

Part III

Soil Health Management



The Soil Health Management Planning Framework

Cornell's Comprehensive Assessment of Soil Health (C.A.S.H.) makes it possible to identify biological and physical constraints in addition to those identified by standard nutrient testing. Soil health constraints beyond nutrient deficiencies and excesses limit agroecosystem sustainability, resilience to drought and extreme rainfall, as well as progress in soil and water conservation.

Each grower is generally faced with a unique situation in the choice of management options to address soil health constraints and each system affords its own set of opportunities or limitations to soil management. A more comprehensive understanding of soil health status can better guide farmers' soil management decisions. However, until recently, there has not been a formalized decision making process for implementing a soil health management system.

Our approach aims to alleviate field-specific constraints, identified through standard measurements, and then maintain and monitor the measurement unit for improved soil health status. To that end, we created a framework for developing Soil Health Management Plans (SHMP) for a farm operation (Figure 3.01).



FIGURE 3.01. The Comprehensive Assessment of Soil Health, used to determine soil health status, is an integral part of the Cornell Soil Health Management Planning and Implementation Framework.



Each grower is faced with unique situations and management options to address each soil health constraint. Growers, usually in conjunction with an Ag Service Provider, will align their needs and abilities to allow for the development of management solutions.

The framework includes:

- Six general steps for the planning and implementation process (Table 3.01, pages 82-86).
- A Comprehensive Assessment of Soil Health report format that more explicitly provides initial interpretation, prioritization, and management suggestions, from which a SHMP can then be developed (page 75 and Appendix A).
- Resource concerns identified through soil health assessment are detailed in a listing specific to each indicator showing constrained soil functioning for which relevant NRCS cost-shared practices may be applied (pages 84-85).
- A pilot SHMP template for such plans that includes purpose, site information, assessment results and interpretation, and planned practices via a multi-year management calendar outlining a specific plan for each field (page 86 and Appendix B).

The soil health assessment, described in Part II, is an integral part of the Cornell Soil Health Management Planning and Implementation Framework that enables farmers, usually with assistance from Agricultural Service Providers, to develop a more direct interpretation of the assessment to guide farm-specific planning and implementation decisions for soil health management systems (Figure 3.02). The process is designed to alleviate field-specific constraints identified through the soil health assessment, and then maintain improved soil health.

The remainder of this section will focus on describing the framework for management planning and implementation, based on information gained from assessments of soil health. A discussion will follow with a summary of the general considerations for management options and opportunities.

A detailed case study¹ demonstrating the Soil Health Management Planning Process is available at the Cornell Soil and Crop Sciences website: scs.cals.cornell.edu

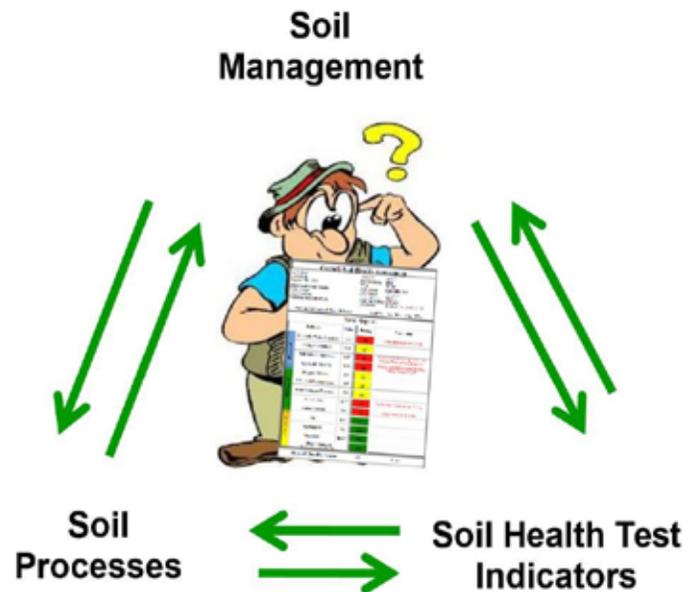


FIGURE 3.02. The soil health report, which identifies constraints and guides prioritization, is just one step in the soil health management planning process.

TABLE 3.01. The six steps of the Soil Health Management Planning Process.

SOIL HEALTH MANAGEMENT PLANNING PROCESS

1. Determine farm background and management history

Compile background info: history by management unit, farm operation type, equipment, access to resources, situational opportunities or limitations.

2. Set goals and sample for soil health

Determine goals and decide on the number and distribution of soil health samples, according to operation's background and objectives (pages 27 and 82).

3. For each management unit: identify and explain constraints, prioritize

The Soil Health Assessment Report identifies constraints and guides prioritization. Explain results based on background where feasible, and adjust priorities.

4. Identify feasible management options

Identify which of the suggestions from Step 3 may be feasible for the operation. For guidance, use the management suggestions table available as part of the Soil Health Assessment Report, or online with [NRCS practice linkages](#) (see page 84).

5. Create short and long term Soil Health Management Plan

Integrate agronomic science of Steps 3 and 4 with grower realities and goals of Steps 1 and 2 to create a specific short-term schedule of management practices for each management unit and an overall long-term strategy (Appendix B).

6. Implement, monitor, and adapt

Implement and document management practices. Monitor progress, repeat testing, and evaluate outcomes. Adapt the plan based on experience and data over time. Remember that soil health changes slowly.

Six Steps of the Soil Health Management Planning Process

The Cornell Soil Health Management Planning Process involves six steps which are described with a brief conceptual example for a corn grain operation here. A worksheet to guide this process is also included at the end of the manual in Appendix B.

1. Farm Background and Management History

Each farm is unique as is each management unit within a farm. In this first step the grower and the Ag Service Provider work together to compile background information. It is critical to first understand the operation's land base, soil types, cropping system, current and past soil management, and the producer's inclinations. Opportunities (such as neighbor's ability to provide manure, easy access to rental equipment, or a son or daughter coming back to the operation with new skills) and limitations (such as having very tight economic margins, having no resources for or access to new equipment, having highly erodible soils, or having a short growing season) need to be identified to guide the planning process.

Step 1. Farm Background and Management History

- Farm is far from dairies so lacks access to manure
- Northern climate with short growing season
- Soil 'addicted to tillage' from decades of use of the moldboard plow, disking and harrowing before annual corn grain
- Access to diverse inventory of equipment
- Grower is very open-minded and willing to try 'anything'

2. Set Goals and Sample for Soil Health

Setting goals facilitates deciding how and where to sample. Typically, soil health sampling falls into one of two categories – sampling for general purposes or for troubleshooting. General field sampling is ideal for establishing a baseline before applying treatments or for areas where you want to assess general needs. Once baseline conditions of the farm are understood, the information can be used to further define problems and opportunities. Troubleshooting samples are more targeted and are ideal for comparing areas with uneven crop performance or different field management units (Area 'A' versus 'B'). With targeted sampling you are trying to answer a particular question. Once the purpose for soil health sampling has been decided, sampling can begin. It is important to collect as much information as possible at this stage to inform the creation of a plan that will fit both the needs of the landowner and the available resources. See page Part II, page 27 for more detail.

