DISCUSSION DRAFT: NOVEMBER 1, 2016

reThink Soil:

A Roadmap for U.S. Soil Health

A ROADMAP FOR COLLECTIVE ACTION TO SECURE THE CONSERVATION AND ECONOMIC BENEFITS OF HEALTHY SOILS

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The Nature Conservancy

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A Roadmap for U.S. Soil Health

Project Leader:

Michael Doane, Director, Working Lands

Primary Contributors:

Larry Clemens, Director, North American Agriculture

Randy Dell, Great Lakes, Agriculture Strategy Manager

Pipa Elias, Senior Policy Advisor, Lands & Climate

Jonathan R.B. Fisher, Senior Conservation Scientist

Jeff Fore, West Tennessee Program Director

Dayna Gross, Senior Conservation Manager

Gina Hancock, Conservation Strategy Director

Tom Hodgman, Director, Conservation Transactions, NatureVest

Amy Jacobs, Director, Watershed Restoration

Bill Toomey, Director, Forest Health Protection

Carrie Vollmer-Sanders, Nutrient Strategy Manager

Greg Wandrey, Iowa Agriculture Program Director

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Executive summary

Soil health is inextricably linked to broader conservation goals

Improving soil health on U.S. agricultural land holds the potential for achieving meaningful conservation and economic benefits, as well as mitigating the growing threat of climate change. Healthy soil is the cornerstone of life on earth, facilitating ecosystem biodiversity, ample food production, effective water filtration and storage, and carbon sequestration.

Advancements in agricultural technology throughout the past century have allowed farmers to feed a population that has grown from less than 2 billion people to more than 7 billion today. Over the same time period, however, soil managed for agricultural purposes in the U.S. has degraded, losing as much as 60% of its original organic carbon content.[1] The degradation of soils has undermined the productivity of farmers and the resilience of croplands while leading to significant direct and indirect environmental impacts annually on a national level:

- 346 million metric tons of greenhouse gas emissions[2]
- 4.4 billion pounds of nutrient loss to the environment[3]
- 996 million metric tons of soil erosion[4]
- 48.4 million acre-feet of water used for irrigation[5]

Drawing upon respected analyses in soil health literature, The Nature Conservancy estimates the annual societal and en- vironmental costs of the status quo are up to $85.1 billion annually through unintended effects on human health, property, energy, endangered species, loss of biodiversity, eutrophication, contamination, agricultural productivity, and resilience. As global food demand grows, U.S. agriculture needs to be competitively positioned to increase production to meet both domestic and international food requirements. Managing for soil health serves as a nexus for achieving increased production while reducing the societal and environmental impacts of the current U.S. row crop production system.

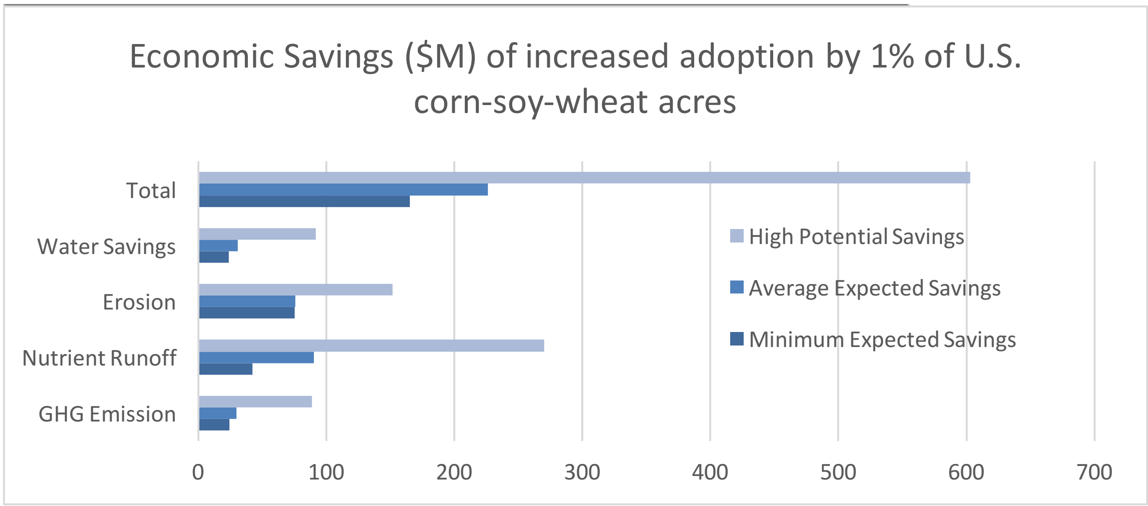
Improving soil health can yield signifcant benefits

The U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS) defines soil health as "the continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals, and humans." The concept of adaptive management is inherent in this well-accepted definition. Adaptive management for soil health means minimizing soil disturbance while optimizing plant diversity, allowing more continuous plant and residue covers to create vital, living ecosystems in the soil. In turn, the soil nurtures a complex web of microbes with the healthiest soils often being those with the greatest diversity and abundance of life. Healthy soil more efficiently stores and recycles carbon, water, and nutrients such as nitrogen and phosphorous.

At the farm level, the benefits of improved soil health include higher rates of productivity and profitability over the long term, as well as reputational value for farmers who put conservation at the center of their management approach. At the societal level, the benefits of boosting soil health are even more profound, including improved water quality, filtration, and storage; richer biodiversity; and reduced greenhouse gas emissions, mitigating the impacts of climate change.

In order to estimate the scale of benefits attributable to changes in soil health, the Conservancy chose three management practices—reduced tillage, cover cropping, and crop rotations—to serve as proxies for the adaptive soil health systems, which will vary geographically. Reduced tillage decreases disturbance of the soil, thereby improving the soil's ability to retain nutrients and sequester carbon dioxide from the atmosphere. Cover cropping between cash crop seasons is a heritage practice that maximizes the time each year that living roots are building soil nutrients and keeping the surface protected. Diverse crop rotations help build nutrients, limit erosion, and foster soil carbon sequestration. While these three practices do not represent the full spectrum of soil health solutions available, they serve as valuable measurement proxies because of the extensive, validated research on the conservation and economic benefits of each.

Economic benefits ($M) of increased adoption by 1% of U.S. corn-soy-wheat acres



Restoring soil health can create net economic benefits for farmers while removing environmental and societal costs associated with intensified agricultural production that will otherwise amass into an unfunded liability to be passed along to future generations. The Nature Conservancy has a rich history achieving conservation goals for the most important landscapes in the world, and this must include the agricultural landscapes that meet society's critical need for food, fiber, and energy, as well as the people whose livelihoods depend on those lands. The Conservancy views soil health restoration as the primary way to bring economic value to farmers while achieving conservation goals. Yet, this strategy is part of an emerging conservation solution set—which also includes targeted edge-of-field and in-stream solutions for water quality and more precise nutrient management timed to plant needs.

Barriers to achieving soil health are multifaceted

A small yet influential segment of farmers, including organic farmers, have catalyzed a movement toward a new array of both innovative and heritage soil health practices that protect and build soils. Despite these efforts, widespread adoption of soil health systems appears unlikely unless the multiple barriers to adoption are systemically identified and addressed. These barriers, which are undeniably complex, cluster around three key areas: science, economics, and policy.

First, the science of soil health is still evolving. Accurate, standardized, and cost-effective on-field soil health measurement tools have yet to be developed and widely implemented. As a result, soil health is not easily measured, thus limiting the ability for timely management responses by farmers, or the development of useful policy and economic signals in the mar- ketplace. Likewise farmers contemplating this change need more evidence and demonstration of operational strategies locally tailored for integrating specific soil health practices on their farms.

Second, current business models between landowners, farmers, and agricultural retailers do not adequately encour- age soil health management. Conservation systems and practices to restore soil health introduce potential operational complexities and may require farmers to make higher capital or variable cost outlays in the short term. Recouping these investments requires a longer planning horizon. Yet the majority of farmers in the U.S. lease the land they manage. While lease terms vary, most incent short-term planning and do not allow the farmer to recover costs or plan for a longer hori- zon. Large segments of landowners have not been brought into the broader conversation about the value of soil health improvements for society and land value. Therefore, lease arrangements do not adequately factor in soil health improve- ments. Likewise, agricultural retailers are often trusted advisors to farmers, and opportunities exist for engaging retailers in providing agronomic knowledge about the transition to soil health systems as well as selling products and services designed to improve soil health.

Finally, public policy has not been fully developed and implemented to encourage landowners and farmers to reduce pro- duction risk and support soil health investments requiring longer planning horizons. Given the value creation potential to address important social and environmental challenges, broadening the coalition of interested stakeholders who advocate for these improvements in state and federal policies is essential.

A roadmap to transform the agricultural management paradigm

A notable change is underway, and momentum is gathering around the opportunity presented by soil health systems. The Nature Conservancy is not alone in recognizing the potential of soil health to be the catalyst for delivering conservation and productivity benefits at a meaningful scale.

Innovative initiatives by government agencies such as USDA, NRCS, and the U.S. Department of Energy (DOE), as well as newer public-private entities such as the Soil Health Partnership and the Soil Health Institute, are already making import- ant progress. The Conservancy is partnering with these efforts and other public and private sector organizations to help further a paradigm shift, but greater coordination, innovation, and investment is still needed.

Rather than a constellation of well-intended efforts, the Conservancy calls for a coordinated and aligned approach toward the goal of transforming the U.S. cropland management paradigm, with soil health becoming the leading indicator of economic and environmental outcomes on the majority (>50%) of farms by 2025. In doing so, we can significantly improve the pace and certainty of reversing the negative trends on water quality over the next decade while establishing one of the most cost effective natural climate solutions. Specific and measureable benefits of attaining the proposal goal in the U.S. are summarized on an annual basis:

- Mitigating 25 million metric tons of greenhouse gas emissions,
- Reducing 344 million pounds of nutrient loss to the environment,
- Eliminating 116 million metric tons of soil erosion,
- Creating 3.6 million acre-feet of available water capacity in cropland soils.

Taken together, these improvements will create a diverse basket of environmental and social benefits valued at $7.4 billion annually. Through higher rates of productivity resulting from higher yields or lower production costs, farmers stand to gain modest, albeit meaningful net economic benefits of $37 million for each one percent of cropland transformed, or $1.2 billion annually across the U.S. corn belt. The Conservancy proposes a roadmap for collective action to secure the conservation and economic benefits of healthy soils. Coordinated and collective actions across ten priorities spanning science, economic, and policy outcomes will overcome the multiple barriers to widespread adoption. The roadmap is offered as a starting point for greater collaboration. In time, it will conform to the combined knowledge and capacity of committed partners, as well as the evolving state of the science, economics, and public policy environment regarding soil health.

Overcome the science and research gap to support expansion of soil health management:

1. Create cost-effective soil health measurement standards and tools

   Create accurate, accessible, and standardized methods for rapid measurement of key soil health indicators at a scale that impacts management choices by farmers and landowners

2. Develop operational management strategies for adaptively integrating soil health practices and systems

   Build evidence and understanding among farmers of operational strategies and regional variabilities for integrating multiple soil health practices on a farm, including optimal cover crop programs

3. Advance the science of soil health benefits

   Further quantify the economic costs and benefits and environmental impacts of different management systems on soil health, with consideration for different regions, soil types, and cultural practices.

