid meal and survival, many microorganisms have evolved the ability to emit enzymes that decompose the chitin-based shells of a variety of organisms from the land (e.g., nematodes) and sea (e.g., crabs, other shellfish). A number of commercial bio-insecticides on the market contain mixtures of enzymes that break down chitin. "Rootgard" is among them and is currently being used by several Florida vegetable growers.

The soil in tomato and pepper fields treated with Rootgard becomes decidedly *unhealthy* to nematodes, but healthier for plants and people. The economic benefits can be impressive. Farmers that forego a traditional soil fumigant application save between $350 and $500 per acre in direct costs and unknown but no doubt significant indirect costs.

Operations applying 200–300 lb per acre of chitin-based products incur costs between $200 and $300 per acre. The yield and crop quality benefits vary across seasons, mostly as a function of population levels and how well applications are timed. Nematode damage can cost a grower up to $10,000/acre in lost production and crop quality, plus control costs. Those who rise to the nematode challenge can increase profits by a comparable margin as a result of:

- Harvesting higher yields
- Reducing the percentage of fruit that does not meet top quality-grade standards
- Keeping plants healthy and productive longer, allowing the grower to carry out a late-season picking when market prices are typically much higher
- Reducing season-long pest management expenditures

Florida vegetable producers who have invested management effort in building healthier soils are able to tap into soil microbial biocontrol as a first and primary nematode line of defense. When such prevention-based systems can be supplemented, as needed, with a cost-effective chitin-inhibiter product, the risks accompanying prevention-based IPM are diminished and average, long-term returns to improvements in soil health will rise.

19.3 Modeling the Impacts of Soil Health on Farming System Economic Performance

Soil quality is intrinsically bounded by the current state of the soil resource on a given farm field – soil depth and composition, organic matter content, nutrient levels, balances in micro- and macronutrient levels, microbial biodiversity, degree of compaction, topography, and available water.

Changes in most soil quality parameters occur slowly, if at all, except in certain circumstances. Unusually high rates of soil erosion will sometimes reduce rooting depth toward or below critical thresholds. Application of a broad-spectrum fumigant will dramatically reduce microbial biodiversity and may shift microbial community structure.

Soil health is a major factor determining the degree to which the productive potential of a given field is taken advantage of fully during a given growing season. Slipping soil health erodes the productive capacity of soils, regardless of their quality, and enhanced soil health will help close the gap between a soil's productive potential and actual outcomes.

Changes in soil health occur over several time frames in multiple dimensions. It is useful to group factors altering soil health into three temporal categories:

- Short-term impacts occurring over a 1- to 3-year time frame
- Medium-term changes that arise over 3–10 years
- Long-term impacts that take 10 or more years to bring about measurable changes in farming system performance

Changes in soil health can alter several soil functional characteristics and as a result also impact farming system performance. Soil health can shift the absolute levels of plant-available micro- and macronutrients, as well as balance across nutrients, with positive, neutral, or negative consequences. Soil health can alter the capacity of soil to take in and hold water, as well as the ability to suppress or otherwise avoid damaging levels of soil-borne pathogens. The presence of weeds, insects, or pathogens that have become resistant to previously effective control measures can erode soil health and farm profits, by driving up pest management costs and/or undermining efficacy.

On most actively farmed fields around the world, soil health is usually improving in some ways and degrading in others. At the end of each production year, the actual economic performance of the farming system, in contrast to the recent past or anticipated performance, is the indictor farmers most closely monitor in judging whether they have a problem rooted in soil health. Unfortunately, high prices, unusually favorable weather, or inputs can sometimes mask incremental erosion in soil health.

The Soil Renaissance Project (SRP), which has evolved into the Soil Health Institute (SHI) (Farm Foundation et al. 2015), recognize that soil health will advance only to the degree that building, or sustaining, high levels of soil health is widely recognized by producers and land managers as a *necessary condition* in order to maximize farm profits per acre. For this reason, the SRP/SHI research agenda will strive to develop the tools and datasets needed to map the linkages between soil health and profitability.

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