Step 2. Goals and Sampling

- Determine what is causing crop growth issues, especially in extremely wet years in a particular field
- Use field diagrams to document representative areas where data on soil performance would provide information useful to troubleshoot growth issues
- Record purposes for sampling each zone

3. Constraints Identified, Explained and Prioritized

The Comprehensive Assessment of Soil Health Report, as described in detail in Part II, measures indicators of agronomically and environmentally important soil processes and then applies scoring functions to interpret measured results in the context of soil conditions and management options (Figure 3.03). The soil health assessment report's color coded results help the user get an overview glance of the field's soil health status. The main benefit of this approach is that the identification of physical, biological and chemical constraints prompts farmers to seek improved – more sustainable - soil and crop management practices. The process links specific constraints in functioning of important soil processes (highlighted in red when the score is below 20), to management solutions through a farmer-centered decision process. Identified constraints should be given the highest priority in targeting management decisions. It is also encouraged to consider improving management for soil processes associated with indicators rated to be functioning sub-optimally (shown in orange), particularly when the score is close to 20. Indicators rated with high scores (light and dark green) should be maintained. Remember, the field's management history can often provide insights that help explain the field's current soil health condition. Step 3 is critical to creating workable management plans. Land managers can monitor changes over time through further assessment, and adapt management plans to achieve chosen goals.

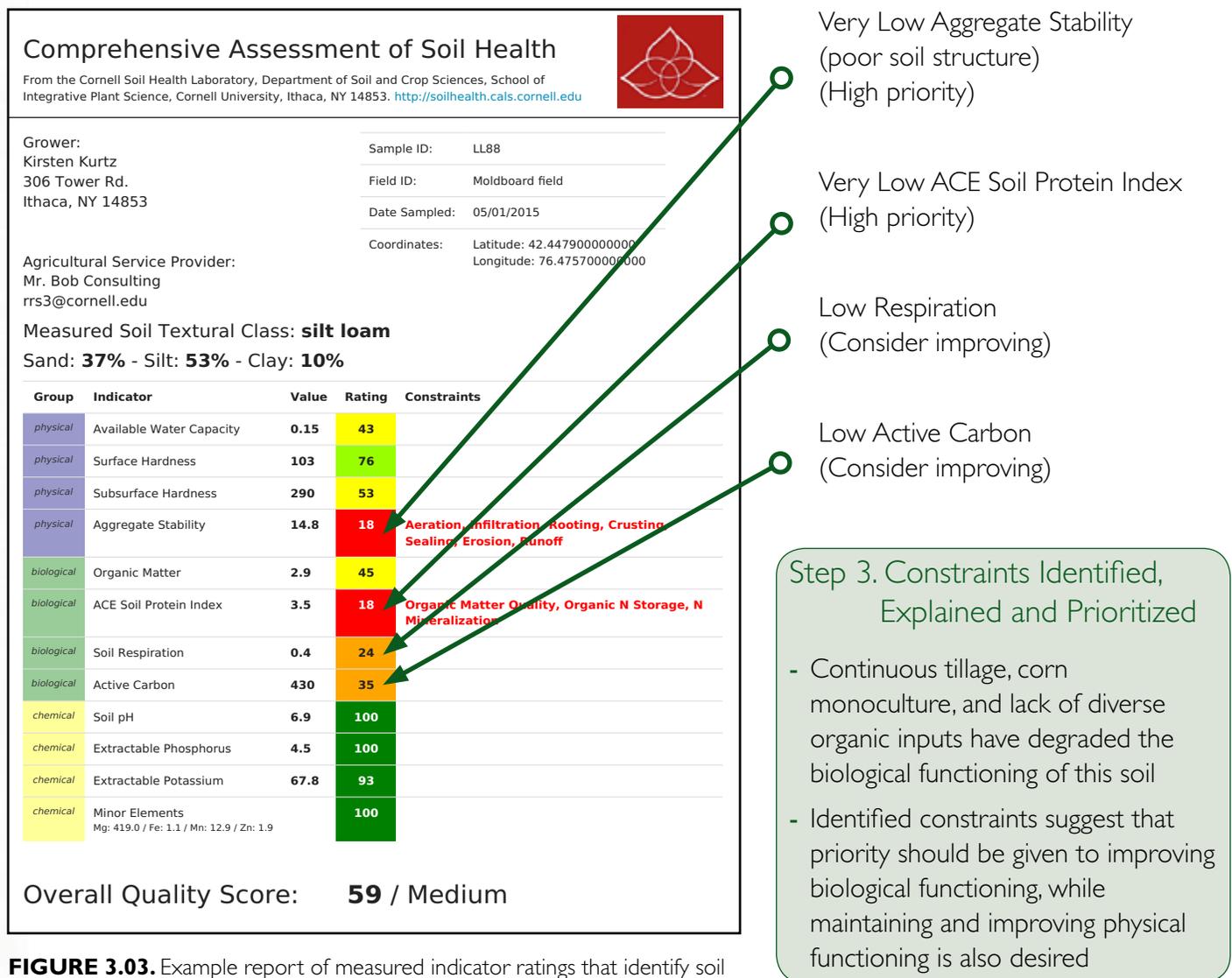


FIGURE 3.03. Example report of measured indicator ratings that identify soil health constraints. For a full sized report see page 73 and Appendix A.

4. Identify Feasible Management Options

Table 3.02, below, and 3.03 on the following page are examples of information included in the soil health assessment report that show recommended management approaches targeted at addressing specific measured soil constraints for both the short- and long-term. Combining these with growers' needs and abilities will allow for an active evaluation scenario and the development of management solutions. In addition, 'success stories' of specific management practices that effectively address targeted soil constraints can enhance the knowledge base of soil management consequences. There are no specific 'prescriptions' for what management regimen should be pursued to address the highlighted soil health constraints, yet we can recommend a number of effective practices to consider when addressing specific constraints. The Soil Health Management Toolbox (page 87) lists the main categories of action for soil management.

Step 4. Identifying Feasible Management Options

- Growing fresh and readily available organic material. Manure is not available to be added, but would have otherwise been an appropriate option
- Reduce tillage intensity
- Rotate with different short season crop to allow for cover cropping
- Identify window for shallow-rooted cover crop mix that includes a legume

TABLE 3.02. Example of management suggestions for Physical and Biological constraints from Figure 3.03 (page 83). Constrained and suboptimal indicators are flagged in red and orange in the report management table. Black text indicates no high-priority constraint.