Overcome economic obstacles by providing the market systems to secure soil health by:

4. Align incentives between landowners and farmers

Cultivate the economic case for action among absentee landowners of soil health benefits for society and land value and encourage new lease arrangements that integrate soil health systems and practices

5. Leverage technological innovation to overcome operational hurdles

Leverage technological innovations, such as sensors, drones, cover crop seeding equipment, precision agriculture software and hardware, to advance adoption and continued implementation of soil health systems and practices

6. Provide broader access to products and services supporting soil health

Develop new business models with agricultural retailers that provide broader access to new products and services to accelerate the adoption of soil health systems and practices

7. Create market signals in sustainability programs for soil health

Develop improved indicators that reward soil health management outcomes in sustainability assessment programs, aligning the incentives of farmers and society

Improve the policy environment to advance soil health:

8. Reward farmers who optimize long-term soil health with lower crop insurance premiums

Advocate for federally subsidized crop insurance programs to value the benefits generated from improved soil health profiles through lower insurance premiums

9. Support policies that enable greater investment in soil health

Support state and federal policy improvements that focus on reducing barriers to soil health practice adoption, target priority areas for implementation, and comprehensively assess impacts for societal value

10. Build a more diverse constituency for soil health policy

Build a strong and diverse network of supporters for soil health policy, including farmers, landowners, the agri-food sector, community leaders, and societal interest groups

Conclusions and invitation

Managing U.S. croplands for soil health offers an exciting value proposition to farmers and society. The Nature Conservancy is compelled—by both our mission and the size of the benefits for people and nature—to lend our support to this important cause. In doing so, we intend to bring about a more concerted and coordinated effort, accelerating the adoption of soil health systems and achieving economic and environmental outcomes at a scale that addresses our most pressing global challenges. The Conservancy is committed to expanding our capacity to seize this important and timely opportunity. The science agenda for soil health will require significant, long-term investments and collaborations. The Conservancy is expanding scientific capacity through the addition of a new lead scientist role for soils. As such, the Conservancy will be a more capable partner with organizations charting the future of soil health research. It is clear new business models will be necessary to align the economic interests of farmers, landowners and agricultural retailers on soil health benefits. The Conservancy seeks to be a collaborative and positive force for the advancement of new value creation opportunities. Expanding on the successful model of the Soil Health Partnership will be a priority given the importance of farmer-to-farmer knowledge transfer with adaptive and locally tailored soil health solutions. The Conservancy has actively engaged in discussions about the current and future opportunities for improved public policies in support of soil health at the state and federal level. These efforts include targeting existing conservation programs for the highest impact as well as policy planning efforts on the future of crop insurance. The Conservancy's network of state chapters and trustees can serve as effective advocates for public policies in support of the soil health movement. The Nature Conservancy invites interested organizations and individuals to share feedback and expressions of interest in the ideas articulated in this paper by emailing soil@tnc.org.

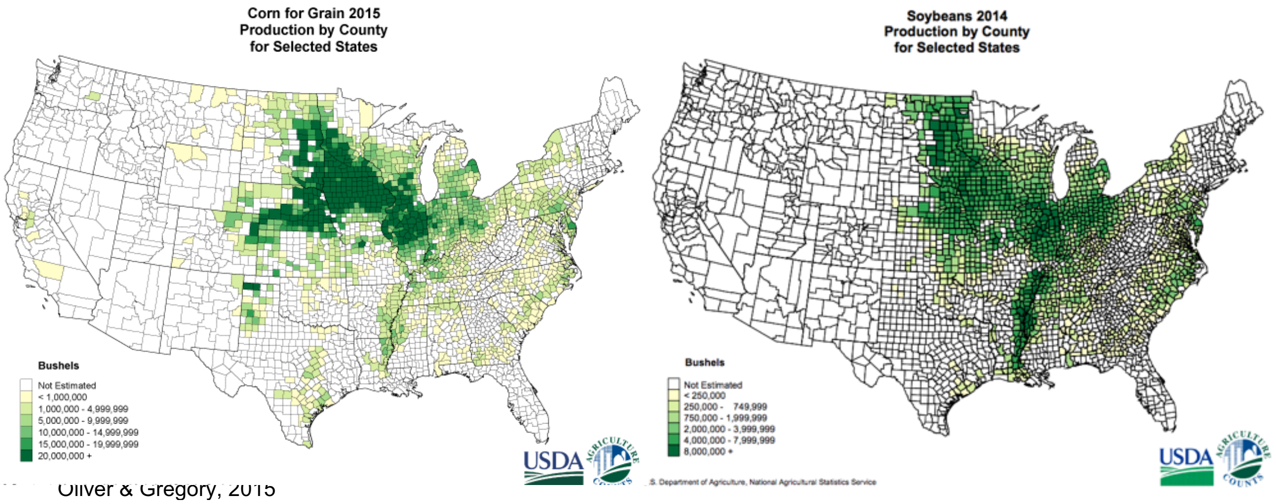
Situation analysis

Soils are essential to multiple life support systems frequently taken for granted, such as water cycle, carbon cycle and nitrogen cycle, in addition to being the foundation of our food systems. Increasingly, farmers, scientists, landowners, environmental experts, and policymakers understand soil health is a keystone issue and that addressing its complex challenges is urgently essential. While the health of soil is influenced by some inherent factors such as formation, geography, and climate, other factors are more dynamic and influenced by how the soil is managed.

Loss of soil organic carbon

Historically, as open prairies in the United States were converted to cropland, rich soils began to gradually degrade through erosion, loss of organic content, contamination, compaction, increased salinity, and other problems.[1] Over time, regions like the U.S. Heartland, where crop production is highly concentrated (Figure 1), have been deeply impacted by the environmental demands of intensified productivity.

Figure 1: Highly concentrated regions of crop production in the U.S.



Source: USDA Census of Agriculture

Oliver & Gregory, 2015

At the crux of this issue is soil organic carbon (SOC), or more specifically, the loss of it. SOC is the portion of soil organic matter that is made up of carbon, and it is increasingly recognized as a proxy indicator of soil health.[2] Soil interacts with other natural resources like air and water and, ideally, is rich with organic matter formed through the natural interchange with plants. Living and decomposing plant matter feeds many kinds of organisms, which in turn produce an array of biological organic compounds. Higher SOC levels are considered by many soil scientists as an indicator of soils that are resilient, agriculturally productive, and more capable of withstanding environmental pressures.[3]

While some organic matter in the soil is quick to break down where it may return to the atmosphere as CO_2, other portions are stable, or "recalcitrant", for many years and can thus serve as carbon sinks, absorbing and storing CO_2 from the atmosphere.[4]

Common cultivation techniques used over the last century involving tillage, such as plowing, disking, and chiseling, as well as monocropping, break down the soil mechanically and biologically, diminish sufficient supplies of oxygen for soil biota and plants, deplete nutrients, increase soil erosion, reduce aggregate stability and water-holding capacity, and decrease levels of organic matter, as measured by SOC.[5] The greatest loss of SOC related to agriculture generally occurs during the first 25 years of cultivation, with losses of 50% being common.[6] In the Midwest, the majority of soils converted from natural to agricultural systems have lost 60% or more of the original SOC level. As SOC levels dropped, the need to fertilize more to compensate rose, which can be a factor in increased nutrient loss.

Soil Health Calls Upon a Wide Array of Practices

Improving soil health in the U.S. will involve a dynamic, continually adaptive process and a broad range of practices that vary from region to region, and even from farm to farm within a region

Although the estimation of benefits later in this paper highlights three soil health practices that have been more comprehensively studied, farmers and scientists are using and investigating a much broader array of soil health practices. These include:

- Cover crops
- Crop rotations
- Reduced or No till systems
- Integrating livestock
- Soil amendments, including biochar
- Adaptive nutrient, pest, and weed management
    - Sustainable nutrient management, conservation nutrient management, 4RPlus, precision agriculture and precision conservation
    - Integrated pest management, biological pest control, avoid soil fumigation and use of persistent pesticides
    - Weed management systems, including consideration of row spacing, crop selection, roller crimpers, etc.

Sources: NRCS, CCSI, Rodale

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[2] Lehmann & Kleber, 2015

[3] Reicosky, Sauer & Hatfield, 2011

[4] Sanderman, Baisden, & Fallon, 2015

[5] Six & Paustian, 2014

[6] Overstreet & DeJong, 2009

The impacts of these common agricultural practices, coupled with SOC losses, are manifold: farms cannot achieve their maximum productivity; nutrients in the soil are lost due to erosion and water runoff; nitrate and phosphorus contamination – a consequence associated with fertilizer loss – compromises the quality of groundwater and waterways; and substantial amounts of greenhouse gases naturally stored in the soil return to the atmosphere. Conversely, through the use of practices that promote soil health, many of these impacts can be reversed as SOC and other key soil properties improve, as described in the following section.

Potential benefits of soil conservation management systems

Soil conservation management systems in agriculture that are aimed at restoring SOC can lessen and even reverse the environmental impacts, and individual farmers who have adopted such systems are already seeing measurable improvements in soil health, including higher yields and less need for nutrient purchases (see “Farmer Profiles”, page 10). These systems include cover crop planting, more crop rotation, and decreased tillage, and each shows potential for farm-level and societal benefits, including:

- **On-farm productivity and profitability:** Increases in the soil’s carbon content can lead to overall better soil health, improved water infiltration and retention, improved nutrient retention, and better crop rooting, all of which contribute to potentially higher productivity and profitability.[7] It is likely that land owners, including corporations, municipalities and individuals, can realize healthier, more productive land that may translate into higher land value.
- **Reduced greenhouse gas emissions:** Achieving even small increases or preventing reductions in the soil’s carbon content can mitigate the emission of greenhouse gases like methane and nitrous oxide to the atmosphere. The NRCS has ranked the potential of various soil health systems, and the National Sustainable Agriculture Coalition has also reviewed the potential of these systems.[8] In addition, the COMET-Farm Tool was developed through a partnership between Colorado State University and the USDA-NRCS as a means of accounting for the carbon sequestration contributions of conservation practices.

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[7] Paustian, Lehmann, Ogle, Reay, Robertson & Smith, 2016

[8] Kane, 2015

- **Nutrient loss reduction:** Phosphorus and nitrogen are often lost in the form of soil erosion and leaching, especially in tile drained systems. Increased soil organic matter can bind the soils with these nutrients to reduce loss. Cover cropping helps store those nutrients in biomass during the non-crop season.[9]
- **Less water runoff:** General improvement of soil health, particularly optimal aggregate structure, permeability, and carbon content, can result in less water runoff, better aeration, increased water penetration, and increased water retention.[10] Further, nitrate content may be reduced in ground water that affects both on-farm and municipal water supplies.[11]
- **Less erosion:** Healthy and well managed fields have a much lower potential for soil loss due to wind and/or water erosion, particularly during severe weather events.[12] Mitigation of soil loss via erosion not only maintains the value of the farm, but also alleviates downstream impacts of eroded soil such as sedimentation and biodiversity losses in waterways.[13]

The science of soil health

The complexity of the issue is reflected in efforts to simply define what “soil health” means. There is not yet a single definition, although an emerging consensus generally aligns with the NRCS and USDA description as “the continued capacity of soil to function as a **vital living ecosystem** that sustains plants, animals, and humans.” The Nature

Soil Health Farmer Profiles:

David Brandt
1,100 acres in Ohio
Corn, soy, wheat
No-till since 1971
Cover crops: all mixes since 1978

Brandt has **reduced his nutrient purchases by 80%.** He gradually moved from single species of cover crops to 10 species, first using single species such as nitrogen-fixing species to reduce input costs from legume covers. Next, he planted two cover crop species to absorb the available phosphorus and potash, and then expanded to additional cover crop species.

Yield: Currently yield is 12% better than county average (for corn, 180-200 compared to country average 140-160; beans stay healthier and yield better, 70-80 with rye covers)

Source: NRCS website

Tim Smith
Iowa farmer, Soil Health Partnership
800 acres, corn and soybeans

Smith started using rye as a cover crop on 300 acres. He expanded to 550 acres and added oats, hairy vetch, and radishes, in different combinations. He received the National Corn Growers Association Good Steward award.

Benefits: prevention of nitrate leaching and erosion; enhanced microorganisms; and complementary with his practices such as strip-till.

He admits that there is a learning curve. It took several years for clear results because of different weather patterns.

Source: Soil Health Partnership website

Mark and Doug Anson
Indiana/Illinois farmers

The Anson brothers started using cover crops in 2010. It took three years to make one of the brothers a believer, during a drought year.

Source: New York Times

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[9] Deng et al, 2016

[10] Overstreet & DeJong, 2009

[11] Associated Press, January 7, 2015

[12] Motha, 2011

[13] Paustian et al, 2016

Conservancy fully supports this definition of soil health, recognizing that it will evolve as the science does.

