WASHINGTON
SOIL
HEALTH INITIATIVE

ROADMAP

2021

EXECUTIVE SUMMARY

Washington State's agricultural sector is as diverse as the soil types and climates in the state. Washington has over 35,000 farming operations spread across 14,600,000 acres contributing more than 10 billion dollars to the economy. The top 10 commodities in the state are: apples, milk, potatoes, wheat, cattle, hops, hay, cherries, grapes, and onions. All of this relies, directly or indirectly, on soils.

Healthy soils are considered a non-renewable resource, providing a variety of functions essential to plants and animals. The concept of soil health continues to evolve as the science in this field progresses.

The United States Department of Agriculture (USDA) Natural Resource and Conservation Service (NRCS) defines soil health as "…the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans".

Farmland with healthy soils benefits agricultural production as well as provides and protects ecosystem services of the surrounding environment. Examples of on-farm benefits include improved soil tilth, nutrient cycling, water holding capacity, and disease suppression. Off-farm benefits include reduced soil erosion, carbon sequestration, and improved water quality.

This Soil Health Roadmap for Washington State is intended to be a living document, outlining current issues and pathways to potential solutions, while setting clear goals and milestones to maintain or improve the health of Washington State agricultural soils. As milestones are reached, new ones will need to be set. Likewise, as the science of soil health improves, priorities and practices will also need to evolve.

This roadmap divides the state into eight focus areas that included Dryland Agriculture in Eastern

Washington, the Environmental Community, Irrigated Columbia Basin, Irrigated Potato Production in the Columbia Basin, Juice and Wine Grapes, Northwestern Washington Annual Cropping Systems, Tree Fruit, and Western Washington Diversified Farming Systems. These focus areas represent over 5.4 million acres, covering roughly 40% of total agricultural land or 72% of non-rangeland cropland in the state. The decision to focus on these areas are to support the parallel efforts as part of the Washington State Soil Health Initiative to establish Long-Term Agroecological Research and Extension sites across the state. The information contained within this roadmap will help to inform the design of these experiments.

The effort to create a Soil Health Roadmap for Washington State was a coordinated effort by many individuals at Washington State University, the Washington State Department of Agriculture, and the Washington State Conservation Commission. The roadmap process began in the fall of 2019 with funding from the Washington State Legislature and was completed in the fall of 2021. This roadmap effort utilized a participatory model through direct and indirect interactions with key stakeholders across the state. Information was sought through previous soil health feedback events/needs assessments, in-person and online feedback sessions specifically for this roadmap, and through surveys with key stakeholders. This information was collected by focus area leaders, then synthesized with key themes distilled by roadmap editors, and finally reviewed by internal and external partners.

While each focus area highlights unique themes of the region and/or production system, several cross-cutting needs and ideas emerged.

Some major goals and priorities included:

- The development of universal low-cost soil health measurement tools and set of metrics
- Improved knowledge of soil health
- Preservation of existing soil organic matter with increases of levels in the future
- Understanding of the concept and value of soil health by the general public

Examples of soil health problems include soil pH, soilborne diseases, compaction, wind and water erosion of soils, and poor soil structure that results in flooding and limits access to fields. Many specific milestones were identified, and examples include increases in soil water holding capacity, 30% increase of landowner enrollments in soil health incentive programs, increased capacity of soil health research particularly in eastern Washington, increases in soil carbon levels, reduced soil erosion rates, and improved access to production system specific soil health information.

The roadmap also identified information gaps in our soil health knowledge. Examples include lack of understanding of soil biology by producers and agricultural professionals, difficulties in translating the current scientific understanding into practical agronomic decisions, improved understanding of the relationship between soil health and food quality, and the return on investment of soil health practices. Major barriers to adoption of soil health practices were the complexity of the practices (e.g., crop rotation) as well as difficulty with enrolling in current incentive programs. To overcome these barriers, stakeholders listed the need to increase agency and University capacity and expertise in soil health and large-scale targeted education. Specific policy changes ranged from altering current and future inventive programs to provide flexibility for farmer experimentation to taxing fertilizers, carbon, and soil erosion. Examples of areas where additional investments are needed include quantifying the value of the various services provided by soil health improving practices, University and Extension capacity in soil health, funding for long-term experimentation, and the development of an effective tool to assess soil carbon levels at scale.

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LIST OF ABBREVIATIONS

AVA	American Viticultural Areas
BMP	Best management practice
CP3	Columbia Plateau PM10 wind erosion program
IAREC	Irrigated Agriculture Research and Extension Center
NWREC	Northwestern Washington Research and Extension Center
PNW	Pacific Northwest
REACCH	Regional Approaches to Climate Change
ROI	Return on investment
SOM	Soil organic matter
STEEP	Solution To Environmental and Economic Problems
USDA	United States Department of Agriculture
V&E	Viticulture and Enology
WA	Washington State
WSDA	Washington Department of Agriculture
WSU	Washington State University

Photo: Waters

INTRODUCTION AND BACKGROUND

Washington State Agriculture

A summary of agriculture in Washington State reads like a cornucopia of crop and livestock production systems. With diverse microclimates resulting from the interaction of the state's topography and geographic location, the state produces a wide range (300+) of commodity and specialty crops (USDA NASS 2019). The 2017 Census of Agriculture listed apples ($1.95 billion), milk ($1.28 billon), potatoes ($934 million), wheat ($792.5 million), cattle ($698.7 million), hops ($475.6 million), hay ($468 million), cherries ($393.5 million), grapes ($308 million), and onions ($180.5 million) as the highest valued commodities in the state.