| Management Suggestions for Physical and Biological Constraints | | |
|--|---|---|
| Constraint | Short Term Management Suggestions | Long Term Management Suggestions |
| Available Water Capacity Low | <ul style="list-style-type: none"> • Add stable organic materials, mulch • Add compost or biochar • Incorporate high biomass cover crop | <ul style="list-style-type: none"> • Reduce tillage • Rotate with sod crops • Incorporate high biomass cover crop |
| Surface Hardness High | <ul style="list-style-type: none"> • Perform some mechanical soil loosening (strip till, aerators, broadfork, spader) • Use shallow-rooted cover crops • Use a living mulch or interseed cover crop | <ul style="list-style-type: none"> • Shallow-rooted cover/rotation crops • Avoid traffic on wet soils, monitor • Avoid excessive traffic/tillage/loads • Use controlled traffic patterns/lanes |
| Subsurface Hardness High | <ul style="list-style-type: none"> • Use targeted deep tillage (subsoiler, yeomans plow, chisel plow, spader.) • Plant deep rooted cover crops/radish | <ul style="list-style-type: none"> • Avoid plows/disks that create pans • Avoid heavy loads • Reduce traffic when subsoil is wet |
| Aggregate Stability Low | <ul style="list-style-type: none"> • Incorporate fresh organic materials • Use shallow-rooted cover/rotation crops • Add manure, green manure, mulch | <ul style="list-style-type: none"> • Reduce tillage • Use a surface mulch • Rotate with sod crops and mycorrhizal hosts |
| Organic Matter Low | <ul style="list-style-type: none"> • Add stable organic materials, mulch • Add compost and biochar • Incorporate high biomass cover crop | <ul style="list-style-type: none"> • Reduce tillage/mechanical cultivation • Rotate with sod crop • Incorporate high biomass cover crop |
| ACE Soil Protein Index Low | <ul style="list-style-type: none"> • Add N-rich organic matter (low C:N source like manure, high N well-finished compost) • Incorporate young, green, cover crop biomass • Plant legumes and grass-legume mixtures • Inoculate legume seed with Rhizobia & check for nodulation | <ul style="list-style-type: none"> • Reduce tillage • Rotate with forage legume sod crop • Cover crop and add fresh manure • Keep pH at 6.2-6.5 (helps N fixation) • Monitor C:N ratio of inputs |
| Soil Respiration Low | <ul style="list-style-type: none"> • Maintain plant cover throughout season • Add fresh organic materials • Add manure, green manure • Consider reducing biocide usage | <ul style="list-style-type: none"> • Reduce tillage/mechanical cultivation • Increase rotational diversity • Maintain plant cover throughout season • Cover crop with symbiotic host plants |
| Active Carbon Low | <ul style="list-style-type: none"> • Add fresh organic materials • Use shallow-rooted cover/rotation crops • Add manure, green manure, mulch | <ul style="list-style-type: none"> • Reduce tillage/mechanical cultivation • Rotate with sod crop • Cover crop whenever possible |

5. Create Short and Long Term Soil Health Management Plans

This step develops the detailed plan that a producer can follow. The plan must address prioritized constraints in a way that is feasible economically and logistically for the producer. Management approaches taken from the soil health management toolbox (page 87) can be used singularly or in combination as the same constraint might be overcome through a variety of management approaches. A specific short-term schedule of management activities is developed for each field or management unit, and an overall long-term strategy and direction is defined. Alternatives for weather contingencies may be listed as well. The options that a grower chooses may depend on farm-specific conditions such as soil type, cropping, equipment, labor availability, etc. It is important to align the agronomic science of Steps 3 and 4 with the grower realities and goals of Steps 1 and 2 to create a specific schedule of management practices for each management unit and an overall long-term strategy in this step. Table 3.04 on the following page provides a template for the Soil Health Management Planning process.

Step 5. Create a Plan

Short Term:

- *Spring*: drill barley, timothy and clover mix (adds fresh, diverse, non-corn derived organic materials and active roots earlier in season than corn)
- *Summer*: harvest barley (produces income)
- *Summer and fall*: mow timothy-clover mix as green manure (adds further and protein-rich organic material)

Long Term:

- *Winter*: learn about strip tillage and prepare to transition soil to reduced tillage system with improved rotation

TABLE 3.03. Example of management suggestions for Chemical constraints from Figure 3.03 (page 83). Constrained and suboptimal indicators, if any, would be flagged in red and orange in the report management table.

Black text throughout this example indicates that there are no high-priority constraints for Chemical indicators.

| Management Suggestions for Chemical Constraints | | |
|---|---|---|
| Constraint | Short Term Management Suggestions | Long Term Management Suggestions |
| Soil pH Low | <ul style="list-style-type: none"> • Add lime or wood ash per soil test recommendations • Add calcium sulfate (gypsum) in addition to lime if aluminum is high • Use less ammonium or urea | <ul style="list-style-type: none"> • Test soil annually & add "maintenance" lime per soil test recommendations to keep pH in range • Raise organic matter to improve buffering capacity |
| Soil pH High | <ul style="list-style-type: none"> • Stop adding lime or wood ash • Add elemental sulfur per soil test recommendations | <ul style="list-style-type: none"> • Test soil annually • Use higher % ammonium or urea |
| Extractable Phosphorus Low | <ul style="list-style-type: none"> • Add P amendments per soil test recommendations • Use cover crops to recycle fixed P • Adjust pH to 6.2-6.5 to free up fixed P | <ul style="list-style-type: none"> • Promote mycorrhizal populations • Maintain a pH of 6.2-6.5 • Use cover crops to recycle fixed P |
| Extractable Phosphorus High | <ul style="list-style-type: none"> • Stop adding manure and compost • Choose low or no-P fertilizer blend • Apply only 20 lbs/ac starter P if needed • Apply P at or below crop removal rates | <ul style="list-style-type: none"> • Use cover crops that accumulate P and export to low P fields or offsite • Consider low P rations for livestock • Consider phytase for non-ruminants |
| Extractable Potassium Low | <ul style="list-style-type: none"> • Add wood ash, fertilizer, manure, or compost per soil test recommendations • Use cover crops to recycle K • Choose a high K fertilizer blend | <ul style="list-style-type: none"> • Use cover crops to recycle K • Add "maintenance" K per soil recommendations each year to keep K consistently available |
| Minor Elements Low | <ul style="list-style-type: none"> • Add chelated micros per soil test recommendations • Use cover crops to recycle micronutrients • Do not exceed pH 6.5 for most crops | <ul style="list-style-type: none"> • Promote mycorrhizal populations • Improve organic matter • Decrease soil P (binds micros) |
| Minor Elements High | <ul style="list-style-type: none"> • Raise pH to 6.2-6.5 (for all high micros except Molybdenum) • Do not use fertilizers with micronutrients | <ul style="list-style-type: none"> • Maintain a pH of 6.2-6.5 • Monitor irrigation/improve drainage • Improve soil calcium levels |

TABLE 3.04. Soil Health Management Planning Process Worksheet. A full version is available in Appendix B.

| Date | Operation implemented | Constraint addressed | Notes |
|--|----------------------------|----------------------|---|
| <i>EXAMPLE:</i> April 2016 | Subsoil with yeoman's plow | Subsoil compaction | Choose appropriate soil moisture conditions |
| | | | |
| | | | |
| | | | |
| | | | |
| <p>Long Term Directions to Pursue:</p> | | | |

6. Implement, Monitor and Adapt

This step is continuous and feeds back into the planning process over time. In this step the grower is implementing the plan from Step 5, documenting actions, successes and failures of management practices, and monitoring progress in problems that were initially identified. This process is critical for continued learning and improved success. The soil health assessment can be used over time to monitor change, measure progress and evaluate outcomes. The soil health management plan becomes a living document that is adapted based on experience and outcomes over time. It is important to remember that soil health has usually degraded over many years or decades, and so building it back up should be expected to take quite some time. Continue to adjust management for continuous improvement.