Nonetheless, the science of soil health, namely how to best define and measure it, how to best promote it, and how it supports other objectives, remains a work in progress. Several long-held tenets of soil science have been challenged in recent years, from the role of no-till agriculture in boosting soil carbon, to how soil decomposes – and how stable the resulting compounds are – to how different types of soil carbon behave. Efforts to improve soil health face two interconnected problems: what soil health means (which of the components of soil health are most important) and how to measure it (which indicators are most appropriate and useful). Scientists have developed several generally accepted indicators of the components of soil health, including the amount of organic and particulate organic matter, water infiltration and water holding capacities, bulk density and aggregate stability, aeration, biological activity, including diversity and abundance of microbes and invertebrates, and pressures from weeds, pests, and disease. However, growing consensus on individual soil-health indicators has not produced agreement on the best overall soil health index. There is also still debate on how to best measure the biological aspect of soil, whether biological properties are crucial to meet objectives or whether they are simply correlated with other soil properties, and which biological properties are the most important, be it microbial diversity, microbial biomass, fluorescein diacetate hydrolysis to measure enzymatic activity, and so on. Existing tests measure for some indicators, but they do not provide information on other important characteristics of healthy soil and therefore provide an incomplete understanding of a soil's health.

New Soil Health Tests

The Haney Test, developed at the Temple, TX, USDA Ag Research Service laboratory by Rick Haney and colleagues, evaluates how much "food" the soil food web has available to it.

This test aims to replicate field conditions by using customized soil extraction processes including:

- H3A soil extractant that mimics soil solutions by using organic acids produced by living plant roots.
- Solvita 1-day CO_2 Burst uses drying and rewetting techniques to mimic natural field events, representing the flush of microbial activity leading to nutrient cycling.

The test also measures water-extractable organic carbon and nitrogen along with organic phosphorous phosphorous, or the pool of these nutrients readily available to soil microbes. The test determines the amount of organic nitrogen already in the soil, which may decrease the amount of commercial nitrogen needed.

Source: Successful Farming

As the science of soil health evolves, new tests have emerged that seek to measure soil health more comprehensively through application of advanced technologies, including genetic sequencing of bacterial and fungal components of soil. However, there is uncertainty about how to interpret the new tests' results and what recommendations the results support in terms of improving soil health. Some of the more comprehensive soil health indices that have been proposed are also expensive, time-consuming, and require considerable expertise and equipment. Further research is needed to identify which soil properties are the best proxies of soil health and how well simple metrics that a farmer can collect correlate with more robust metrics that require assistance from scientists with access to laboratory equipment.

Both the Soil Health Institute and the U.S. Department of Energy's ARPA-E have recently stepped up efforts to develop better ways to measure soil health and provide management information (see next page).

In addition to the study of the biophysical and chemical aspects of soil, there is also a growing body of social science research around the behavioral and cognitive aspects of why soil health practices have not been adopted more widely. For example, The Nature Conservancy is currently collaborating with Cornell University on a project to investigate why some fruit and vegetable farmers are adopting these practices, what barriers there are to adoption by the farmers currently not using them, and what ecological, economic, and social benefits these practices provide. Further, more research into the biological connections between soil health and human health will be valuable to society.

There is also a need for more comprehensive scientific understanding of the role that improved soil health practices can play in the management of other environmental issues. For example, while some of the strategies to improve nutrient use efficiency have shown significant benefits in watershed projects, it remains difficult to predict how much environmental improvement can be achieved through these changes. Further complicating the effort to quantify the impact of soil conservation practices on SOC levels is the fact that many of these practices directly result in positive, yet unintended, conservation outcomes, as well as the improved soil health. For example, cover crops can reduce erosion <u>and</u> boost SOC, but reduced erosion is a parallel effect, not an intended effect, of the SOC increase. Additional research is needed to better understand the interactions and cumulative effects of different agricultural systems and practices in meeting environmental objectives.

Momentum building toward soil health

Globally, predictions of increasing population growth and changes in diet mean we will need 70% more food by 2050[14], making increased agricultural productivity imperative. Strategic investement and commitment from a wide range of stakeholders is needed to prevent further degradation of our soils. Fortunately, an unprecedented convergence of factors and developments in science, technology, agriculture, society, environmental protection, and public policy have spurred activity and interest in soil health

The United Nation's Sustainable Development Goals and the Paris Climate Change Agreement heightened attention on policies related to environmental problems, which drove many governments and companies to increase their environmental and sustainability commitments. On the science and technology front, the USDA's NRCS has taken the lead on advancing soil health, well before it was on the radar of other organizations. The NRCS is actively promoting soil health through various programs, including the current campaign called "Unlock the Secrets in the Soil" (see sidebar, p. 11). Recently the USDA dedicated more than $15.9 million for FY 2017 to expand computational capacities for microbiome research and human microbiome research through the Agricultural Research Service. This link between soil health and human health is being explored by the National Institutes of Health in its work on the Human Microbiome Project and the biological similarity between the microbiology of the human intestinal tract and that of a well balanced soil.

In addition, approximately $8 million will support investigations through the National Institute of Food and Agriculture of the microbiomes of plants, livestock animals, fish, soil, air, and water

Some of the Initiatives Underway

The USDA's Natural Resources Conservation Service (NRCS) launched its **"Unlock the Secrets in the Soil"** awareness and education campaign to help farmers, ranchers, and interested stakeholders improve soil health, through online videos, features, and other materials. The campaign has highlighted producers who are successfully implementing soil health systems in different regions of the country.

In late 2015, the Samuel Roberts Noble Foundation and the Farm Foundation announced the creation of the **Soil Health Institute**, whose mission is aimed at safeguarding and enhancing the vitality and productivity of the soil. The institute's early focus has been on identifying key indicators of soil health and facilitating a national soil health assessment to establish a baseline measurement of soil health in the U.S.

Formed in 2014. **The Soil Health Partnership** has been active in research efforts to quantify the benefits of improved agricultural practices from an economic standpoint, showing farmers how healthy soil benefits their bottom line. In early 2016, the Soil Health Partnership expanded its efforts to 65 farm test sites across eight Midwestern states.

The **U.S. Department of Energy's Advanced Research Projects Agency (ARPA-E)** recently made $30 million in funding available for its Rhizosphere Observations Optimizing Terrestrial Sequestration (ROOTS) program aimed at developing new root-focused cultivars that economically reduce atmospheric CO_2 concentrations without decreasing agricultural yields. The goal of the ROOTS program is to develop crops that enable a 50% increase in carbon deposition depth and accumulation, a 50% decrease in fertilizer N_2O emissions, and a 25% increase in water productivity.

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[14] FAO, 2011

as they influence food-production systems.[15]

At many universities across the U.S., including Iowa State, University of Minnesota, Purdue and UC Davis, faculty and students are advancing knowledge about soil health through education, research on the basic and applied science of soil health, and contributions soil health can make to conservation and other environmental protection objectives. Many have established centers or institutes that focus on different aspects of soil health and its relationship with agricultural management systems and practices, environmental concerns, and social needs, such as UC Berkeley's Food Institute and Iowa State's Leopold Center for Sustainable Agriculture.

Similarly, scientific progress in other areas, including plant genetics and information technologies, has found expanded application in agriculture, including for improving soil health. For example, precision agriculture is a dynamic field, fueled by integrating digital technologies, such as sensors and on-equipment hardware and software, with expanded networking of devices (the "Internet of Things") and "big data" analytics. Precision agriculture tools that support soil health include soil grid sampling and precise application of nutrients and chemicals, and sensors and controls for irrigation. According to a report by the Research and Markets, global spending on precision agriculture will reach nearly $4 billion per year by 2018, growing annually at more than 13%.[16]

On the supply side, many U.S. farmers have already begun implementing and experimenting with soil health management systems including no-till farming, conservation tillage, crop rotation, crop diversification, cover crops, controlled wheel traffic,

Organic Farming

At the heart of organic farming is a focus on building and protecting soils. Soil health practices required by USDA certified organic farming (205.203b) include:

- Crop rotations
- Cover crops
- Soil fertility: use of mulch and manure to build organic matter

Reduced tillage is less common in organic farming because of the challenges of weed control without herbicide-resistant crops.

While several conservation practices such as the ones above are mandatory for USDA organic farms, other practices are optional (e.g., some organic farms seek to improve biodiversity, but others clear natural habitat). As with all farming, tradeoffs between objectives are often made to mitigate specific local challenges.

Pest and weed control strategies (including pesticides and herbicides) vary widely in organic farming, and there is debate over how best to reduce losses while promoting conservation outcomes.

While organic farming does not guarantee soil health or the key conservation outcomes noted in this paper, organic farming is one important pathway to soil health and clearly includes soil health as a leading performance indicator.

Sources: USDA Organic Practices Fact Sheet, Evanylo, McGuinn 2009, Lotter 2003.

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[15] https://www.whitehouse.gov/the-press-office/2016/05/12/fact-sheet-announcing-national-microbiome-initiative

[16] http://www.precisionag.com/production/research/report-precision-farming-to-value-4-billion-by-2018/

and precision agriculture. According to the USDA, Agricultural Resource Management Survey, 2010-2011, approximately 33% of farming operations in the U.S. Midwest Heartland used no-till in 2010. The same survey showed more than 45% of soybean acres using no-till practices, the highest rate among the four major row crops. In 2015, a Conservation Technology Information Center (CTIC) survey showed that the average acres planted to cover crops, while still low, had nearly tripled between 2010 and 2015. Additionally, the number of farmers using cover crops for the first time was on the rise. As an example, Ohio farmer David Brandt, who has embraced a number of these systems, describes better economic and conservation outcomes (see sidebar, p. 9).

In the marketplace, younger generations, such as “Generation Z” (under 20) and “Millennials” (21-34) are transforming demand for food with their preference for healthy foods that are sustainably sourced or organic, according to Pew Research and Nielson Global Health and Wellness Report. These preferences are changing the landscape of food production, processing, marketing, and distribution in the United States, which affects farmers, food retailers, restaurant chains, and online food sellers alike. Soil health is gaining attention with food companies as they respond to the marketplace demand for sustainably sourced or organically grown foods.

Policy pressures are also highlighting the need to improve soil health. In the United States, governments are facing mounting problems associated with agricultural practices, particularly their impact on water quality. For example, a municipal water company has sued three county governments in Iowa to recover costs associated with removing nitrates used in agriculture from drinking water.[17] Improvements in soil health would mitigate many of these challenges.

Increased funding for soil health and sustainable agriculture underscores this reality. In addition to the hundreds of millions of dollars the National Microbiome Initiative plans to spend, the federal government is investing in soil health through other initiatives, such as the $72 million allocated to the USDA’s 10 Building Blocks for Climate Smart Agriculture, a set of programs to help the agricultural community be part of the response to climate change. As Agriculture Secretary Tom Vilsack stated at its announcement, “American farmers, ranchers, and forestland owners are global leaders in conserving rural America’s natural resources and reducing greenhouse gas emissions.” In late

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[17] http://www.agweb.com/article/des-moines-utility-lawsuit-likely-over-nitrates-in-water-associated-press/

2015, the Foundation for Food & Agriculture Research announced $200 million in funding to catalyze agricultural research in its target areas, one of which is "transforming soil health."

Interest in soil health has also produced public-private partnerships often found in policy areas requiring scientific, economic, environmental, and political inputs. The National Corn Growers Association launched the Soil Health Partnership to identify, test, and measure "management practices to improve soil health and benefit farmers' operations." Financial support for the Soil Health Partnership comes from the private sector, the federal government, and a philanthropic foundation, and technical assistance from the Environmental Defense Fund and The Nature Conservancy (see sidebar, p. 13).

Challenges to Restoring Soil Health

To achieve the benefits of improved soil health management practices across the U.S., a formidable set of obstacles needs to be addressed. These obstacles generally revolve around three themes: the lack of scientific consensus, as discussed earlier in this paper; market/economic challenges; and policy challenges.