As of 2017, 35,793 farms operate on 14,679,857 acres with 66% of farm ownership below 49 acres in size. Cropland and pastureland represent 51% and 31% of total acreage, respectively. Wheat is the crop with the highest number of acres (2,219,069) being grown in both irrigated and dryland areas. Forage (791,783 acres), vegetables (325,634 acres), apples (179,899 acres), and chickpeas (170,401 acres) are the next highest-ranking crops, respectively.

Eastern Washington contains most of the agricultural acreage in the state and consists of both rainfed crops and large-scale irrigation. Within eastern Washington the production system types are highly concentrated, but diverse. In the easternmost portions of the state, dryland wheat and legume systems dominate the landscape representing over 3.7 million acres. Moving west into the coarse-soil, irrigated region of the Columbia Basin (671,000 acres), irrigated land is roughly six times more valuable than non-irrigated land, underscoring the importance of irrigation water in this region. Higher value horticulture crops such as apples ($839.1 million), potatoes ($664.6 million), and onions ($163.6 million) are commonplace, but other agronomic crops such as wheat ($313.3 million) and hay ($225.9 million) are also present. Almost two-thirds of Washington's potatoes and 20% of all U.S. potatoes are grown in the irrigated Columbia Basin. Juice and wine grape production is present in the Columbia Basin, but more acreage is concentrated in south-central counties such as Benton, Franklin, and Walla Walla.

West of the Cascades agricultural production is concentrated in northern and southern counties. Snohomish, Skagit, and Whatcom Counties comprise 27% of western Washington acreage with Clark, Grays Harbor, Lewis, and Thurston providing another 38% of western Washington acreage. In Island, Snohomish, Skagit, and Whatcom Counties, vegetable seed crops, fresh market potatoes, and perennial crops like red raspberries and blueberries are commonplace. These crop farms are alongside livestock operations such as dairies, nursery/greenhouse/sod farms, short rotation woody crops (trees harvested in less than 10 years typically for pulp, paper, or engineered wood and exclude trees cut for timber), as well as direct-market farms producing a diversity of crops and livestock products which are common throughout much of western Washington.

Washington State Soils

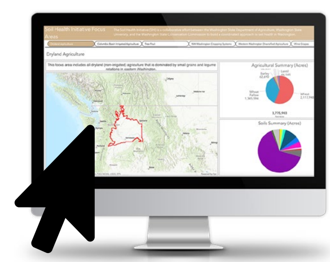
Washington State is home to a wide variety of soils, with several hundred unique soils identified and mapped by the NRCS, representing ten of the twelve soil orders recognized by the U.S. Department of Agriculture (USDA) soil classification system (Hipple 2011). The wide array of soil types is due to variation in the five soil forming factors: parent material, climate, topography, organisms, and time.

Parent material, the material from which the soils formed, includes windblown silt that formed the loess soils of the Columbia Plateau and the Palouse to the glacial till and alluvial river valleys formed by sediments eroded from nearby parent material forming the soils of the Puget Sound area in western Washington. Much of the soil in northeastern Washington is from volcanic parent material, the ash blown, again by prevailing winds, from the volcanoes of the Cascades (Steury 2011).

Climate includes both precipitation and temperature, which vary considerably across Washington. For example, annual precipitation varies from about seven inches in parts of the Columbia Basin to more than 300 inches in the Olympic Rainforest (Hipple 2011).

Topography, *organisms*, and *time*, the other soil forming factors, interact to result in the wide array of Washington soils.

Washington State Department of Agriculture has created an interactive web tool showing cropping systems in Washington addressed in this report and the soil textures associated with each cropping system.



While *inherent* soil properties (e.g., texture, minerology) are dictated by the soil forming factors discussed above, soil management impacts the *dynamic* properties of soils (e.g., organic matter, pH, nutrient content) on a more immediate time scale. Types of management affecting soil properties may include tillage, application of fertilizers or organic amendments, irrigation, and crop rotations. However, the impact of agriculture on dynamic soil properties can vary significantly depending on the context. For example, estimates indicate that intensive dryland agriculture in the inland Pacific Northwest (PNW) has depleted more than 50% of native soil organic matter, a major determinant of soil health, and has led to increased soil erosion (Awale et al. 2012). Meanwhile, in the Columbia Basin of Washington, irrigated agricultural land has undergone conversion from the native semi-arid shrub-steppe ecosystem with low precipitation and thus low inputs of organic matter. Conversion to irrigated agricultural production of high residue crops has actually *increased* soil organic matter levels in some areas (Cochran et al. 2007).

The What and Why of Soil Health

Soils are vitally important to national security, food and nutritional security, water quality and renewability, climate change mitigation and adaptation, human health, and biological diversity (NASEM 2017). Though soils impact human lives in a myriad of ways, agricultural production is perhaps the most direct connection. Land degradation afflicts over a quarter of Earth's ice-free land

(Olsson et al. 2019). In the U.S., agricultural soils have lost as much as 60% of their carbon content over the last century (Lal 2004). Historic farming practices have resulted in compromised soil health in agricultural systems throughout Washington State, as measured by reduced soil carbon and fertility levels, wind and water erosion, soil compaction, increased incidence and severity of soilborne crop disease, and detrimental impacts to air and water quality. It is imperative to prevent (and reverse) land degradation on agricultural soils occurring through soil erosion, nutrient losses, and losses of ecological integrity (IPCC 2019) if the ecosystem services that healthy soils provide (e.g., nutrient holding capacity, water holding capacity, filtration of nutrients and contaminants, food and fiber production) are desired.