Step 6. Implement, Monitor, Adapt

- This farmer may find, for example, that the timothy and clover mix is ready to mow earlier or later than initially planned, or may decide that it is worth leaving the mix growing in that field for an additional season for hay, if a nearby market develops



Soil Health Management Options and Opportunities

Once a grower has entered and gone through the initial steps of the planning process, including getting the soil health status and identifying constraints of a particular management unit, the next action is to identify feasible management options.

As has been understood for a long time, soil chemical constraints can be managed through application of amendments such as lime or wood ash for low pH, or fertilizers, manures, and composts to add required nutrients. For soil health management the scope of alleviating constraints and maintaining balance is broadened to also include managing for biological and physical soil process functioning, as was previously discussed for each indicator.

In general the goals are to decrease soil disturbance, and increase soil cover, species diversity, and the portion of time when living roots are growing (NRCS soil health management principles). However, specific practices need to be chosen based on what is known about current soil health status and farm characteristics. Practices may even temporarily need to counter the above principles to most effectively alleviate current constraints, and redirect the system toward building soil health. Practices, especially new ones, need to be implemented thoughtfully and appropriately to avoid failures that can occur, especially in degraded systems. Not all soil management practices are practical or adaptable to all farm situations. Trying out practices on a smaller scale first, and modifying them to suit the particular farm operation is recommended. A lot can be learned from local and regional innovative farmers and researchers, especially when no such information is readily available.

Growers like Donn Branton of Le Roy, New York work with their Ag Service Provider to test their soil health status and guide management decisions.

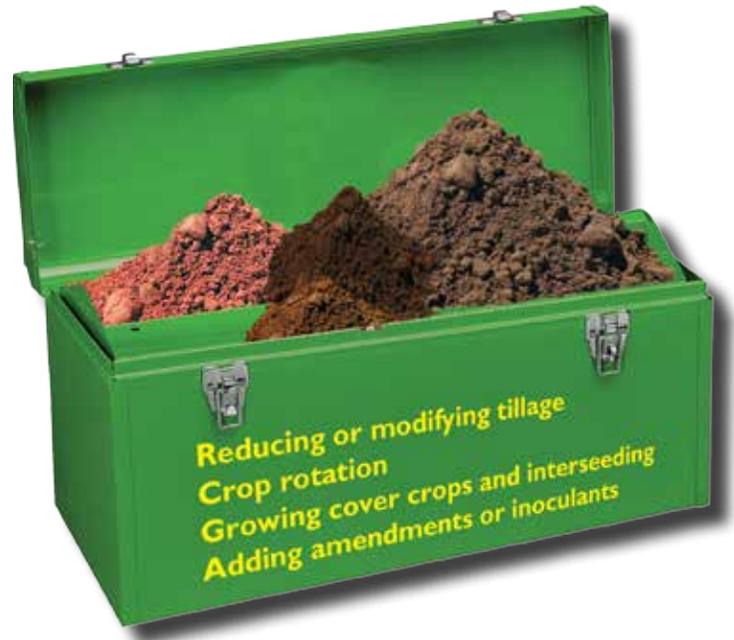


FIGURE 3.04. Four management strategies in the Soil Health Management Toolbox.

The Soil Health Management Toolbox

There are four main management strategies for improving soil biological and physical health in annual or mixed production systems: reducing or modifying tillage, rotating crops, growing cover crops or interseeding, and adding amendments or inoculants (Figure 3.04).

The options within each strategy are numerous and the combinations are endless. In livestock systems, there are additional modifications to grazing strategies that can be employed. These are beyond the scope of this manual at this time, although the same soil health concepts and principles can be applied to these systems.

Adopting broader soil health management systems is particularly critical to our agriculture as extreme weather conditions are increasing due to our changing climate. Soil health management facilitates both adaptation to extreme and changing conditions, and coincidentally also mitigation of these changes.

Information and additional resources can be found in Part IV, beginning on page 103.

General Management Considerations from the Toolbox

Tillage Considerations

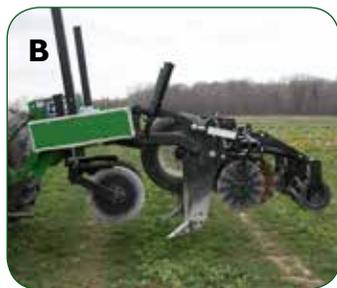
As new technologies have been developed, the reliance on full width tillage to kill weeds, incorporate crop debris and amendments, and prepare seedbeds has been diminished. At the same time, we now have a better understanding of how critical decreasing soil disturbance is for diverse and active biological activity that is critical for well-functioning, healthy soil. Extensive tillage temporarily stimulates certain species making up the microbial community to ‘burn off’, or decompose, organic matter quickly. This reduces soil aggregation, resulting in crusting and soil compaction, in addition to decreased beneficial microbial activity. It is now well understood that reducing tillage intensity, and mechanical soil disturbance in general, can improve soil health and, over time, maintain or even increase yields, while reducing production costs due to saved labor, equipment wear, and fuel.

There are many different strategies for reducing tillage intensity

- **No Tillage:** A no-till planter or transplanter does minimal soil disturbance to plant the crop (Figure 3.05 A). This is true, “single-pass” planting.
- **Ridge Tillage:** Crops are planted into minimally disturbed ridges that generally remain in the same place. Only surface soils are disturbed when ridges are rebuilt annually around the planted crop.
- **Strip Tillage:** A shank set just below the depth of the compacted layer (if present, B) rips a compacted layer while a series of coulters forms a narrow, shallow ridge in preparation for planting (C). Plants are later sown into tilled strips with a pass of the planter.
- **Zone Tillage:** Similar to strip tillage, but without the rip shank, which is not necessary when you lack subsoil compaction. Instead of preparing the entire field as a seedbed, only a narrow band is loosened by zone and strip tillage, enabling crop or cover crop residue to remain on the soil surface as a mulch. In single pass planting, the strips are simultaneously prepared and the seeds are sown.
- **Permanent drive rows:** Drive rows are particularly possible with new GPS enabled technologies and often better facilitates reduced tillage systems.
- **Roller crimpers, rotovators:** These are being developed to be set to disturb only the surface inch of the soil, and other minimal disturbance methods for managing spring cover crops.
- **Cover crop interseeders and no-till drills:** These may be used to avoid additional tillage passes for establishing cover crops.
- **Frost Tillage:** Frost Tillage can be a means of alleviating soil compaction or injecting manure in the winter. It is done when the soil is frozen between 1 and 3 inches deep. Such conditions generally only occur on a few days per winter, depending on location and year in the Northeast (D).



(A) No-till planted sweet corn into a killed sweet clover fall cover crop.



(B) Two-row strip tillage unit with an opening coulters, followed by a vertical shank, two closing coulters to form a small ridge then a rolling basket to prepare the ridge for planting.



(C) Strip tillage with a vertical shank followed by two wavy coulters.



(D) Soil following frost tillage. The large clods will mellow and break down as a result of subsequent freeze-thaw action.

FIGURE 3.05 A-D. Examples of different reduced tillage systems.