For farmers, the management practice changes required to restore soil health introduce significant operational complexity and short-term costs, adding burden to their already-complex job. For example, what package of soil health management systems and practices should a farmer implement in order to achieve the promised economic benefit and any positive environmental impact? How easy and expensive is the package to acquire and implement? How much time and attention is required to integrate soil health practices and technologies into operating the farm? Are there any short- or long-term trade-offs that a farmer should be aware of? At present, most farmers do not see a near-term return on investing in soil health. Various market pressures, such as low commodity prices, adversely affect the farmer's willingness to incur short-term costs to achieve long-term value creation through soil health improvements. Research into the drivers of adoption of soil health systems suggests that there is no one-size-fits all solution in that farmers are not a homogeneous group and do not always follow an economic model for decision making. Solutions are more complex and must be tailored to specific sub-groups.[18]

Agricultural retailers could play a role here, as they are often viewed by farmers

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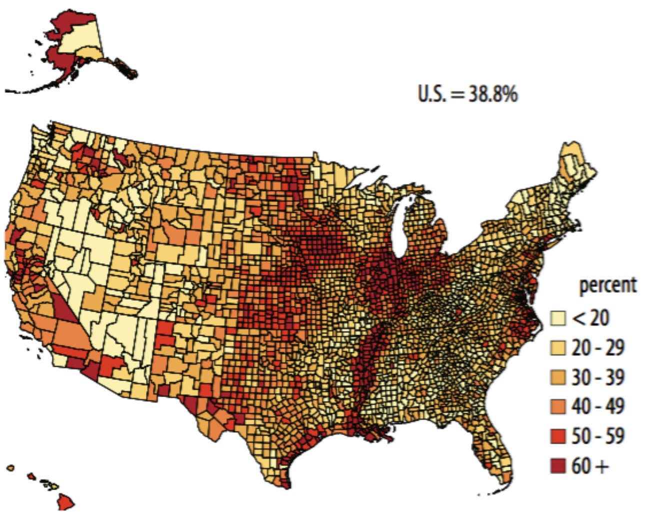
[18] Carlisle, 2016

as trusted and credible advisors. Currently, agricultural retailer business models are only tangentially connected to the new products and services which could accelerate improved soil health practices, including technological innovations such as sensors, drones, cover crop seeds and precision ag software. To shift practices, it is clear that agricultural retailers need to be drawn in to the conversation around soil health.

The structure of land ownership also contributes to a quandary for soil health management. Today, many farmers rent the land they cultivate (as shown in Figure 3), which has limited their adoption of conservation management systems[19] that generally take several years to pay off financially. Owners of agricultural land have an interest in the long-term value of their property, but, so far, efforts to improve soil health have focused on farmers rather than landowners. Landowners must be engaged in soil health efforts, as investing in and integrating soil health systems and practices can improve the long-term sustainability and value of their land.

Figure 3: Farmland Rented or Leased, by County

Percent of U.S. Farmland Rented or Leased, by County, 2012



Source: USDA NASS, 2012 Census of Agriculture.

Other barriers must also be addressed to accelerate adoption of conservation practices and investments in soil health. Key aspects of agricultural production, such as loans to cover operating expenses, crop insurance, and purchase contracts for seed and fertilizers, typically operate on an annual basis. Such a short-term horizon for these services is not compatible with producing long-

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[19] Carolan, 2005

term investments in soil health for farmers. Change here must come from bankers, insurance companies, government agencies, and agricultural retailers so that loans, insurance, and contracts do not hinder soil health activities or investments.

Finally, public policy on agriculture does not tie the benefits and services the government provides with soil health objectives and practices. Most current state and federal policies related to agriculture do not include provisions to support or reward a farmer’s or landowner’s interest in making investments in soil health. With public resources often limited, policymakers need to consider policies supporting soil health improvement that could significantly benefit water quality, biodiversity, climate mitigation, or other outcomes. Policies generating payments for ecosystem services such as clean water or mitigating climate change, should evaluate the off-farm benefits of soil health practices.

Size of the prize:
Measuring the benefits of soil health

Note: Appendix A contains a detailed description of the methodology and assumptions used in our estimation. Below is a brief summary of the results.

The environmental benefits of soil health practices are often considered in isolation from the economic benefits. Additionally, well-known soil health practices such as conservation tillage, cover cropping, and increased crop rotations are often studied individually, providing a limited view on potential outcomes.

To further a broad understanding of the impact a suite of soil health practices could have on both nature and people, The Nature Conservancy has developed an estimation of how integrating conservation tillage, cover crops, and crop rotations into farming operations on corn, soy, and wheat acres could deliver economic and environmental benefits. Specifically, it draws upon a range of literature to estimate the current and potential impact of agriculture on carbon sequestration or greenhouse gas mitigation, nutrient loss reduction, erosion or sediment loss reduction, and water storage capacity. We define conservation tillage as no-till or strip-till, cover cropping as crops left in the ground over winter primarily for non-commercial reasons, and increased crop rotation as adding greater diversity into annual cash crop rotations. Cover crops were estimated to be currently adopted on 1-5% of U.S. acres,[20] crop rotation about 25%,[21] and

We emphasize that the three practices, three crops, and four environmental outcomes in this estimation do not exhaust all possible avenues or opportunities to improve soil health.

Rather, they were selected because of the extensive scientific analyses available on them, which allows us to provide directional insight as to how row crop agriculture can play a critical role in reducing environmental

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[20] Wade, Claassen, & Wallander, 2015

[21] Foreman, 2014

conservation tillage about 25%.[22]

We emphasize that these three practices, three crops, and four environmental outcomes do not exhaust all possible avenues or opportunities to improve soil health. Rather, they provide directional insight as to how row crop agriculture can play a critical role in reducing environmental and economic impacts to both farmers and society. There is much more analysis that can and should be done to estimate and implement a wide range of practices and systems for many crops. We recognize that changing our assumptions and underlying literature could result in substantial changes to the estimated benefits of these practices. Accordingly, so others can make adjustments where they disagree with the choices we have made, the spreadsheet is available by emailing soil@tnc.org.

First, we estimated the impact from an additional 1% of total acres of corn, soy, and wheat managed under these conservation practices. This is an increase from 5% to 6% in cover crop adoption, and an increase from 25% to 26% in crop rotation and conservation tillage adoption. We also estimated the impact of 50% adoption of acres – roughly a tenfold increase in cover crops and a doubling of crop rotation and conservation tillage – as well as the impact of 100% full adoption for all three practices.

Next, we gathered literature estimates of the current contribution from North American row crop agriculture to greenhouse gas emissions (metric tonnes CO2e), nutrient loss in leaching (pounds), erosion (U.S. tons converted to metric tonnes), and water use (acre-feet). Given the cross-cutting nature of this analysis, we opted to use the units – whether English or metric – that were most familiar or commonly reported for the four outcome areas. A wide range of societal economic costs associated with these environmental contributions from agriculture were drawn from literature such as the per-pound cost of cleaning leached nutrients from waterways.

Finally, to determine the potential societal environmental and economic outcomes from increasing adoption of these three practices, we multiplied the potential reduction of impact from each acre of practice (e.g. X lb N/acre by the current amount of environmental or economic costs of the impacts being reduced (e.g. $Y/lb N), multiplied by the number of acres being considered. Acknowledging that the relationship among different practices is not widely understood, we averaged the potential reduction of impact across the three practices as the base case estimate which is a leading figure, but also provided the sum of the three impacts as a high-end estimate – a parenthetic figure.

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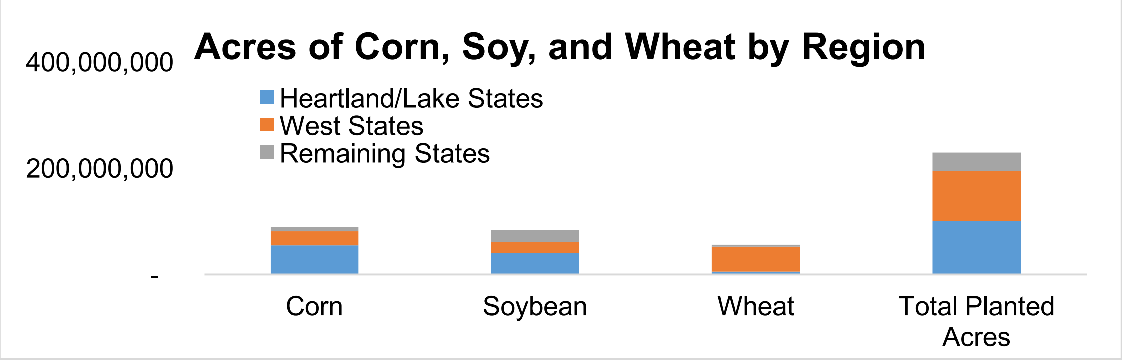
[22] Wade et al, 2015

Further study and analysis is required to understand the potential additive or synergistic effects of these and other practices which promote soil health.

Studies used in our estimation were largely concentrated in a few regions. Most data were primarily sourced from studies in the Heartland and Great Lake Region – specifically Indiana, Illinois, Iowa, Ohio, Missouri, Michigan, Minnesota, Wisconsin, and Kentucky, referred to as “Heartland/Lake” – where corn and soybean are commonly grown, as well as the West region – specifically Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington State, and Wyoming, referred to as “West” – where wheat is a primary crop. See Figure 4 below for the relative acres of these crops across these two regions as compared to all U.S. acres of these crops.

Figure 4: Total acres of corn, soybean, and wheat in Heartland/Lake and West Regions



Source: USDA[23]

While the estimation is more representative of regional impacts, we brought forward estimates of potential impacts for all U.S. acres of these three crops, using data from regional and some national studies. We acknowledge the limitation of the estimation in this way, given that the effects of soil health practices can vary widely by region, soil type, climate, and other conditions.

Currently, U.S. row crop agriculture has several significant environmental effects, either directly or indirectly. Specifically, we estimated that U.S. row crop agriculture, excluding livestock, haylands, and pasture, accounts for:

- about 346 million metric tonnes of greenhouse gas emissions (346 Mt[24]

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[23] www.usda.gov/nass/PUBS/TODAYRPT/acrg0615.pdf

[24] Million metric tons

CO_2e), as estimated using USDA ERS[25] data of fossil fuel combustion, crop residue burning, and soil management;

- about 4.4 billion pounds of nutrient leaching, as estimated using average nitrogen application reported by USDA ERS[26] and typical leaching as reported by a USDA NRCS study[27];
- about 996 million metric tonnes of soil erosion, as estimated using USDA NRCS figures for wind and water erosion[28]; and
- about 48.4 million acre-feet of water used for irrigation, as estimated using figures from a USDA ERS report.[29]

Using additional sources as detailed thoroughly in Appendix A, we estimated that these combined environmental impacts cost society about $85.1 billion through negative effects on human health, property, energy, endangered species, loss of biodiversity, eutrophication, contamination, degraded soils leading to lost potential yield, and/or taxpayer dollars for crop insurance.

The estimation indicates that the societal "size of the prize" for increasing conservation practice adoption rates is significant. For each additional 1% (or about 2.3 million acres) of U.S. planted corn, soy, and wheat acres under soil health practices, an average of 825,000 (up to 2.5 million) metric tonnes CO_2e of GHGs could be sequestered, 10.5 million (up to 31.5 million) pounds of nutrient leaching could be reduced, 3.3 million (up to 6.6 million) metric tonnes of soil erosion could be reduced, and soils could retain 120,000 (up to 360,000) more acre-feet of water.