Farmers have long known that taking care of the soil is a critical part of crop production. The Dust Bowl era gave rise to an emphasis on minimizing soil erosion (e.g., conservation agriculture), and more recently attention has shifted to rebuilding degraded soil (e.g., regenerative agriculture). Historically, emphasis on soil management for crop production has been focused on managing the chemical (e.g., pH, nutrient levels) and physical (e.g., compaction) characteristics of soil. However, with a growing awareness of the complexity of soil systems there is a better understanding of the critical role of soil biology.

The concept of "soil health" recognizes soil as a dynamic living system and emphasizes the multiple functions of a soil essential to sustaining agricultural production: plant production, nutrient cycling, water storage and availability, and diversity of biological habitats. The USDA Natural Resources Conservation Service (USDA-NRCS) has adopted the description of soil health proposed by Doran et al. (1996) "the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, maintain the quality of air and water environments, and promote plant, animal, and human health."

Healthy soils are resilient against disturbances such as flooding, drought, or high winds; support crop production with suitable nutrient, moisture, and physical conditions; support beneficial biological activity that decomposes crop residues, cycles nutrients, forms soil structure, and helps suppress disease; and contribute to environmental sustainability by filtering pollutants and reducing run-off. While the specific characteristics that constitute a healthy agricultural soil are context dependent, they generally include high levels of crop productivity; stable structure; high water-holding capacity, infiltration, and drainage and a level of organic matter that sustains all these; nutrient retention and recycling; the presence of beneficial soil organisms within the microbial community; low populations of plant pathogens and pests; minimal erosion; and an ability to quickly recover from stresses. In contrast, soils that are not healthy have properties that limit crop productivity and are constrained by problems such as erosion, compaction, poor structure, poor water and nutrient retention, and high levels pest pressures (Larkin 2015).

Soil health is assessed by evaluating the soil's ability to perform desired ecosystem functions and involves measuring soil physical, chemical, and biological indicators in response to changes in management (Awale et al. 2017).

Table 1. Potential physical, chemical, and biological properties used in soil health assessments.

Physical	Chemical	Biological
› Soil color › Aggregate stability › Water infiltration › Bulk density › Penetration resistance › Water holding capacity › Runoff and erosion › Rooting depth	› Organic C and N › Particulate organic matter › Active carbon › pH › Cation exchange capacity and base saturation › Electric conductivity › Heavy metals	› Soil respiration › Potentially mineralizable nitrogen › Microbial biomass › Soil enzymes › Eathworms › Crop condition, root growth › Weed and disease pressure

(Adapted from Awale et al. 2017)

Soil health assessment frameworks are an active area of research, particularly with respect to better understanding how soil health assessment relates to crop yield and quality in the context of regional cropping systems. Much of the past work on soil health assessment in the U.S. has taken place in the Northeast or Midwest, with more recent efforts underway in the PNW.

Management Practices that Can Improve Soil Health

There are several principles growers can follow to support soil health: minimize soil disturbance (reduce tillage), keep soil covered (cover cropping, mulching), maximize the duration of living roots (cover cropping, including perennial crops in rotations), and maximize diversity of crops within rotation (USDA-NRCS 2012). Though it should be pointed out that the means to achieving healthier soils will vary as farmers adapt these principles to their own farm similarly as variations in achieving a human health vary person to person. Examples of specific practices that are used to improve soil health include increasing organic matter by retaining crop residues, addition of organic (carbon-based) amendments and green manures - crops grown to be plowed into the soil. Management practices are typically targeted to address a particular issue of concern (e.g., soilborne disease, wind erosion). It should be noted that feasibility of implementing specific practices varies significantly based upon constraints of particular cropping systems. For example, perennial systems such as tree fruit do not offer opportunities for diversifying rotations or reducing tillage. Farmers are already accustomed to managing complex biological systems, but regional differences in climates, soils, pest pressures, and other complexities of farming may limit the transfers of successful strategies from one region to another.

Benefits

Healthy soils can result in the production of healthy crops, while minimizing the negative off-farm impacts of agriculture. Ascribing value to “internal” (on-farm) benefits is relatively straightforward, as healthy soils can result in increases in crop yield or quality, or decreased costs. “External” (off-farm) benefits of soil health, however, are more challenging to value. However, the valuation of external public benefits is a critical piece of the puzzle for widespread adoption of soil health practices (Bennett et al. 2010). Various categories of benefits are described below.

Soil Health and Food Production

Healthy soils can help agricultural systems be more resilient in the face of environmental stresses (e.g., drought). In an ideal scenario, improvement of soil health leads to improvements in yield-limiting factors (e.g., through improved water-holding capacity, improved nutrient cycling, or reduction of soilborne pathogens), which can result in closing the gap between realized and potential crop yield. However, crop yield and quality increases are not inevitable outcomes of soil health management (Miner et al. 2020) or may take years to be realized. Targeted approaches are needed to identify the specific cropping systems contexts in the region that hold promise for positive impacts on crop yield and quality. Existing soil research in regional cropping systems can provide relevant insights, particularly research on effects of specific management practices relevant to soil health (e.g., conservation tillage, cover cropping).