Frost Tillage (continued): The soil below the frost layer is non-plastic or dry, ideal conditions for tillage without compaction. Frost-tilled soil leaves a rough surface, but subsequent freeze-thaw action loosens the soil and allows the clods to fall apart in the spring, so that it is ready for an early spring crop.

Details about benefits and disadvantages of different strategies can be found in [Building Soils for Better Crops](#) and other resources. A summary table is below (Table 3.05).

Reduced tillage can be used for all crops, or it can be part of a rotation, modified based on the cropping sequence. Different tillage practices can be rotated depending on crop and soil management goals and concerns.

For some crops such as potato, more intensive tillage and soil disturbance is generally used to establish and harvest the crop, although some growers even plant potatoes using zone tillage. The subsequent sweet corn (or other) crop(s) may be more easily strip- or no-tilled into a killed winter cover crop.

The type and timing of tillage are site-specific and dependent on the cropping system and equipment availability. Reducing both tillage frequency and intensity will reduce the loss of organic matter and lead to improved soil aggregation and microbial activity. This will result in soils that are less susceptible to compaction and other soil health problems, and more resilient to extreme weather.

TABLE 3.05. Tillage System Benefits and Limitations. Modified from: *Building Soils for Better Crops, 3rd Edition*

| Tillage System | Benefits | Limitations |
|---------------------------|---|--|
| Full-Field Tillage | | |
| Moldboard plow | <ul style="list-style-type: none"> Easy incorporation of fertilizers and amendments. Buries surface weed seeds and also diseased debris/pathogen surviving structures. Dries soil out fast. Temporarily reduces compaction. | <ul style="list-style-type: none"> Leaves soil bare. Surface crusting, lack of infiltration and water storage, and accelerated erosion is common. Destroys natural aggregation and enhances organic matter loss. High energy requirements. Causes plow pans. |
| Chisel Plow | Same as above, but with more surface residues. | Same as above, but less aggressive destruction of soil structure, less erosion, less crusting, no plow pans, and less energy use. |
| Disc harrow | Same as above. | Same as above, but additional development of disk pans. |
| Restricted Tillage | | |
| No-till | <ul style="list-style-type: none"> Little soil disturbance and low organic matter losses. Few trips over field. Low energy use. Most surface residue cover and erosion protection. | <ul style="list-style-type: none"> Harder to incorporate fertilizers and amendments, but new injection equipment is being developed. Wet soils slow to dry and warm up in spring. More challenging to alleviate compaction without tillage options. Higher disease and weed pressure if not combined with appropriate rotation and cover cropping. |
| Zone-till/ Strip-till | Same as above. | Same as above, but fewer problems with compaction and cold spring soils. |
| Ridge-till | <ul style="list-style-type: none"> Easy incorporation of fertilizer and amendments. Some weed control as ridges are built. Zone on ridge dries and warms more quickly for better germination. | <ul style="list-style-type: none"> Hard to use together with sod-type or narrow crop rotation. Equipment needs to be adjusted to travel without disturbing ridges. |

Crop Rotation Considerations

Initially, crop rotation was practiced as a way to avoid depleting the soil of various nutrients and to manage pathogens and pests. Today, crop rotation is also an important component of soil health management in many agricultural production systems. Crop rotations can be as simple as rotating between two crops and planting sequences in alternate years or they can be more complex and involve numerous crops over several years or even at the same time for improved soil health. Proper crop rotations generally increase species diversity, and reduce insect pressure, disease-causing pathogens, and weed pressure by breaking life cycles through removal of a suitable host or habitat. Additionally, crop rotation can improve nutrient management and improve soil resiliency (to drought, extreme rainfall and disease) especially after root crops such a carrot or potato that usually involve intensive tillage. Generally yield increases when crops in different families are grown in rotation versus in monoculture (referred to as the “rotation effect”).

One basic rule of crop rotation is that a crop should not follow itself. Continuous mono-cropping generally results in the build-up of disease causing pathogens, nematodes, insects and weeds that can lead to yield reductions and the need for increased inputs such as herbicides, insecticides and other pesticides. A cropping sequence for soil health management should include the use of cover crops and/or season-long soil building crops. Rotating with a diversity of root structures and make-ups, from taproots to fibrourooted crops from a variety of plant families, will also improve the soil’s physical, chemical and biological health and functioning. Note that successful crop rotation sequences are farm specific and depend on unique combinations of location and climatic factors, as well as economic and resource limitations.

The following page contains a list of general principles for crop rotation.



Wheat is a good rotation crop in an intensive vegetable production rotation especially if Northern root-knot nematode is a problem. All grain crops are non-hosts for *Meloidogyne hapla*.

General Principles for Crop Rotation

- **Grow the same annual crop for only one year**, if possible, to decrease the likelihood of insects, diseases, and nematodes becoming a problem.
- **Don't follow one crop with another closely related species**, since insect, disease, and nematode problems are frequently shared by members of closely related crops.
- **Use crop sequences that promote healthier crops.** Some crops seem to do well following a particular crop (for example, cabbage family crops following onions, or potatoes following corn). Other crop sequences may have adverse effects, as when potatoes have more scab following peas or oats.
- **Follow a legume forage crop, such as clover or alfalfa, with a high nitrogen-demanding crop**, such as corn, to take advantage of the nitrogen supply. Grow less nitrogen-demanding crops, such as oats, barley, or wheat, in the second or third year after a legume sod.
- **Use crop sequences that aid in controlling weeds.** Small grains compete strongly against weeds and may inhibit germination of weed seeds, row crops permit mid-season cultivation, and sod crops that are mowed regularly or are intensively grazed help control annual weeds.
- **Use longer periods of perennial crops, such as forages, on sloping land, highly erodible soils, or soils where intensive tillage is required to establish annual crops.** Using sound conservation practices, such as no-till planting, extensive cover cropping, or strip-cropping (a practice that combines the benefits of rotations and erosion control), may lessen the need to grow perennials.
- **Grow a deep-rooted crop or cover crop**, such as alfalfa, safflower, sunflower, sorghum sudan grass, or radish, as part of the rotation. These crops scavenge the subsoil for nutrients and water. Channels left from decayed roots can promote water infiltration and access to subsoil water and nutrients by following crops.
- **Grow some crops that will leave a significant amount of residue**, like sorghum or corn harvested for grain, to help maintain organic matter levels.
- When growing a wide mix of crops - as is done on many direct marketing vegetable farms - **try grouping crop mixes into blocks according to plant family, timing of crops (all early season crops together, for example), type of crop (root vs. fruit vs. leaf), or crops with similar cultural practices** (irrigated, using plastic mulch) to facilitate integrating cover crops.
- The SARE publication [Crop Rotations on Organic Farms](#) has more information that is useful for conventional as well as organic systems.

Modified from: *Building Soils for Better Crops, 3rd Edition*

Cover Cropping Considerations

Cover crops are usually grown for less than one year. They provide a canopy, organic matter inputs, increased species diversity, and living root activity for soil protection and improvement between the production of main cash crops. They can also be interseeded between some main crops. They can be grown as monocultures, or as mixes of two or many more species. When specifically used for improved soil fertility (often by incorporating), cover crops are also referred to as green manures. However it should be noted that often the greatest benefits are derived from cover crops that are terminated in place as this prevents damaging soil disturbance, and allows roots to decompose in the field and create continuous pores. Roots are also generally more effective at contributing to soil organic matter than above ground biomass.