According to our estimates, these environmental benefits could translate to around $226 million (up to $603 million) of societal gross economic savings per year, or an average of $99/acre (up to $264/acre). Note that these off-farm economic benefits do not take societal costs of implementation into account, such as the cost of infrastructure or programs to incent farmers to adopt soil health systems, nor the actual costs of implementation to the farmers. Figure 5 below shows the ranges based on the minimum, average, and maximum estimated

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[25] http://www.ers.usda.gov/media/434512/tb1909_1_.pdf

[26] http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx, Tables 10, 22, 28

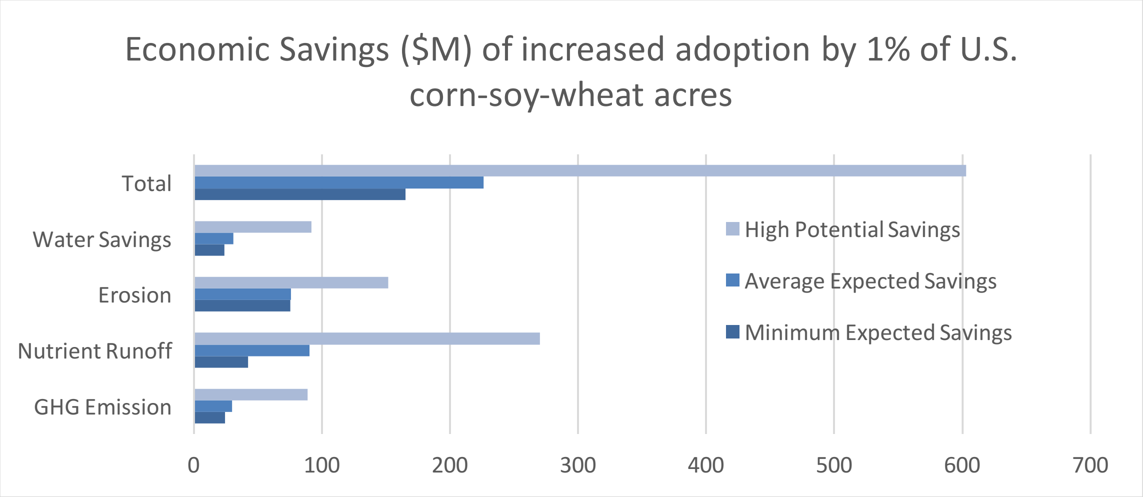
[27] http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/landuse/crops/?cid=nrcs143_014202

[28] http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/nra/nri/results/?cid=stelprdb1041678

[29] http://www.ers.usda.gov/media/884158/eib99.pdf

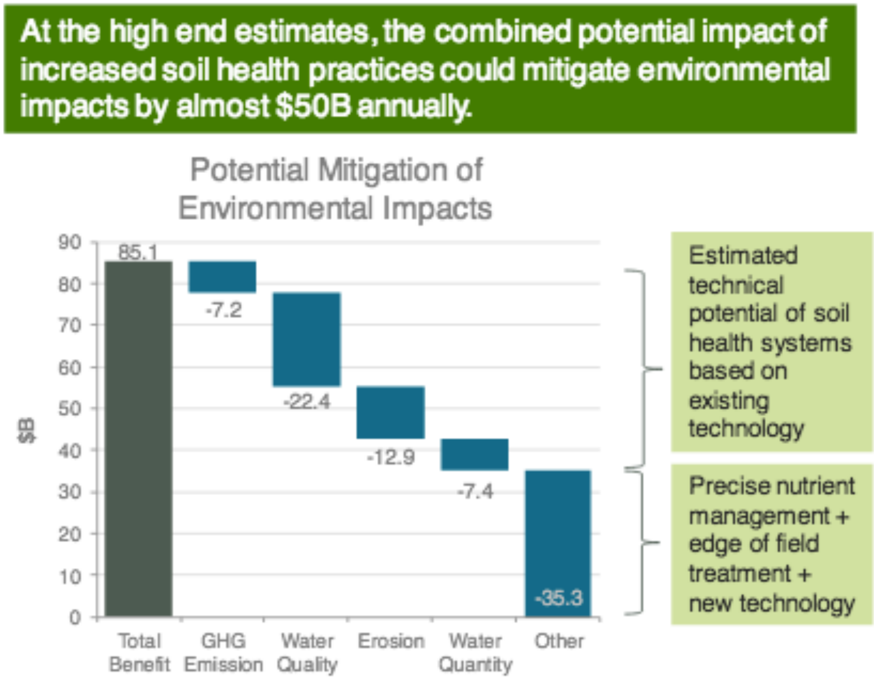
savings from these environmental metrics based on the three representive practices.

Figure 5: Estimated cost savings based on minimum, average, and maxium potential impacts of cover crops, conservation tillage, and increased rotation practices



Expanding these three soil health practices to 50% of all U.S. corn, soy, and wheat acres, the societal cost savings could range from $7.4 billion to $19.6 billion, and about 18.7 billion to $49.8 billion at full adoption.

Figure 6


At the high end estimates, the combined potential impact of increased soil health practices could mitigate environmental impacts by almost $50B annually.

OFF-FARM ECONOMIC BENEFITS (in $ millions / year) [GROSS]

Resource Concern	**Effect of increased adoption by 1% of U.S. acres of corn-soy-wheat**	**Effect of Adoption on 50% of U.S. acres of corn-soy-wheat**	**Effect of Adoption on 100% of U.S. acres of corn-soy-wheat**
GHG Emissions	$29.7	$903	$2,387
Nutrient Loss	$90.1	$2,951	$7,457
Erosion	$75.8	$2,657	$6,447
Water Savings	$30.6	$923	$2,453
Total	**$226**	**$7,435**	**$18,744**

Table 1: Estimates of GROSS societal off-farm economic benefits of implementing all three conservation practices. Benefits are listed with the mean estimated value of economic benefits.

On-farm economic benefits are also compelling. Although farmers incur upfront costs as they initially adopt and transition from conventional practices, the longer-term 3–5 year time horizon indicates that farmers utilizing soil health practices will enjoy an average annual benefit.

Taking the same three conservation practices into consideration, we estimated an annual benefit of $41/acre for corn in the Heartland/Lake region (taking into account both change in costs and change in yield), and an upper range of $124 per acre. Expanding the estimate to 1% of corn acres within the Heartland/Lake region is likely to generate an additional $22 million – with the potential as high as $67 million – in on-farm profit per year compared to conventional farming. If these practices were expanded on an additional 1% of the total U.S. corn acres, we estimate a profit gain of $37 million, and possibly as high as $110 million, per year.

Note that the on-farm economic estimates do not include potential environmental benefits that accrue to the farmer, such as cleaner water on their land; it focuses specifically on how these practices impact farmers' direct costs and profits. Unlike the off-farm estimates, the on-farm estimate does consider the positive or negative change in costs to the farmer, such as impacts of cover crop seeds, equipment wear, labor expenses, and fertilizer requirements. Table 2 summarizes these net on-farm benefit estimates of adopting all three practices.

Table 2: Estimates of NET on-farm economic benefits of implementing all three conservation practices. Benefits are listed with the mean estimated value of economic benefits.

ON-FARM ECONOMIC BENEFITS **(in $ millions / year) [NET]**			
Total U.S. Potential Savings	**Effect of increased adoption by 1% of U.S. acres of corn**	**Effect of Adoption on 50% of U.S. acres of corn**	**Effect of Adoption on 100% of U.S. acres of corn**
On-Farm potential; corn only	$36.7	$1,156	$2,991

As shown above, working to improve soil health in the United States has the potential to increase economic and environmental benefits to individuals (including farmers), communities, and the nation. The scale of the potential benefits presents a compelling case for a change in American agriculture to facilitate and support a strategic approach to soil health practices.

Roadmap for action: Recommendations

The emerging alignment of interest and resources around soil health and its place in agriculture and environmental protection is unprecedented. This strong momentum is highly aligned with The Nature Conservancy's vision of a dramatic paradigm shift in which croplands are actively managed for soil health, with soil health emerging as the leading indicator of a farm's financial and environmental sustainability

The Nature Conservancy seeks a transformation of the U.S. cropland paradigm, with soil health becoming the leading indicator of economic and environmental outcomes on the majority (>50%) of farms by 2025.

However, maximizing the impact of this moment requires strategic thinking because many challenges remain underexplored, misunderstood, or inadequately coordinated. A cohesive roadmap is crucial to ensuring "on the ground" soil health activities succeed individually and collectively to improve agricultural productivity, preserve land value, mitigate environmental problems, and build a more secure future for farmers, landowners, rural communities, and urban populations dependent on sustainable agriculture.

Going forward, we recommend a 10 point plan with activities clustered into three broad strategic areas of focus: science, economics, and policy.

It will be crucial to continue building the **science-based rationale** and experience for soil health. Access to information, both fundamental scientific research as well as the understanding gained by demonstrating practices in the field, is foundational to establishing the credibility and justification to improving soil health. This information is needed at a variety of scales. At the farm-level, decisions need to be informed by recommendations on tailored best practices, local soil conditions, and climatic data. Innovation is needed in the decision-support tools farmers can use to determine daily, seasonal, and annual soil health management practices.

Broadly, there needs to be accurate and standardized methods for measuring soil health on a time-scale relevant to farming decisions. Finally, the causal links between building soil organic matter, carbon storage, decreased costs of food production, and improved productivity need to be improved to help fully value all the economic and environmental services provided by soil health.

In addition, developing **markets that value the benefits** created by improved soil health will be crucial to supporting the shift towards conservation agriculture practices. Various approaches will be needed to ensure these incentives impact farmers and landowners alike. Farmers need market opportunities to lower the cost of shifting toward those practices that build soil health, as well as reduced risk during this transition. Variable rate loans, payments for ecosystem services, targeted cost-sharing, and prioritized purchasing can all be explored as market-based approaches to help address these fundamental barriers.

An increasing role for landowners is key to improving soil health in U.S. row crop agriculture. They need to be made aware that soil health increases the potential rental income from their land, and that innovative lease agreements may help encourage the producers farming their land to adopt soil health practices (leading to benefits for both the landowner and tenant). Farm management companies may be a crucial intermediary to helping landowners find farmers who are willing to improve a farm’s soil health. Finally, farmland funds that own vast acreages can have a large impact by adopting policies that promote soil health.

Furthermore, new business models for agriculture retail companies, through which they profit from the distribution of goods and services that promote soil health, will be critical for reaching farmers and overcoming some operational challenges, like availability of the most appropriate cover crop seed. Some of this could be done by exploiting technological innovations in drones, sensors, precision agriculture software and hardware, and other technologies to advance adoption and sustained use of soil health practices. Retailers are also a critical link in the communications chain that impact the practices adopted by farmers. Along with peer-to-peer learning opportunities, communicating about soil health benefits among those that farmers trust is fundamental for overcoming cultural and knowledge barriers.

Finally, **policies** need to be adopted to promote soil health. Policy-makers at the national and state levels have the opportunity to create incentives that can drive soil health improvements. Soil health outcomes can be integrated into farm-related legislation, but also supported by policies that provide incentives for provisioning of environmental services. A strong constituency network of diverse stakeholders is needed to bolster such policy changes. Individuals, organizations, and companies in the agri-food sector should come together to show support to their policy-makers of action on soil health.

To move quickly along this roadmap and catalyze a paradigm shift in which all stakeholders engage in improving soil health through a balanced and increasingly biological approach, The Nature Conservancy has developed the following 10 recommendations.

Science

RECOMENDATION #1

Create cost-effective soil health measurement standards and tools

Create accurate, accessible, and standardized methods for rapid measurement of key soil health indicators at a scale that impacts management choices by farmers and landowners

Developing enhanced soil health measurement standards and tools that can be cost effectively deployed by researchers, farmers, crop consultants, and others will accelerate understanding of the relationship between changes in management practices and soil health. Fostering clear and usable standards for new soil health measurement technologies will aid commercial market development and rapid deployment of effective measurement tools.

Over the past decade, research and development into new testing methodologies has increased. These efforts should continue; however, additional investment is necessary, given the complexity and importance of this task. The Soil Health Institute (SHI) has emerged as a strong leader and has established a visionary agenda for research and development to address this issue. Likewise, the U.S. Department of Energy's Advanced Research Program for Energy has also recently established an investment program—Rhizosphere Observations Optimizing Terrestrial Sequestration (ROOTS)—to support novel technologies to create advanced measurement tools.

Lead Actors: Research institutions, private sector, Soil Health Institute, grower organizations

RECOMENDATION #2

Develop operational management strategies for adaptively integrating soil health practices and systems

Build evidence and understanding among farmers of operational strategies and regional variabilities for integrating multiple soil health practices on a farm, including optimal cover crop programs

Managing for soil health is a decision farmers do not take lightly. The timing of planting, harvesting, and operational decisions spanning the weed, insect and disease spectrum can be critical to achieving profitable yields and minimizing weather-induced crop losses.

Farming for soil health may require changes in equipment, changes in allocation of time and resources for planting and terminating cover crops, and testing and evaluating the benefits of various crop rotations. Changing one element of the management operation mix often has consequences on other operational decisions, sometimes spanning several seasons. For example, crop rotations need to be designed that facilitate cover crop establishment to improve soil health while allowing for efficient food and commodity production.

Additionally, there is significant variability within and across fields. The impact of an operational management approach designed to improved soil health could markedly differ within the same farm, let alone farms in the same county, region, or state. As a result, farmers will need strong evidence of the benefits of making soil health practice changes and will also need to easily share information and knowledge with other farmers, trusted advisors, and specific topic experts.

Lead Actors: Research institutions, extension, conservation districts, NRCS, grower organizations, Soil Health Partnership retailers, private sector

RECOMENDATION #3

Advance the science of soil health benefits

Further quantify the economic costs and benefits and environmental impacts of different management practices and integrated systems on soil health, including organic systems, with consideration for different regions, soil types, and cropping systems

There is a growing body of scientific evidence demonstrating the productivity and environmental benefits of improved soil health. However, there are also many unanswered questions about the relationship between changes in soil health and specific anticipated impacts, especially given the variability of soils and climatic conditions across the U.S.