Soil Health and Food Quality

The connection between soil health and food quality is currently not well understood. While some studies (e.g., Reeve et al. 2016, Antunes et al. 2012) have explored the links between these two factors, differences can be largely attributable to variables such as soil nutrient levels, but not necessarily healthy versus unhealthy soils. This is an area that could use additional investment of resources to further evaluate the connection.

Soil Health and the Environment

In addition to benefits to agricultural production, soil health can provide off-farm environmental benefits. The major benefits in this category include carbon sequestration, water storage and drainage, water quality improvement through reduced soil erosion and nutrient runoff, air quality improvement through reduced wind erosion, biodiversity, and ecosystem health and resilience. Some details on each of these are provided below.

Carbon Sequestration

Soil holds an enormous amount of carbon – an estimated 1,500 Gt of soil organic carbon is stored in the top meter of soils (Powlson et al. 2011), compared to roughly 270 Gt carbon stored in standing forest stocks globally (FAO 2010). Soil carbon levels may be increased through management practices promoting soil health, offering an important opportunity to drawdown atmospheric carbon through sequestration. Though research on the potential for carbon sequestration in agricultural soils in Washington is limited, Yorgey et al. (in review) provide a summary of the available research in the inland PNW, finding that the opportunities to build soil organic carbon are greater in annually cropped systems with higher productivity, though the benefits of particular management practices are variable and depend on multiple environmental and physical conditions. Yorgey et al. (2017) identified the following as a priority for cropland agriculture in the PNW: Develop technical or other approaches to overcome existing barriers to increasing organic inputs (e.g., compost, manure, biosolids, biochar) in cropping systems, to support adoption of practices with substantial potential to increase carbon sequestration across the region.

Water Infiltration and Storage/Water Quality

Water is an important limiting factor for agriculture due to Washington's Mediterranean climate pattern where the potential evapotranspiration exceeds precipitation during the growing season. Thus, crops often rely on soil water storage or on irrigation during the dry months of the growing season. Increasing soil organic matter through soil health practices tends to improve both water infiltration and the capacity of soils to store water. Improved water-holding capacity and infiltration means less leaching and surface runoff, both helpful for minimizing sedimentation and nutrient and chemical losses into lakes, streams, and groundwater. Conversely, inadequate drainage can result from poor soil structure with intensive use, loss of organic matter, and compaction, contributing to poor soil drainage in wet climates (Magdoff and Van Es 2010).

Water and Wind Erosion

Water erosion is a serious issue in areas such as the hilly Palouse region with soil losses of 10 to 30 tons per acre per year. This issue is largely caused by exposed soil during precipitation events, and its importance varies by production system and geographic region. Wind erosion is a significant issue in parts of eastern Washington's Columbia Basin. In some cases, there's enough blowing soil to close roadways due to lack of visibility. More important for producers is the loss of topsoil and damage to young plants that can result from windstorms. Soil health practices that promote soil cover or stabilize soil, such as high residue farming, tillage reduction, or incorporation of green manures can reduce wind erosion (McGuire 2011).

Figure 1. Ditch erosion in the Palouse region. (Photo: Sullivan)

Biodiversity

It's estimated that soils contain more than 25% of all living species on Earth (Turbé et al. 2010). Soil biodiversity is critical not only for ecosystem functions such as nutrient cycling, water filtration, and plant disease suppression, but soil organisms have also provided some of humanity's most commonly used antibiotics - penicillin and streptomycin. Meanwhile, only a small fraction of soil microorganisms have been identified.

Ecosystem Health and Resilience

Benefits that can result from ecosystem services provided by healthy soils include improved water quality (less eutrophication), due to reduced sedimentation and nutrient runoff from farmland, and reduction in use of pesticides and off-farm nutrient inputs with their associated environmental impacts. There has been little quantification of these benefits in the PNW, but several (Bennett et al. 2010, Dominati et al. 2014, Dominati et al. 2016) have provided a framework for thinking about soil health and private vs. public benefits.

Economic Value of Ecosystem Services

The Nature Conservancy (2016) estimates that for each 1% of cropland in the U.S. adopting an adaptive soil health system, annual economic benefits translate into $226 million of societal value through increased water-holding capacity, reduced erosion and nutrient loss to the environment, and reduced greenhouse gas emissions, as well as $37 million of on-farm value through greater productivity. Such calculations were based on soy-corn-wheat rotations in the Midwest but given the lack of such estimates currently available for the PNW, these figures may provide some indication of the magnitude of the potential economic value that exists.

Barriers

Given all of the benefits mentioned above, why isn't attention to soil health the norm in agricultural production? Advances in science, economics, and policy are all needed to work toward more widespread adoption of soil health practices (The Nature Conservancy 2016). The science of soil health assessment is still evolving, and farmers need accurate, standardized, and cost-effective on-field soil health measurement tools as well as demonstration of effective soil health strategies relevant to particular cropping systems. Current business models do not encourage investment in soil health, particularly as the results of soil health practices on increasing yield and quality of crops can be quite variable and benefits often accrue over many years. The thin margins and inability to take on additional risk make financial incentives and support for on-farm experimentation critical for adoption of practices. Likewise, policy changes are needed that value societal and environmental benefits and encourage long-term investment in soil health by farmers and landowners.