Cover crops with shallow fibrous root systems, such as many grasses, build soil aggregation and alleviate compaction in the surface layer. Cover crops with deep tap roots can help break-up compacted layers, bring up nutrients from the subsoil to make them available for the following crop, and provide access to the subsoil for the following crop via root channels left behind. Cover crops can thus recycle nutrients that would otherwise be lost through leaching during off-season periods. Leguminous cover crops can also fix atmospheric nitrogen that then becomes available to the following crop. Other benefits from cover crops include protection of the soil from water and

When selecting cover crops it is important to consider:

- What are your goals for using the cover crop(s)? Which constraints are you addressing, or which aspects of soil health are you aiming to maintain?
- Where can cover crops fit into the rotation? Summer, winter, season-long, interseeded?
- When and how should the cover crop be killed or incorporated? Winter-kill vs. chemical applications vs. rolled or chopped?
- What cover crops are suitable for the climate?
- What cover crops fit with the current production practices including any equipment constraints?
- What is the susceptibility or host status of the cover crop to major pathogen(s) of concern on your operation?

wind erosion, improved soil aggregation and water storage, suppressing soil-borne pathogens, supporting beneficial microbial activity, increasing active and total organic matter, and sequestering carbon.

Dead cover crop material left on the soil surface can become an effective mulch that reduces evaporation of soil moisture, increases infiltration of rainfall, minimizes temperature extremes, increases soil organic matter, and aids in the control of annual weeds. Leguminous cover crops suitable for the Northeastern US include various clovers, hairy vetch, field peas, alfalfa, and soybean, while popular non-leguminous cover crops include rye, oats, wheat, oilseed radish, sorghum Sudan grass, and buckwheat. Additional resources for cover crop species that can be used for building soil health are included in Part IV of this manual.



Winter wheat after unseasonable rainfall.

Winter cover crops

Winter cover crops are generally planted in late summer to fall, typically following harvest of a cash crop. Certain grasses, legumes, and other cover crops can be planted. Some crops like buckwheat, radishes, and oats will be winter-killed, so they are a good option before a cash crop planted in early spring, or when termination options are limited (Figure 3.06).

Other winter cover crops will require termination in the spring via tillage, rolling, herbicides or other early spring management prior to the planting of the next cash crop. These can also produce biomass and help protect and dry out the soil in favorable conditions. Winter cover crops are a good option before main crops planted in late spring or early summer, or when there are good termination options, including spring grazing or forage harvest. Although in northern climates the choices are limited by the short growing season, planting a winter cover crop can provide protection from soil erosion, suppression of weeds and root pathogens, contribution of nitrogen to the next crop, and increased soil organic matter and aggregation. For late harvested crops, winter cover crops might be better interseeded into the cash crop, allowing for a larger range of options (especially for including legumes), since interseeding can occur much earlier. Some winter cover crops commonly planted in the Northeast include winter rye, hairy vetch, oats, wheat, red clover, radish, and various mixtures of the above (Figure 3.07, following page).



FIGURE 3.06. A radish cover crop will winter kill. Desiccated roots will create channels in the soil surface, improving infiltration, surface drainage and soil warming
Photo credit: Troy Bishopp

Season-long cover crops

Full season cover crops serve as rotational crops and are an excellent way of accumulating a lot of plant biomass to build organic matter, alleviate compaction problems, feed the soil microbial community and suppress disease. However, this often means taking the field out of cash crop production for a season. This will especially benefit fields with low fertility, farms with limited access to manures and other sources of organic amendments, or farms that can use this cover crop as a forage for livestock.

Relay cover cropping is also another option. This is when a cover crop such as red clover is spring seeded into wheat, and then continues to grow after the wheat crop is harvested. It is important to keep in mind that some cover crops such as buckwheat, ryegrass, crown vetch and hairy vetch have the potential to become a weed problem if they set seed.

Summer fallow cover crops

Summer fallow cover crops are more common in vegetable than field crop rotations. A fast growing cover crop can be planted between vegetable crops. For example, buckwheat can be grown after early spring lettuce and prior to planting a crop of fall broccoli. This option is severely limited in the north by the short growing season. In shorter season climates, a more successful option may be to interseed a cover crop into the main crop once the latter becomes established, but it is important to avoid competition by the cover crop for water and nutrients.



FIGURE 3.07. Mix of winter rye, wheat, barley, and hairy vetch. Cover crop mixes are an excellent way of accumulating plant biomass to build organic matter, alleviate compaction problems, feed soil microbes and suppress disease. Photo credit: Dorn Cox

Cover crop mixes

Cover crop mixes are getting increasing attention these days, as it is being recognized that greater plant diversity also increases microbial community diversity and functioning. Grass and legume combinations have long been used (as for example oat-pea mix in the fall, or rye-vetch mix over winter), but “cover crop cocktails” that often include eight or more species of various grasses and legumes are being increasingly evaluated by farmers and researchers alike. There are several reasons for this approach:

- 1) Different cover crops provide different benefits, so mixes can be chosen to improve a larger number of soil functions. For example a legume (for nitrogen contributions), a shallow rooted grass (for improved aggregation and to alleviate surface hardness), and a deep rooted crop such as radish (to alleviate subsoil compaction) can be combined to achieve all of these benefits.
- 2) Depending on weather factors, some species may do better in a given year than others. Seeding a mix of many species ensures that at least some of these species can take advantage of the prevailing weather conditions.
- 3) Because different species have different root architectures and growth habits, various niches can be occupied, so that often more biomass is produced by a mix of species than by a single species.

The SARE publications [*Managing Cover Crops Profitably*](#) and [*Building Soils for Better Crops*](#) have additional, useful information (see Part IV).

Four common cover crops in the Northeast:

Winter rye (*Secale cereale*) is very winter hardy and can be seeded late into the fall after late harvest crops (Figure 3.08 A). It can serve as a nutrient catch crop, reduce erosion, increase organic matter, suppress weeds, reduce soil-borne pathogen populations. It can be sown with legumes if desired, but it has also been found to somewhat inhibit the growth of certain crops following it. Rye will grow aggressively in spring and sometimes may need to be quickly killed before it matures to reduce potential weed problems, deplete soil moisture and immobilize nitrogen. Rye can be incorporated as a green manure, mowed, rolled, or killed with an herbicide in reduced tillage systems, preferably several weeks prior to planting the main crop. Some farmers have had great success no-till planting soybeans into rolled rye (page 100).



Winter rye (*Secale cereale*)

Oat (*Avena sativa*) is not winter hardy in the Northeast. However in early spring the killed oat biomass can serve as mulch for weed suppression (B). It can be mixed with a legume and also be used to prevent erosion, scavenge excess nutrients, add biomass, and act as a nurse crop. A nurse crop is an annual crop used to assist in the establishment of a perennial crop.