The level of soil carbon sequestration and the permanence of sequestered carbon is still an open question. Currently, there are compliance grade credits for carbon sequestration for forest management practices; however, no such protocols exist for cropland soil management. Efforts should be undertaken to conduct the basic scientific research that would support the development of such protocols.

Likewise, potential changes in yields, total productivity, and nutrient loss under various soil health management practices have not been conclusively documented. Organic management practices and their relationship to soil health benefits deserve special attention, given the increasing interest in organically certified food products.

As linkages between management practices, soil health changes, productivity gains, and conservation outcomes become more clear, policy development or incentive payments must be targeted to achieve a compelling set of economic and environmental benefits.

Lead Actors: Research institutions, Soil Health Institute

Economics

RECOMENDATION #4

Align incentives between landowners and farmers

Cultivate understanding among absentee landowners of soil health benefits for society and land value and encourage new lease arrangements that integrate soil health systems and practices

Managing for soil health requires a multi-year planning horizon, yet the majority of cropland is owned by absentee landowners. Many of these landowners implement lease arrangements with tenant farmers, which encourages profit maximization in the short run, versus long-term management of the lands as an asset.

Landowners may be unaware of the potential benefits or consequences of different management practices on soil health benefits. To date, there have been no significant efforts to engage landowners on this topic through education outreach or incentives. Therefore, it is unclear which factors will compel or influence landowners to support management practice changes for soil health.

The opportunity to involve landowners in soil health may be the single most important near-term factor in unleashing rapid adoption of management practice change. However, it is also the factor that is currently least understood.

Lead Actors: Landowners, farm management companies, lenders etc.

RECOMENDATION #5

Leverage technological innovation to overcome operational hurdles

Leverage technological innovations (such as sensors, drones, cover crop seeding equipment, precision agriculture software and hardware) to advance adoption and continued implementation of soil health systems and practices

The operational complexities and upfront costs of implementing soil health practices may be limiting adoption. For example, with cover crops, farmers may have a very narrow growing season window in which to establish and grow them. Based on scientific advancements, technologies to improve intercropping cover crops with cash crops or allowing cover crops to be seeded weeks in advance of harvest may greatly improve adoption patterns, especially in northern latitudes.

Weed resistance is a looming threat to adoption of no-tillage practices, which depend on cost-effective herbicidal weed control. Therefore, innovative approaches to controlling weeds will be a lynchpin in the soil health movement. Organic producers will need non-chemical, no-tillage approaches to both weed control and cover crop termination.

Precision nutrient management programs when utilizing cover crops requires adequate, real-time and spatially explicit information about the level of plant-available nutrients. Given the interaction effects of crop rotation, tillage, and cover crops on nutrient balances, accurate soil fertility sensors, or software programs could greatly improve all forms of nutrient management.

Lead Actors: Public and private research institutions, agricultural retailers

RECOMENDATION #6

Provide broader access to products and services supporting soil health

Develop new business models with agricultural retailers that provide broader access to new products and services to accelerate soil health systems and practices

Farmers depend on agricultural retailers and crop consultants to provide training, knowledge, recommendations, and products and services that are applied to manage and produce crops. In this way, agricultural retailers are the trusted advisors of farmers, who are highly influenced by their agricultural retailers' knowledge and promotional activity.

Currently, agricultural retailers earn their profits by warehousing and selling fertilizer, seed, and crop protection products. Additionally, retailers earn service revenue for applying fertilizer and crop protection products. Most farmers do their own planting, and many are also licensed to apply fertilizer and crop protection products also.

Providing cover crop seed, as well as planting and terminating services, may be a growing area of opportunity for agricultural retailers. Farmer adoption of soil health practices could also be bolstered by localized recommendations on services, such as cover crop management, soil testing, and site-specific plant nutrient services, all of which are growing areas of need. Finally, assisting farmers in weed resistance management without resorting to tillage is a critical area of focus where agricultural retailers will be called on for support.

Lead Actors: Agricultural retailers

RECOMENDATION #7

Create market signals in sustainability programs for soil health

Develop improved indicators that reward soil health management outcomes in sustainability assessment programs, aligning the incentives of farmers and society

Over the past decade, farmers, agribusiness, food companies, conservation organizations, government, and academia have established programs to assess and communicate the sustainability of their integrated supply chains in response to stakeholder concerns about product impacts. In the U.S. row crop arena, leading programs are Field to Market and The Sustainability Consortium.

Given the significant societal benefits of soil health improvements, sustainability programs are a logical way to begin conveying incentives from societal stakeholders or consumers to farmers. Meaningful incentives may be financial or non-financial, such as preferred market access or recognition.

Developing appropriate market signals will rest on the development of effective measurements and standards, which reinforces the primacy of Recommendation

1. Once this is accomplished, weighting of indicators in sustainability programs to prioritize soil health improvements would send a stronger signal to farmers about the value that society places on the issue.

Lead Actors: Field to Market, food companies, agribusinesses, leading sustainability programs and farmers

Policy

RECOMENDATION #8

Reward farmers who optimize long-term soil health with lower crop insurance premiums

Advocate for federal subsidized crop insurance programs to value the benefits generated from improved soil health profiles through lower insurance premiums.

Crop-yield insurance programs can help reduce farmers' risk through unusual years of extreme weather events by paying for some of their missed income in the case of crop loss. The Risk Management Agency currently uses county-level data to calculate the premium rates for different crops in different areas of the country. For many farmers, the federal government subsidizes significant portions of this insurance premium.

With improved data that connects soil health improvements to increased resilience to weather extremes, policymakers could create a system in which subsidy rates for insurance premiums would vary according to soil health. For example, reducing rates for farmers who have improved their soil's health provides a significant financial rationale for the adoption of soil health practices. As of 2012 there were 1.17 million policies enrolled in the Federal Crop Insurance Corporation, covering 282 million acres[30], making this a policy change that could incentivize soil health improvements on hundreds of millions of acres.

Lead Actors: Agri-food sector, conservation organizations seeking to expand constituency, federal and state governments

RECOMENDATION #9

Support policies that enable greater investment in soil health

Support state and federal policy improvements that focus on soil health practice adoption, target

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[30] http://www.rma.usda.gov/pubs/rme/aboutrma.pdf

priority areas for implementation, and comprehensively assess impacts for societal values.

Numerous policies and programs at the federal and state levels influence farm management choices. Incorporating incentives for soil health practices into these policies could expand adoption. For example, the NRCS is increasingly incorporating soil health-promoting practices into their financial and technical assistance programs. Additionally, many research programs funded by public sources could advance soil health research objectives.

With public resources often limited, policymakers should consider policies supporting high-priority areas where soil health improvement would significantly benefit water quality, biodiversity, climate mitigation, or other outcomes. Both national and state-level resources could also be used to improve and increase data collection from participating farms in order to share that knowledge.

Policies that generate payments for ecosystem services such as clean water or mitigating climate change should evaluate the off-farm benefits of soil health practices. For example, California's Healthy Soils Initiative promotes soil health to advance multiple outcomes, including supporting the state's leading status as an agriculture producer, ensuring farms are more resilient to climate change, and contributing to the state's greenhouse gas sequestration goals.

Lead actors: State and federal governments, conservation organizations seeking to expand constituency

RECOMENDATION #10

Build a more diverse constituency for soil health policy

Build a strong and diverse network of supporters for soil health policy, including farmers, landowners, the agri-food sector, community leaders, and societal interest groups.

The on-farm and off-farm benefits of soil health could translate into support from a diverse range of stakeholders. There is increasing interest in this space, from top academic research institutions, to environmental and conservation organizations, to the agri-food supply chain and more. To address barriers to soil health practice adoption and advance the policies that could significantly expand these practices, this diverse group of stakeholders should identify common positions on soil health. There is strength in such partnerships, which could rapidly advance policies for soil health. Many of the existing partnerships and programs on soil health will be a useful platform for initiating broader discussions.

Lead actors: Farmers, landowners, agri-food sector, community leaders, societal interest groups

Conclusion

The Nature Conservancy is proud of our heritage as a leading conservation organization. In its earliest day, our organization was dedicated to identifying and protecting rare species – plants and animals requiring a special habitat to survive wild places and lands. Over the years, our focus has expanded to encompass not only places in need of protection, but also species and systems in need of protection. Today, our mission is to "conserve the lands and waters on which all life depends," ensuring the long-term survival of all biodiversity on earth. The scale of our ambition has fundamentally changed. To achieve this mission, we must rethink our conservation strategies. Through this lens, leveraging the economic and conservation gains owing to management practices that improve soil health aligns with our mission and provides a means to scale our impact on an issue we feel passionately about. The actions we take today to improve soil health hold the promise of significant economic and environmental returns for tomorrow.

We have articulated a new vision for soil health: transform the U.S. cropland management paradigm toward making soil health the leading indicator for on-farm operational decision, thereby incurring the adoption of soil health practices on more than 50% of U.S cropland by 2025. Achieving the vision is at once a compelling opportunity and a daunting challenge.

As the roadmap recommendations illustrate, there is not a single technology, market signal or policy change which will achieve the vision. It is also well beyond the reach of any single institution to implement a change of this magnitude. Achieving the vision will require parallel efforts across science, markets and policy, working in a more coordinated fashion and committed to obtaining results field by field across the vast and variable U.S. farming sector.

TNC is committed to playing a much larger role in facilitating this opportunity, while also recognizing the significant efforts highlighted in this paper. The science agenda for soil health will require significant, long-term investments and collaborations. TNC is expanding our science capacity in this area with a new lead scientist role for soils. The Lead Scientist will provide new capacity for TNC to design strategies to assess the relationship between management practices changes and conservation impacts. Perhaps more importantly, TNC will be a much more capable partners with organizations charting the future of soil health research.

On the policy front, TNC is actively engaged in discussions about current and future opportunities at both the state and federal level. TNC has supported efforts to target existing conservation programs for highest impact and is engaged in policy planning projects on the future of crop insurance. Most importantly, TNC's network of state chapters and trustees can be activated to provide much needed support for innovative policy opportunities in support of soil health.

To reach the vision, however, it is clear that address the economic or marketplace barriers discussed in this paper. Chief among these barriers are the potential disincentives for soil health practices between landowners and farmers. Over the years, TNC has curated a set of working farms, which can serve as a living laboratory to test new ideas and serve as the basis for broader engagement with absentee landowners. Likewise, agricultural retailers serve as the trusted advisors of farmers. Through both new and existing relationships we seek to support agricultural retailers who share our vision and are interested in building product and service models to achieve it. Finally, innovation must occur to address the cost and operational hurdles that have been discussed. Thankfully, investment is increasing in multiple segments of need and TNC is open to new collaborations, which will increase the pace of conservation impact.

We are bringing our science-based "Conservation by Design" approach to the complex issues around soil health, which means utilizing the best available scientific information and tools to set goals and priorities, develop strategies, take action, and measure results. We intend to apply that time-tested approach to achieving our vision for soil health: to transform the U.S. cropland management paradigm to make soil health the primary indicator for on-farm operational decisions, leading to the adoption of soil health practices on more than 50% of U.S. cropland by 2025. By convening with a number of stakeholders, The Nature Conservancy intends to expand its resources and initiatives to champion the recommendations outlined in this paper, which aim to address scientific, economic, and policy challenges or factors that currently limit the adoption of soil health practices.

To this end, we invite interested organizations and individuals to share feedback and expression of interest in the ideas articulated in this paper by emailing soil@tnc.org.

Appendices

Appendix A: Size of the Prize assumptions, estimates, and approach

Summary of Approach

Our approach to the estimation can be broadly divided into "off-farm" and "on-farm" estimates, meaning we analyzed society's incentives and benefits of soil health separately from farmers' benefits. Before explaining each of those approaches below, we provide an overview of practices and outcomes considered as well as important regional assumptions that apply to both off-farm and on-farm methodologies.