Soil Health Related Initiatives

Across the U.S., 16 states have undertaken or are in the process of undertaking initiatives that focus (at least in part) on maintaining soil health on working lands. Below is a compiled list of such programs as of June 6, 2021.

Table 2. List of current soil health initiatives across the United States.

State	Bill and Scope	Funding
California	SB 859 and AB1613 established a Healthy Soils Program that provides incentives (loans, grants, research, technical assistance, and educational outreach) for management practices that contribute to healthy soils and result in greenhouse gas benefits.	$7.5 million annual
Connecticut	HB6496 defines soil health, supports research on soil health, and updates the regulation on soil and water conservation, and defined soil health.	$200,000 annual
Hawaii	HB1578 established a Carbon Farming Task Force to identify agricultural practices that improve soil health and carbon sequestration.	$25,000 one time
Illinois	SB1980/HB2737 adds "conservation of soil health" to the Soil and Water Conservation Act and makes adjustments such as allowing districts to make equipment available to landowners. HB2819 requires the establishment of soil health practices on Department of Natural Resources land used for agricultural purposes.	$0
Iowa	HSB78 provides partial property tax exemption when certain agricultural land is planted with cover crops. HF102 requires Iowa State University and the state Department of Agriculture to monitor statewide soil resource health and recovery and provide a bi-annual report to the Governor.	$0
Maryland	HB1063 established the Maryland Healthy Soils Program, directs the Department of Agriculture to incentivize practices that improve soil health, and defined soil health.	Unclear at this point
Massachusetts	SD1438/HD873 defines healthy soils and created the Massachusetts Healthy Soils Program.	Unclear at this point

Minnesota	HF1569/SF1637 creates a pilot program to protect drinking water including the use of practices (e.g., perennial crops and cover crops) that benefit water quality, soil health, carbon storage, habitat, and the rural economy.	$8.5 million one time
Nebraska	LB243 created the Healthy Soils Task Force to develop an action plan that includes goals, research and education, and incentives. LB283 provides resources to the University of Nebraska to develop a plan to mitigate changes resulting from climate change.	$250,000
New Mexico	HB204/SB218 also known as the Healthy Soils Act defines soil health and beneficial agricultural practices, initiates a grant program, an advisory group, education programming, and landowner training.	$5.15 million
New York	A3218 also known as the Carbon Farming Act did not pass, but funds were provided to study incentives for carbon farming tax credits and grants.	$50,000
Oklahoma	HB1192 also known as Oklahoma Carbon Sequestration Enhancement Act underscores the potential for carbon sequestering on working lands, created a Carbon Sequestration Advisory Committee that works to identify ways that landowners could participate in carbon emissions marketing or trading, develop educational material and identify research opportunities.	Currently unfunded
Oregon	HB2020/SB1507 introduced a cap and trade system to reduce carbon emissions and acknowledges that soil health can play a role in that.	Unclear at this point
Pennsylvania	SB634/HB1517 created the Conservation Excellence Grant Program that provides technical and financial assistance to agricultural operations to implement conservation best management practices (BMPs) such as cover crops. HB1526 creates the Agriculture Linked Investment Program that provides low-interest loans for BMPs that protect resources such as water and soil.	Unclear at this point
Utah	HCR8 recognizes climate change impact on Utah and that soil carbon sequestration can help to mitigate the impact.	$0
Vermont	S43 requires the Secretary of Natural Resources to establish the Vermont Regenerative Soils Program regenerative soils program to increase carbon sequestration, reduce sedimentation, and promote cost-effective and healthy soil management practices. S160 convened a Soil Conservation Practice and Payment for Ecosystem Services Working Group that recommends financial incentives to encourage practices that improve soil health.	$0

Washington State Soil Health Initiative

This is a coordinated effort between the Washington State Department of Agriculture, Washington State Conservation Commission, and Washington State University. This effort emerged from interests across various sectors including the agricultural industry, environmental interests, and the general public. Projected outcomes from this effort include knowledge of the status of soil health across the state, better understanding of management practices that positively impact soil health, increased adoption of these practices, and increases in food productivity and farm profitability as well as benefits to the environment. Initial rounds of state funding began in 2019, with full funding taking shape in 2021.

Current Soil Health Related Support Mechanisms and Efforts in Washington State

Several federal and state resources are available to landowners. In the state of Washington, landowners typically work with their local conservation district to determine availability for funds and to enroll in a specific program. Below is a current list of the programs that include soil health-promoting practices available to Washington landowners.

Conservation Innovation Grants Program (NRCS)
Funds are available to select counties to undertake practices such as no-till, strip-till, direct seeding, mulch till, cover cropping, or conservation crop rotation.

Conservation Stewardship Program (NRCS)
Funds are provided for a variety of practices used to protect and improve soil health that include crop rotation, no-till, controlled traffic farming, cover cropping, intensive cover cropping, use of multi-species cover cropping, intensive cover cropping, soil health assessments, reduce tillage, enhanced field borders, increase riparian herbaceous cover, mulching, conversation of cropland to grass-based agriculture, forage and biomass planting, improved grazing management, range planting, use of precision agriculture technologies, and planting specifically for high soil carbon sequestration.