Oat (*Avena sativa*)

Sudan grass and sorghum sudan grass hybrids (*Sorghum bicolor* x *S. bicolor* var. *sudanese*) are fast growing during warm weather, although they are not winter hardy in the Northeast (C). However, in early spring the killed biomass can serve as mulch for weed suppression. It can be used as a soil builder, subsoil loosener and weed suppressor when sown at high rates. When used for their biofumigant properties, incorporating young tissue (1 to 3 months old) when the soil is warm (microbially active) is recommended, especially for control of plant-parasitic nematodes. To promote increased root growth, it should be mowed or grazed multiple times during the growing season.



Sudangrass and sorghum-sudan-grass hybrids (*Sorghum bicolor* x *S. bicolor* var. *sudanese*)

Hairy vetch (*Vicia villosa*) is an excellent spring biomass producer and leguminous nitrogen contributor therefore making it good for weed suppression and as a nitrogen source (D). It improves topsoil tilth by reducing surface crusting, ponding, runoff, and erosion. In the Northeast, it needs to be planted by late summer for good establishment and overwintering.



Hairy vetch (*Vicia villosa*)

FIGURE 3.08 A-D. Common cover crops in the Northeast.

Organic Amendment Considerations

Organic matter is critical for maintaining balanced soil biological communities, as these are largely responsible for maintaining soil structure, increasing water infiltration and building the soil's ability to store and release water and nutrients for crop use. Organic matter can be maintained better by reducing tillage and other soil disturbances, and increased by improving rotations and growing cover crops as previously discussed. Organic materials can also be added by amending the soil with composts, animal manures, and crop or cover crop residues imported to the field from elsewhere. The addition of organic amendments is particularly important in vegetable production where minimal crop residue is returned to the soil, more intensive tillage is generally used, and land is more often a limiting factor making the use of cover crops more challenging. Various organic amendments can affect soil physical, chemical and biological properties quite differently, so decisions should be based on identified constraints and soil health management goals. Organic amendments derived from organic wastes should not only be tested for nutrients, but also for contaminants such as heavy metals.

Animal manure

Applying manure can have many soil and crop health benefits, such as increased nutrient levels (nitrogen, phosphorus, and potassium in particular, but also micro-nutrients) as well as easily available carbon that will benefit the soil microbial community (Figure 3.09). Not all manures are equal however. Manure nutrient and carbon contents vary depending on the animal, feed, bedding, and manure-storage practices. Manure containing a lot of bedding is typically applied as a solid, while manure with minimal bedding is applied as a liquid. Manure solids and liquids may be separated, and solids can also be composted prior to application to help stabilize nutrients, especially nitrogen. Due to the variability in nutrient content, manure analysis is beneficial and takes the guesswork out of estimating manure nutrient content and characteristics.



FIGURE 3.09. Applying manure can have many soil and crop benefits.

Manuring soil can increase total soil organic matter, cation exchange capacity and water holding capacity over time, and fresh uncomposted manure, especially when solid, is very effective at increasing soil aggregation. Careful attention should be paid to the timing and method of application to meet the needs of the crop or cropping sequence. Excessive or untimely application can cause plant or soil damage, food pathogen concerns, or degraded water resources.

Compost

Unlike manure, compost is very stable and generally not a readily available source of nitrogen, but it is important to recognize that phosphorus remains highly available. The composting process uses heat and microbial activity to quickly decompose simple



FIGURE 3.10. The stable products of composting are an important source of OM.

compounds like sugars and proteins, leaving behind more stable complex compounds such as lignin and humic materials. The stable products of composting are an important source of organic matter (Figure 3.10). The addition of compost increases available water holding capacity by improving organic matter content and pore space that holds water. It also improves cation and anion exchange capacities, and thus the ability for nutrients to be stored and released for plant use. Compost is less effective at building soil aggregation than fresh manure, because the readily-degradable organic compounds have already been decomposed, and it is the microbial process of decomposition that helps build aggregates. Composts differ in their efficiency to suppress various crop pests, although they can sometimes be quite effective. Compost should not be used alone to meet crop nitrogen demand, as this will result in over-application of phosphorus, and thus can increase environmental risk. Properly produced composts are safe to use on human food crops with respect to pathogens.

Crop and cover crop residues

Crop or cover crop residue (whether grown in place or imported from a different field) is usually referred to as “green manure” and is another important source of organic matter (Figure 3.11). Green manure cover crops can be grown specifically to improve soil fertility, organic matter content, and microbial diversity and activity. Crop residues and green manures can either be incorporated or left on the surface to protect the soil against erosion and disturbance, and to improve surface aggregation (Figure 3.12). This results in reducing crusting and surface compaction. A soil with better aggregation (aggregate stability) is more resilient in heavy rain storms and is capable of greater water infiltration and storage. However, diseased crop debris can harbor inoculum that can become a problem during the next season if a susceptible crop is planted. Crop rotation with non-host crops belonging to different plant families, and/or the appropriate use of cover crops will reduce pathogen inoculum. Removal and composting of diseased crop debris may be an option in some situations. Incorporation or plowing down of crop debris to encourage the decomposition process may be an option depending on the tillage system and crop rotation sequence.

Other Sources of Organic Amendments

- Municipal wastes (yard debris, biosolids, municipal composts)
- Organic wastes from food processing industries
- Organic wastes from paper mills, timber industry and brewing facilities
- Post-consumer food wastes (home, restaurant, and institutional)



FIGURE 3.12. Residue mulch on surface. Crop residues can either be incorporated or left on the surface to protect the soil against erosion and disturbance. *Source: USDA-NRCS*



FIGURE 3.11. Crop residues (green manure) can improve soil fertility, OM content, and microbial diversity and activity. *Photo credit: Jeff Vanuga, USDA-NRCS*

Considerations for adapting to and mitigating climate change

Soil health management provides an opportunity to increase profits and decrease risks through adaptations to a changing climate, and to contribute to solving this critical environmental issue.

Throughout the long history of life on Earth, soil organisms, plants, and other living things have played a major role in the cycling of three important greenhouse gases: carbon dioxide (CO₂), nitrous oxide (N₂O), and methane (CH₄). In our atmosphere, these gases trap heat that otherwise would escape. For many millions of years the concentrations of these gases were relatively constant and created a planet with a comfortable average temperature of about 59° F, which has promoted the abundant life we are familiar with. Since the Industrial Revolution, however, all three of these gases have been steadily on the rise, leading to a rapid pace of climate change that is affecting natural ecosystems and agriculture worldwide (Figure 3.13).

Soil organisms, plants, and animals are important as both sources (producers) and sinks (absorbers)

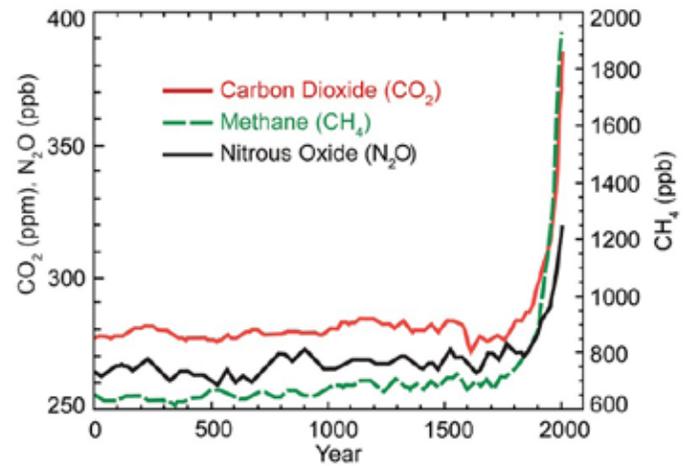


FIGURE 3.13. Greenhouse gas concentrations have been rising significantly since the Industrial Revolution. Source: IPCC Fourth Assessment Report (2007)

of greenhouse gases. How we manage our soils, crops, and livestock will thus play a major role in determining the future pace of climate change, with implications for farming and food security. We can mitigate (decrease the magnitude of) these impacts – particularly the impacts of CO₂ and N₂O – through better soil health management, and at the same time build resistance and resilience, so that our systems are better adapted to these changes.