Outline of Appendix A:
I. Soil Health Practices Assumptions and Adoption Rates
II. Land and Region Assumptions
III. Off-Farm
    a. Estimates of Current Off-Farm Impact
    b. Estimates of Off-Farm Outcomes
IV. On-Farm Outcomes

<u>Soil Health Practices Assumptions and Adoption Rates</u>

Key Practices (both on- and off-farm):

- Crop rotation: increased diversity into annual cash crop rotations
- Cover crops: crops left in the ground over winter primarily for non-commercial reasons
- Conservation till: no-till or strip-till

Key Outcomes:

- Off-Farm: GHG emission reduction / Carbon sequestration, Erosion reduction, Nutrient loss reduction, Water use/increased water capacity, and societal costs associated with each of these environmental impacts
- On-Farm: Profit based on yield and cost changes compared to baseline conventional farming

Data indicated that cover crops are adopted on 1-5% of U.S. acres,[31] crop rotation on about 25%,[32] and conservation tillage on about 25%.[33] The estimation calculated the impact of an

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[31] Wade, Claassen & Wallander, 2015

[32] Foreman, 2014

[33] Wade et al, 2015

additional 1% of total acres of corn, soy, and wheat managed under these conservation practices, meaning an increase from 5% to 6% in cover crop adoption, and an increase from 25% to 26% in crop rotation and conservation tillage adoption. Then, it estimated the impact of 50% adoption of acres, or roughly a tenfold increase in cover crops and a doubling of crop rotation and conservation tillage, and finally what 100% full adoption would look like for all three practices.

Land & Region Assumptions

Given the variability of effects of soil health practices by region, climate, soil type, and others, we identified certain representative regions from which to gather data. With the scope of this initiative being focused on U.S. row crops, we chose the Heartland/Lake region and West region to capture the majority of corn, soy, and wheat acres in the U.S. The scale of relative acres and our assumptions of these regions are summarized below.

We defined the Heartland/Lake region as Iowa, Illinois, Indiana, Kentucky, Ohio, Missouri, Michigan, Minnesota, and Wisconsin. According to USDA ERS[34], the total planted acres of corn, soy, and wheat in this region was about 99.8 million acres as of 2015, over half of which is corn and about 40% of which is soy. This region was selected as representative for carbon sequestration, reduced erosion, and reduced nitrogen loss estimations.

The West region we defined as Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington State, and Wyoming. According to USDA ERS[35], the total planted acres of corn, soy, and wheat in this region was about 93.8 million in 2015, about half of which was wheat. This region was selected as representative for water storage capacity estimations.

Total U.S. planted acres in 2015 was about 88.9 million acres of corn, 83.7 million of soybean, and 56.1 million of wheat. Total acres of these three row crops in the U.S. were therefore about 228.7 million. Aggregating the acres of all three crops, the Heartland/Lake region accounts for 44% of acres planted and the West 41% so we believe we have captured 85% of the total acres for these three crops.

Estimates of Current Off-Farm Impact

We gathered literature estimates of the current contribution from North American row crop agriculture to greenhouse gas emissions (metric tonnes CO_2e), nutrient loss in leaching (pounds), erosion (U.S. tons, converted to metric tonnes), and water use (acre-feet). Additionally, societal economic costs associated with these environmental contributions

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[34] http://www.usda.gov/nass/PUBS/TODAYRPT/acrg0615.pdf

[35] http://www.usda.gov/nass/PUBS/TODAYRPT/acrg0615.pdf

were drawn from literature. Note that the “baseline” estimates are current contributions from U.S. row crop agriculture, meaning any progress is in addition to benefits from current adoption. Additionally, estimates are of gross benefits (not including the costs of incenting farmers to implement the practices), meaning that in most cases net societal benefits would be lower.

Greenhouse Gas Emission (GHG)

GHG emissions from crop agriculture in 2004 was estimated using USDA ERS[36] data of fossil fuel combustion, crop residue burning, and soil management, accounting for carbon, methane, and nitrous oxide (but excluding estimates not attributable to row crops). The total carbon equivalent of emissions was estimated to be 94.3M metric tons of carbon equivalent or **345.8 million metric tons of carbon dioxide**, the majority of which was contributed by soil management.

The EPA[37] estimated the social cost of CO_2 with a comprehensive estimated of climate change damages including net agricultural productivity, human health, property damages from increased flood risk, and changes in energy system costs. We selected a conservative estimate for 2015 at 3% average discount rate to reach $36 per metric ton of CO_2. At the 345.8M metric tons of CO_2 estimated above, the US societal cost of GHG emissions is estimated to be about **$12.4 billion.**

The assumption is that about 44% of US GHG emission occurs in the Heartland/Lake region because that is the proportion of total U.S. planted acres of corn, soy and wheat that occur in that region. Therefore, Heartland/Lake estimates were 345.8 million metric tonnes*0.44 = **150.8 million metric tonnes** CO_2 eq and $12.4 billion*0.44 = **$5.43 billion**.

Nutrient Loss (Leaching)

The USDA ERS published an estimated 140 pounds/acre for corn, 16 pound/acre for soybean and 65 pounds/acre for wheat of N or N equivalent (including N, P2O5, and K) was applied in the U.S. in 2013.[38] It was also estimated in a USDA NRCS study[39] that about one-fourth of nitrogen applied is lost to leaching.

Using the U.S. number of acres for each of these three crops, the total estimated pounds of N applied in the U.S. is about 17.4 billion. One-fourth of 17.4 billion pounds is **4.4 billion pounds of N or N equivalent** per year in the U.S. from major row crops.

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[36] http://www.ers.usda.gov/media/434512/tb1909_1_.pdf

[37] https://www3.epa.gov/climatechange/EPAactivities/economics/scc.html

[38] http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx, Tables 10, 22, 28

[39] http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/landuse/crops/?cid=nrcs143_014202

The cost of nitrogen leaching was estimated by Sobota et al in 2015[40]. We selected the surface, groundwater, and coastal N loading damages to humans and society and excluded the air estimates, which are included in our GHG emission methods. Specifically, parameters of damages included are declining waterfront property value, loss of recreational use, loss of endangered species, increased eutrophication, undesirable odor and taste, nitrate contamination, and colon cancer risk for a total median estimated cost of $18.93/kilogram N or $8.59/pound N. At the 4.4 billion pounds of nitrogen estimated above, the U.S. societal cost of N leaching is estimated to be **$37.4 billion**.

One shortcoming we acknowledge is the emphasis on nitrogen in our estimates, given that phosphorous is the key culprit in driving water quality problems in most freshwater systems. However, the hypoxic zone in the Gulf of Mexico has some areas that are nitrogen-limited.. While both have impacts in many dimensions, we viewed reducing nitrogen as a more attainable and representative opportunity for positive change in row crop agriculture for this rough analysis.

The assumption is that about 49% of N loss occurs in the Heartland/Lake region. This figure comes from multiplying Heartland/Lake planted acres of corn, soy, and wheat by the mass of N applied to each crop acre (per numbers and source above), and dividing by all U.S. acres of these crops by the average U.S. nitrogen applied per acre. Therefore, Heartland/Lake estimates were 4.4 billion pounds*0.49 = **2.14 billion pounds** and $37.4 billion*0.49 = **$18.4 billion**.

<u>*Erosion*</u>

The USDA NRCS quantifies erosion from Cropland by Year as of 2007 as 2.7 tons per acre from water (sheet & rill) and 2.1 tons per acre from wind[41]. At 4.8 total tons per acre multiplied by the total number of acres in the U.S. of corn, soy, and wheat (228.7 million acres), the resulting estimate is 1.1 billion tons of erosion from US row crops per year, or **996 million metric tonnes**.

The USDA NRCS estimated in 2001 an annual cost of erosion of $247 per hectare or $100 per acre[42] from cropland agriculture. This estimate takes the costs of nutrients and water into consideration as well as societal costs of degraded and/or deserted soils.

At $100 per acre times the total number of acres in the U.S. of corn, soy, and wheat of

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[40] http://iopscience.iop.org/article/10.1088/1748-9326/10/2/025006/meta;jsessionid=CEAF9C2B0978DAA48726D057E3DF9EFD.c2.iopscience.cld.iop.org

[41] http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/nra/nri/results/?cid=stelprdb1041678

[42] http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/use/?cid=nrcs142p2_054028

228.7 million, the resulting estimate is **$22.9 billion** of erosion costs from U.S. row crops per year.

According to these estimates, the cost per ton of erosion = $22.9 billion /1.1 billion tons = $21/ton, or $22.9 billion / 996 million = $23/metric tonne.

The assumption is that about 31% of U.S. erosion takes place in the Heartland/Lakes region per estimates from USDA NRCS[43]. This figure comes from the amounts of water and wind erosion specific to the Heartland/Lake states as a proportion of the U.S. total. Therefore, Heartland/Lake estimates were 996 million metric tonnes*0.31 = **309 million metric tonnes** and $22.9 billion*0.31 = **$7.10 billion**.

Water Use

Agriculture's impact and potential remedies in relation to water was measured using rough proxies related to irrigation water use and crop insurance payments from drought/flooding. Note that due to limitations on data availability we use "water use" to mean water withdrawals from both ground and surface water for irrigation, which does not consistently represent water *consumption* – namely evaporation and transpiration – which is the driver of water scarcity in much of the U.S.

According to a 2012 USDA ERS report, 75% of irrigated land is in the Western states. Irrigated acres of our focus crops in the West is about 17.7 million, or 41% of corn, 15% of soybeans, and 8% of wheat[44]. Total U.S. irrigated land was therefore estimated to be about 17.7M/.75 = 23.6 million.

The average application on irrigated acres was 2.05 acre-feet/acre in 2008[45], so water use was estimated to be 17.7 million acres * 2.05 acre-feet/acre = **36.3 million acre-feet in the West** and 23.6 million acres * 2.05 = **48.4 acre-feet** in the U.S. total per year. Note that the same source estimated total agricultural water use in the U.S. (for all crops, not just corn, soy, and wheat) as 143 million acre-feet.

Cost associated with this magnitude of irrigation was estimated using the price of water across the U.S. regions. (Note: this does not include cost of pumping or irrigation equipment, as our goal is to simply get an economic or societal value for the water being

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[43] http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/nra/nri/results/?cid=stelprdb1041678; http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/nra/nri/results/?cid=nrcs143_013656;

http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/nra/nri/results/?cid=nrcs143_013655

[44] http://www.ers.usda.gov/media/884158/eib99.pdf

[45] http://www.ers.usda.gov/media/884158/eib99.pdf

used, not the economic cost of irrigation to the farmer). The logic is that by increasing water capacity in the soils, less irrigation would be required on some land. Average cost of purchased water in the West is $66.28/acre, but in the East and rest of U.S. the cost is more around $10/acre[46]. Using the weighted average of cost and number of acres of these two regions, the total cost of water in the U.S. was estimated to be ($66.28/acre * 17.7 million acres) + ($10/acre * 5.9 million acres) = **$1.2 billion.** While the value of irrigation water in terms of how much farm profit increases for each unit varies (as water gets scarcer, the marginal value goes up, Fenichel et al 2016), for simplicity we used a constant value for a unit of water.

A second economic factor related to water that we included in the estimate relates to the societal cost of flooding and drought through crop insurance indemnities. The average of indemnities paid from 2011-2015 was about **$11.1 billion**[47], the majority of which was attributed to losses related to drought and excess moisture/precipitation[48]. Unlike the irrigation estimate of the West, in this case, the assumption is that the West accounts for 41% or less of these crop insurance damages as that is the percent of production of these three crops as a proportion of the total U.S. planted acres.

Between these two metrics, water-related economic costs in the U.S. were estimated to be **$12.3 billion** total**.** West region cost estimates were calculated as ($66.28 * 17.7 million) + ($11.1 billion * 0.41) = **$5.74 billion**.

Estimates of Off-Farm Outcomes

We drew upon a broad range of literature that indicates the impact on carbon sequestration or greenhouse gas mitigation, nutrient loss reduction, erosion or sediment loss reduction, and water storage capacity as a result of integrating each soil health practice of conservation tillage, cover crops and crop rotations into farming operations. Below is a summary of how we calculated potential broad impacts based on these published literature points.

Carbon Sequestration Estimates

While the permanence of carbon sequestration from agricultural practices is still widely unknown, we adopted data, which suggested that carbon sequestration could be an average 0.29 metric tonnes of CO_2 equivalent per acre with cover crops, 0.50 metric tonnes per acre with conservation tillage, and 0.29 metric tonnes per acre with crop rotations[49].