Environmental Quality Incentives Program (NRCS)
Provides financial and technical assistance to agricultural producers and landowners to protect soil on working lands. Specific funding pools related to soil health include Organic Initiative (assists with transition to organic production), Conservation Activity Plans (customized conservation practices to address specific natural resource concerns), and Statewide Soil Health (conservation practices that improve soil health).

Emergency Watershed Protection Program (NRCS)
A program that responds to emergencies created by natural disasters. Funds can be used to repair conservation practices, repair erosion, or establish cover on eroding soils.

Agricultural Conservation Easement Program Agricultural Land Easements (NRCS)
This program works with a variety of entities to purchase a perpetual agricultural easement to protect agricultural use.

Regional Conservation Partnership Program (NRCS)
Promotes NRCS conservation activities to address on-farm, watershed, and regional concerns. Project examples include the development of environmental/carbon markets for landowners, reduction of soil erosion, farmland protection, riparian protection, and carbon sequestration.

Conservation Reserve Enhancement Program (Conservation Districts)
This program partners with landowners to install riparian buffers for 10-15 years and landowners are paid rent during that period.

Natural Resource Investments Program (Conservation Districts)
This program supports the installation of best management practices that reduce soil erosion and increase the use of direct seeding.

Voluntary Stewardship Program (Conservation Districts)
This program helps to protect critical areas where agricultural activities occur and assist to protect farmland by preventing urban growth.

Sustainable Farms and Fields Program (Conservation Districts)
This new program as part of the coordinated Washington State Soil Health Initiative aims to mitigate carbon emissions by improving fossil fuel efficiencies on farms and implementing carbon farming practices.

Resources

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Soil Health Institute https://soilhealthinstitute.org/

Soil Health Partnership https://www.soilhealthpartnership.org/

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OBJECTIVE AND ROADMAP PROCESS

Objective of the Roadmap

The objective of this roadmap is to outline the current situation of soil health in Washington State, identify goals and milestones looking forward, and then set a detailed plan to maintain and improve soil health. This effort sought input from a diverse group of stakeholders across the state and acquired information through a variety of mechanisms, described below. This roadmap is meant to educate an audience with varying levels of understanding of soil health.

Roadmap Process

Washington State has a diversity of production systems and for the purpose of simplicity, this roadmap was broken into seven production regions (Figure 2). These regions represent the major production systems in the state and are often coupled with unique geographies and climates. In addition to these seven focus areas, an eighth group "the environmental constituency" was added to represent the interest of environmental groups. A local expert was identified for each of the eight major focus areas to act as the lead information acquirer. For some focus areas, previous efforts documenting soil health issues and goals and were utilized where applicable. If existing resources were not present, the local lead designed an effort to acquire this information through a variety of means (e.g., focus groups, web-based interviews/conversations, direct conversations with stakeholders, web-based survey). This information was then distilled by the local lead and the roadmap editors. Once the roadmap was compiled, feedback from both internal and external reviewers was sought.

Figure 2. An outline of the roadmap process and a timeline of stages.