Soil health management for carbon sequestration: capturing and storing carbon in soils

Many of the practices emphasized in this manual for increasing soil organic matter and improving soil health also increase soil carbon (since organic matter is mostly carbon). This carbon stored (“sequestered”) in soil is carbon that otherwise would be in the air as the greenhouse gas, carbon dioxide (CO₂).

- **Winter cover cropping and growing perennial forages or other vegetation** increases the annual carbon capture from the atmosphere (via photosynthesis), and some of this carbon remains in the soil as organic matter.
- **Reducing tillage** slows decomposition of soil organic matter and release of CO₂ into the atmosphere. Also, fewer tillage operations reduces the CO₂ emissions from tractor driving (and saves on labor and fuel costs for the farmer).
- **Including nitrogen-fixing legumes** as winter cover crops or rotation crops adds benefit by reducing the need for synthetic nitrogen fertilizers, which are energy-intensive to manufacture and transport. This further reduces CO₂ emissions associated with farming (and saves money on nitrogen fertilizer).
- **Using manure, composts, and other organic amendments** directly adds carbon-rich organic matter to the soil, and also can reduce the need for synthetic nitrogen fertilizers and associated CO₂ emissions.

Rebuilding soil organic matter thus plays a role in climate change mitigation (reducing the “carbon footprint” of agriculture). At the same time, it increases adaptation to these changes by building resilience to extreme weather. Improved infiltration and drainage minimize crop stress, valuable top soil loss, and flooding during extreme rainfall events. Increased water holding capacity, in combination with better infiltration, allows for more water storage to buffer against short term drought.

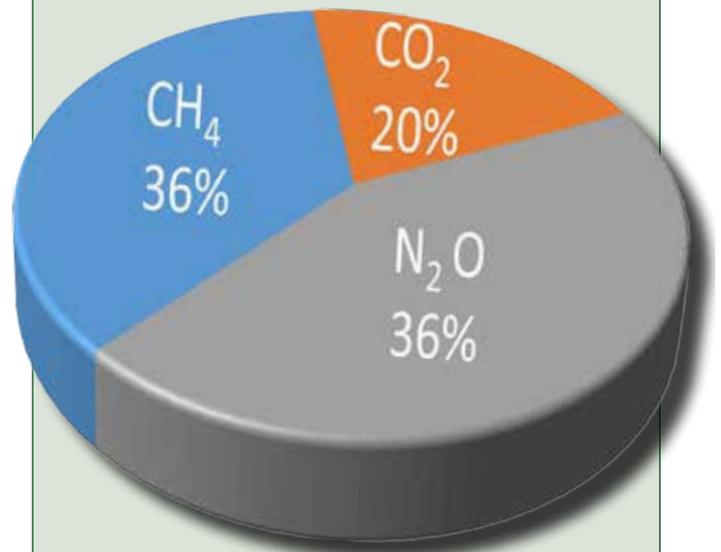
Soil health management to prevent nitrous oxide emissions

Nitrous oxide (N_2O) is about 300 times more potent in its global warming potential than CO_2 on a molecule-to-molecule basis. Over 70% of total U.S. N_2O emissions come from agriculture, largely from excessive and poorly timed use of nitrogen fertilizers. While small amounts of this come from soil microbial nitrogen mineralization processes that cycle nitrogen from organic nitrogen to ammonium and nitrate, most comes from “denitrification” in water logged (low oxygen, anaerobic) soils that convert most of the nitrate (NO_3^-) to the inert form of nitrogen gas (N_2), while releasing significant amounts of N_2O (Part I, Figure 1.10).

- **Improved soil drainage** will reduce denitrification and nitrogen losses (as well as CH_4 losses) from water-logged soils, and greater water storage will reduce risk of applied nitrogen to be lost to the environment after a crop lost to drought. This also cuts costs for the farmer!
- **Optimizing timing and amount applied, and splitting fertilizer applications** can significantly reduce emissions and improve profit margins. Timing and amount should be based on crop demand, soil health measures, and new web-based decision tools and apps that take into account real-time weather effects (e.g., soil temperature, moisture, rainfall) on available nitrogen.
- **Organic sources of nitrogen**, such as legume rotation crops, manures, and composts will release nitrogen more slowly and ‘spoon feed’ the crop.

U.S. Agriculture's Greenhouse Gas Emissions

While nationally and globally, CO_2 emissions (mostly fossil fuels like coal, oil, and gas) are the biggest contributor to climate change, N_2O and CH_4 are of bigger concern for agriculture. They are such potent greenhouse gases that on a “ CO_2 equivalent basis their emissions from the U.S. agriculture sector contribute more to global warming than CO_2 emissions from tractor driving or other fossil fuel energy use on the farm.



Greenhouse gas emissions from U.S. Agriculture (CO_2 equivalent basis, 2007, USEPA).

These sources have the added benefit of allowing you to reduce the fossil fuel emissions associated with manufacturing and transporting synthetic fertilizers.

- **Perennial plants and winter cover crops** such as winter rye “scavenge” excess nitrogen from the soil and help store this in plant tissue over the winter and spring when it could otherwise be lost due to wet conditions. Decomposition then releases nitrogen to the subsequent cash crop.

In summary, healthy soils store more carbon and require fewer inputs. Thus, they have reduced carbon emissions associated with manufacture, transport, and application of inputs. They are also better able to prevent saturation and soil loss, and store water from large rainfall events to carry a crop through a short-term drought. Healthy soils therefore minimize greenhouse gas emissions, plant stress, and risk to the farmer of challenging weather events. Sustaining healthy productive soils also reduces the need for land clearing, deforestation, and related CO₂ emissions internationally.



Cover crop being planted without tillage on previously manured field. Photo credit: Troy Bishopp



The larger picture above shows a rolled rye crop with emerging soybeans planted two weeks previous on 30 inch centers. The inset photo shows the roller/crimper on the front of the tractor with the soybean planter on the back. This method has found success in organic systems where the rye controls weeds by mulching the soil below the beans.

Cited References

- ¹Adapted from work presented in: Moebius-Clune, Bianca, Dorn Cox, Brandon Smith, Dan Moebius-Clune, Robert Schindelbeck, and Harold van Es. 2014. Implementation of a Soil Health Management Plan Resolves Pond Eutrophication at Tuckaway Farm, NH. [What's Cropping Up? Vol. 24, No.5, Sep – Oct](#), a newsletter for NY field crops and soils, Soil and Crop Science Section, Cornell University, Ithaca, NY.