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[46] http://www.ers.usda.gov/media/884158/eib99.pdf

[47] http://www.rma.usda.gov/data/indemnity/2015/

[48] http://www.rma.usda.gov/data/cause.html

[49] http://www.ers.usda.gov/media/434512/tb1909_1_.pdf

To calculate the impact of increased acres under these practices on carbon sequestration, the following formula as used:

[increase in adoption] * [# acres in Heartland] * [metric tonnes of CO_2e per acre sequestered] = metric tonnes of CO_2e sequestered

For example, an adoption increase of 1% of row crop acres under cover crops, the calculation was

1% * 99.8 million acres * 0.29 metric tonnes CO_2eq/acre = 292,645 metric tonnes of CO_2e/year.

For conservation tillage, 0.29 metric tonnes of CO_2 eq sequestered was replaced by 0.50 metric tonnes, and for crop rotation, 0.29 metric tonnes was used.

That yielded three figures (292,645, 493,822, and 292,645 metric tonnes/year, the potential impacts of each practice in isolation), which were averaged and then divided by 44%, the proportion of total U.S. planted acres of corn, soy and wheat that occur in the Heartland/Lake region as described above, to reach a likely impact in all of U.S. acres at 1%, 826,000 metric tonnes/year, presented in the Size of the Prize section. The figures were summed and then divided by 44% to indicate a potential high extreme impact of the practices, assuming additive effects, in all of U.S. acres (provided in parenthesis of the Size of the Prize section).

To calculate the corresponding societal cost, this average value of 824,508 metric tonnes was multiplied by $36/metric tonne per the EPA estimate to yield a societal cost savings of about $29.7 million per additional 1% of acres adopting these practices.

The same approach was applied to calculate a total of 50% adoption – averaging the impact of an additional 45% of crop acres on cover crops and an additional 25% of acres on conservation tillage and crop rotations – and 100% adoption. All of these estimates were divided by 44% to estimate the potential impact of all of U.S. acres.

Nutrient Loss, Erosion, and Water Use Estimates

Data suggested that nutrient loss could decrease by 28%[50] with the use of cover crops, by 33%[51] with the use of conservation tillage, and by 11%[52] with the use of crop rotations. Erosion could decrease by 33%[53] with the use of cover crops and by 33%[54] with the use of

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[50] https://www.cals.iastate.edu/sites/default/files/misc/183758/sp435.pdf

[51] Syswerda et al, 2011

[52] http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0047149

[53] https://www.farmfoundation.org/news/articlefiles/1904-Jay%20Atwood.pdf

conservation tillage. Finally, water storage capacity could be 19%[55] greater with the use of cover crops, 25%[56] greater with the use of conservation tillage, and 30%[57] greater with the use of crop rotations. The methodology for estimating potential reduction of these three environmental indicators was similar. An example of how an increase of 1% of acres could reduce nutrient runoff will be provided below and is applicable for erosion and water use as well.

The basic formula was: [increase in adoption] * [Estimated nutrient runoff (pounds) in Heartland] * [% reduction of nutrient runoff from cover crops]

Therefore, an adoption increase of 1% of row crop acres under cover crops was calculated as: 1% * 2.14 billion pounds/year * 28% reduction = 5.998 million pounds/year

For the benefits of conservation tillage on an additional 1% of U.S. acres, which would reduce leaching by 33%, we replace 0.28 with 0.33 to get 7.069 million pounds/year of N loss avoided. For crop rotation we use 0.11 to get 2.410 million pounds / year of N loss avoided in the Heartland/Lake region.

These three figures – specifically 5.998, 7.069, and 2.410 million pounds/year, the potential impacts of each practice in isolation – were averaged and then divided by 49%, the weighted average of nitrogen applied in the Heartland/Lake region versus the rest of the U.S. as described above, to reach a likely impact in all of U.S. acres at an additional 1% of acres adopted, about 10.5 million pounds/year presented in the Size of the Prize section. The figures were summed and then divided by 49% to indicate a potential high extreme impact of the practices, assuming additive effects, in all of U.S. acres (provided in parenthesis of the Size of the Prize section).

The same approach was applied for a total of 50% adoption (averaging the impact of an additional 45% of crop acres on cover crops and an additional 25% of acres on conservation tillage and crop rotations) and 100% adoption. All of these estimates were divided by 49% (proportion of N loss in Heartland/Lake vs. all of U.S. as explained above) to get an estimate to represent the potential impact of all of U.S. acres.

Estimates of On-Farm Outcomes

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[54] https://dl.sciencesocieties.org/publications/sssaj/abstracts/77/4/1329

[55] https://www.farmfoundation.org/news/articlefiles/1904-Jay%20Atwood.pdf

[56] http://www.sciencedirect.com/science/article/pii/S2095633915300630

[57] http://sustainablecorn.org/PDF_download.php/doc/Resilient_Ag_Articles/Strock_Understanding-Water-Needs-of-Diverse-Multi-year-Crop-Rotations.pdf

It is important to note that for on-farm estimates, the literature cited a variety of time horizons. For the sake of our analysis, a simple annual average was taken to determine potential benefits and costs to farmers over the long-term (beyond 5 years) for adopting soil health practices. As such, while on-farm economic benefits were determined to be positive, it is not likely to be positive in the first year for farmers due to up-front learning curves, equipment, and investment costs. Likewise, these on-farm benefits could vary widely by region, watershed, soil type, and other conditions.

Another important note is that on-farm benefits were calculated as net benefits, calculating both the benefits and costs to farmers. This is in contrast to off-farm outcomes, which only considered gross benefits. By this, we mean that not only changes in yield were considered, but also changes in costs to farmers associated with adopting these three soil health practices.

Estimates of on-farm economic benefits were based on corn acres only, as that was where we had the most data on yield and cost impact of adopting the three practices. Numerous studies were reviewed to determine average impact, taking costs such as equipment, inputs, and labor/time into account as compared to conventional farming practices. Costs varied from positive to negative based on the practice. For instance, costs increased on average for cover crops due to seed costs, but decreased on average for conservation tillage due to reduced passes in the field as well as for crop rotation due to less fertilizer requirements. The average and standard deviation of yield and costs impacts were measured in order to calculate a range of potential impacts.

Through this method, we estimated a yield impact of -1% for conservation till[58], 10% for cover crops[59], and 6% for increased crop rotations[60]. Cost impact estimates were +$21/acre for conservation till[61], --$34/acre for cover crops[62], and +$28/acre for increased crop

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[58] 1) http://extension.psu.edu/plants/crops/soil-management/conservation-tillage/economics-of-conservation-tillage; 2) http://www.agronext.iastate.edu/smse/tillage/pdfs/research-report.pdf; and 3) https://www.ideals.illinois.edu/bitstream/handle/2142/50633/Patrick_Henry.pdf?sequence=1

[59] 1) https://www.pioneer.com/home/site/us/agronomy/library/managing-winter-cover-crops/#firsttable; 2) https://www.cals.iastate.edu/sites/default/files/misc/183758/sp435.pdf; and 3) http://sustainableagriculture.net/wp-content/uploads/2015/07/Working_Group_Report_and_Recommendations.pdf

[60] 1) http://corn.agronomy.wisc.edu/AA/A014.aspx; 2) http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0047149; 3) https://www.extension.iastate.edu/agdm/crops/html/a1-90.html; and 4) http://extension.psu.edu/plants/crops/soil-management/conservation-tillage/crop-rotations-and-conservation-tillage

[61] 1) http://www.nrcs.usda.gov/wps/portal/nrcs/detail/ia/home/?cid=nrcs142p2_008633; 2) http://www.nrcs.usda.gov/wps/portal/nrcs/detail/ia/home/?cid=nrcs142p2_008633; 3) https://www.nrdc.org/experts/claire-oconnor/farmers-reap-benefits-no-till-adoption-rises

[62] 1) https://www.farmfoundation.org/news/articlefiles/1904-DC%20soil%20health%20conf%20Tyner%2022sep2015.pdf; 2) http://www.nrcs.usda.gov/wps/portal/nrcs/detail/ok/soils/health/?cid=stelprdb1260243

rotations[63].

Using the 2015 average yield[64] of corn as 168.4 bushel/acre and cost as 94% of sales[65] as the baseline for conventional practices, the profit per acre on average was calculated based on the 10-yr average of corn prices ($/bushel), $4.47[66]. Our baseline was therefore about $752/acre revenue, $707/acre costs, and $45/acre in profit.

The change in revenue was calculated by multiplying baseline yield by (1+x%) of the change in each practice, multiplying it by $4.47, then subtracting the baseline. Likewise, cost changes were calculated by the change from the baseline $707/acre.

For example, for cover crops, yield was estimated to be (168)+(168*.1) = 185 bushel/acre. Revenue was estimated to be 185 bushel/acre * $4.47/bushel = $826/acre. Costs were estimated to be $707+$34 = $741/acre. Profit is therefore estimated to be $826--$741 = $85/acre for cover crops, which is $40, or 47%, higher than the baseline conventional farming profit estimate of $45/acre.

The average profit change by practice resulted in $40/acre for cover crops, $14/acre for conservation till, and $70/acre for increased crop rotations. To estimate aggregated potential on-farm profit gain through these soil health practices on corn acres, the following formula was used:

[% adoption] * [# U.S. corn acres] * [Profit change from cover crops]
For an increase of 1% of acres on cover crops, the follow figures were used:
1% * 88.9 million acres * $40/acre = $35.8 million

As with the off-farm benefits, the estimated economic outcomes of the other two practices were used in place of $40 ($14 for conservation tillage and $70 for crop rotation). The average of the three practices was taken to estimate the likely economic gain to corn farmers in the U.S.

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[63] 1) http://extension.psu.edu/plants/crops/soil-management/conservation-tillage/crop-rotations-and-conservation-tillage; 2) https://www.extension.iastate.edu/agdm/articles/duffy/DuffyDec11.html

[64] http://www.nass.usda.gov/Quick_Stats/Lite/index.php#B91D2210-3926-31EE-B539-FFB3E6183ABC

[65] http://www.ers.usda.gov/data-products/commodity-costs-and-returns.aspx

[66] http://www.farmdoc.illinois.edu/manage/uspricehistory/us_price_history.html

Appendix B: Soil health glossary*, adapted from NRCS Soil Health Glossary (see Appendix C)*

Dynamic soil properties: Soil properties that change over the human time scale in response to anthropogenic (management, land use) and non-anthropogenic (natural disturbances and cycles) factors. Many are important for characterizing soil functions and ecological processes and for predicting soil behavior on human time scales.

Indicator of soil quality: A quantitative or qualitative measure used to estimate soil functional capacity. Indicators should be adequately sensitive to change, accurately reflect the processes or biophysical mechanisms relevant to the function of interest, and be cost effective and relatively easy and practical to measure. Soil quality indicators are often categorized into biological, chemical, and physical indicators.

Indicators of soil quality, biological: Measures of living organisms or their activity used as indicators of soil quality. Measuring soil organisms can be done in three general ways: 1) counting soil organisms or measuring microbial biomass, 2) measuring their activity (e.g. soil basal respiration, cotton strip assay, or potentially mineralizable nitrogen), or 3) measuring diversity, such as diversity of functions (e.g., biolog plates) or diversity of chemical structure (e.g. cell components, fatty acids, or DNA). Each approach provides different information.

Indicators of soil quality, chemical: These include tests of organic matter, pH, electrical conductivity, heavy metals, cation exchange capacity, and others.

Indicators of soil quality, physical: Physical characteristics that vary with management include bulk density, aggregate stability, infiltration, hydraulic conductivity, and penetration resistance.

Monitoring soil quality: Tracking trends in quantitative indicators or the functional capacity of the soil in order to determine the success of management practices or the need for additional management changes. Monitoring involves the orderly collection, analysis, and interpretation of data from the same locations over time.

Soil organic matter: The total organic matter in the soil. It can be divided into three general pools: living biomass of microorganisms, fresh and partially decomposed residues (the active fraction), and the well-decomposed and highly stable organic material. Surface litter is generally not included as part of soil organic matter.

Soil health: The continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals, and humans.

Appendix C: Additional soil health resources

NRCS Soil Health Glossary

http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/health/?cid=nrcs142p2_053848

NRCS Soil Health Information and Resources

http://www.nrcs.usda.gov/wps/portal/nrcs/detail/id/soils/health/?cid=nrcs144p2_046415

FAO Importance of Soil Organic Matter

http://www.fao.org/docrep/009/a0100e/a0100e0d.htm

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