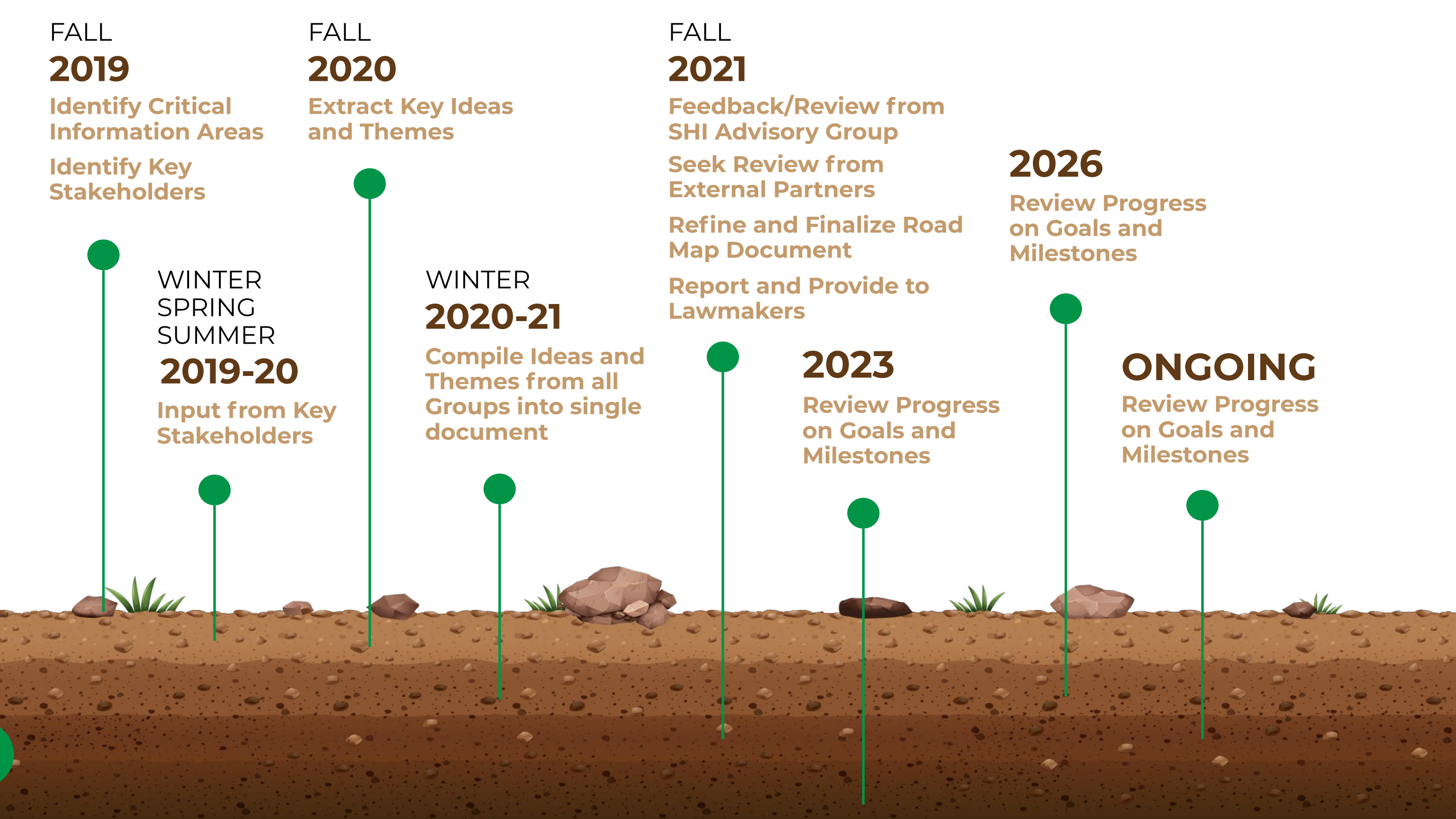

Photo: Sullivan

DRYLAND AGRICULTURE IN EASTERN WASHINGTON

Primary Author: Rich Koenig

Summary

Dryland production in eastern Washington over the last 130 years has led to several soil health issues such as erosion and soil acidification. Farmers' understanding of soil health is rooted in the issues that this production region faces such as physical and chemical components. Use of innovative tactics such as no-till/direct seeding have overcome some of the issues, but other factors (environmental/economic) can limit their use. Goals and priorities for this region are diverse but examples include improved understanding of soil biology/plant interaction, use of additional off-farms inputs (e.g., amendments), and better soil health assessment tools. Barriers to improvements include economic barriers, sociological barriers, and lack of information. These can be overcome through improved research capacity, innovative extension/outreach methods, and long-term investments in education.

Methods

Content for this section of the roadmap was assembled from knowledge of historical and present-day soil health challenges in the dryland agriculture areas of eastern Washington, north-central Oregon, and northern Idaho. Sources of information include published research, perspectives from the long-running Solution To Environmental and Economic Problems (STEEP) and Columbia Plateau PM^{10} wind erosion (CP3) project special research grants, the more recent Regional Approaches to Climate Change (REACCH) project, stakeholder meetings, and various other reports.

Recent stakeholder meetings (Washington State Soil Health Summit, 2018, Pullman, WA; Healthy Soils-Healthy Region Workshop, 2019, Pendleton, OR) involving over 200 participants and facilitated by the Washington State University (WSU) Center for Sustaining Agriculture and Natural Resources provided current stakeholder perspectives and priorities. These meetings included a broad cross-section of stakeholders from farmers to those who serve them, including university research, extension, ag industry, and state/federal agency personnel.

Current Situation

Farming in dryland areas of the inland PNW began in the late 1800's. Early settlers found the area to be perfectly suited to wheat production due to the combination of deep, fertile, loess soils and Mediterranean climate that combine to effectively store winter moisture and produce high yields of winter wheat. Erosion was likely the first soil health challenge in the inland PNW and has been a perennial problem in this area since the inception of farming. In the early to mid-1900's, annual erosion rates were estimated at 10 to 30 tons per acre per year (approximately ⅛ inch of topsoil) with conventional farming practices (USDA 1978). By some estimates this was equivalent to ¾ ton of topsoil eroded for each bushel of wheat produced.

Erosion in the inland PNW has been the result of several factors including: 1) extensive use of conventional tillage; 2) predominance of winter precipitation with the potential for frozen soil and runoff; 3) steep and irregular topography that does not lend itself to conventional structure or landscape modification practices to control erosion; and 4) a winter wheat cropping system that leaves the soil nearly bare during the winter precipitation season. While erosion by water has been a major soil health and environmental concern, wind erosion is also a problem, particularly in the Columbia Plateau region of the inland PNW where, historically, lower annual rainfall amounts led to rotations that alternate between crop and tillage fallow.

Figure 3. Soil erosion within wheat stubble. (Photo: Sullivan)

Figure 4. Field edge soil erosion. (Photo: Sullivan)

By the 1970's it became clear that major changes in farming practices were needed in the inland PNW to reduce erosion rates. The STEEP special research grant was initiated in 1975 (Kok et al. 2009) to address soil erosion concerns in the inland PNW. The CP3 special research grant was initiated in 1993 to focus primarily on wind erosion on the Columbia Plateau sub-region of the inland PNW. Both projects involved integrated research and education and a systems approach that addressed all of the characteristics of conservation farming from planting to harvesting. Through the successful development of conservation technology and farming systems, soil loss rates were reduced to five tons per acre per year or less per year with long-term benefits of improved soil, water, and air quality (Kok et al. 2009).

Today (Schillinger and Papendick 2008), dryland crop production areas of the inland PNW (Washington, Idaho, and Oregon) encompass nearly 8.2 million acres (5.5 million acres in Washington) and produce some 13% of the nation's wheat supply and 80% of its specialty soft white wheat for export. While soil erosion by wind and water has been greatly reduced throughout the dryland areas, it is still an ongoing concern. Further, conservation measures adopted to control erosion have created new soil health challenges that in many cases threaten to undermine progress made in soil conservation to reduce erosion.

Current Understanding of Soil Health

Farmers in the dryland region broadly interpret soil health to include a myriad of physical, chemical, and biological properties that impact short-term yield and the long-term sustainability of farming practices in dryland areas of the inland PNW. These properties are inherently interrelated and influenced by management practices in complex ways and over a range of time scales.

Farmers in the dryland region understand that soil biology is complex but fundamentally important to disease causation and resistance, residue decomposition, nutrient cycling, herbicide carryover, soil structure, and several other important outcomes. While they understand the importance, soil biology is a “black box” and largely unknown and untapped in terms of understanding management implications and opportunities. The concept of a microbiome in soil adds both promise and complexity to the understanding and management of soil biology.

Farmers in dryland areas understand that no-till/direct seeding has improved soil structure and water infiltration and percolation rates. However, they are concerned about soil physical properties such as compaction associated with the adoption of reduced tillage practices. With no-till/direct seeding, farmers can enter a field earlier in the spring to spray and plant while the soil is at a higher moisture content. This has promoted more soil compaction and, coupled with less tillage, has made it more challenging to remediate subsoil compaction.

Figure 5. Tilled wheat field (left) and no-till wheat field (right). (Photo: Sullivan)

Nutrient depletion has been a concern as farmers focus on nitrogen and phosphorus, but perhaps neglect other nutrients. Increasing occurrence of micronutrient deficiencies and potential concern or opportunities associated with subsoil nutrient levels have been cited. Farmers also question the reliability of conventional soil testing assays for plant nutrients that may not accurately assess availability.

No-till/direct seeding coupled with high yields can pose problems with residue (particularly winter wheat) management. Increased restrictions on residue burning have led to more baling and removal, which removes large quantities of basic cations such as potassium, calcium, and magnesium in the residue, as well as smaller quantities of other secondary and micronutrients. The opening of a straw pulping plant in Starbuck, Washington has provided an economic incentive to remove more residue. The long-term consequences of residue removal bear careful monitoring.

Figure 6. Surface wheat residue in the Palouse. (Photo: Sullivan)

Soil pH has emerged as a major concern in the higher rainfall areas of the inland PNW. Early work by Mahler et al. (1985; 2016) documented soil acidification in northern Idaho as a yield-limiting factor for dryland wheat and pulse crops and projected that this problem would grow and encompass a larger area of the high rainfall zone in northern Idaho and eastern Washington as farmers continued to use ammonium-based fertilizers. This projection has come true, though perhaps not on the scale or timeline originally predicted by Mahler. Interactions between soil pH and plant diseases, nutrient availability and cycling, and herbicide residue carryover complicate soil acidification issues. Stratification of soil acidity in reduced tillage systems also has unknown consequences. Further, residue removal (described above) has the potential to accelerate acidification and associated problems (e.g., aluminum toxicity).

Farmers increasingly understand and appreciate that necessary steps taken to reduce soil erosion through conservation tillage have created new soil health and cropping systems challenges that require ongoing research to develop solutions to these emerging problems. Examples of these include increased soil compaction in conservation tillage systems, stratified acidity in no-till/direct seeding, and diseases that are more prevalent when tillage is reduced.

Farmers associate improved soil health with improved function, productivity, and resiliency in the face of climate and other challenges, both known and unknown.

Goals, Priorities, and Milestones

- Adoption of known soil health practices is widespread and "automatic." Equipment for no-till is easily accessible/affordable.
- Economic improvements are experienced by producers via soil health practices. Soil health is valued in the marketplace and supports thriving businesses and communities.
- Healthy food is grown sustainably in a system rooted in soil health.
- Erosion reduced, in turn decreasing dust storms, road closures, and soil runoff.
- Water quality improved through lowered nutrient and sediment loads.
- Water infiltration and storage increased, creating better drainage in winter and drought resistance in summer.
- Soil organic matter levels increased.

- Resiliency to climate stressors, leading to more stable crop yields.
- Disease, pest, and invasive weed pressure reduced as well as herbicide resistance.
- Metrics and measurements have been developed that are cheap, universally accepted, relevant to specific cropping systems, and can be easily used to inform management decisions.
- Grazing/livestock practices improved through the integration of crops and livestock or crops and organic wastes.
- Soil amendment knowledge and adoption increased and accepted within soil health initiatives (e.g., biosolids, compost, biochar, other organic materials).
- Reduction of fertilizers and pesticides use while maintaining stable yields.
- Cover cropping systems relevant to PNW are developed and adopted.
- No-till/reduced tillage practices are widely adopted.
- Policy approaches emphasize voluntary, incentive-based approaches (as opposed to regulatory), are consistent among agencies and reduce barriers to improving soil health.
- The general public understands soil health and its relationship to sustainable land management, ecosystem services, and healthy food.
- Effective diagnostic tools and tests for soil health.
- Understanding soil biology/ecology.
- Understanding plant-soil interactions.
- Long-term soil health research.

Soil Health Issues

- Defining and understanding what soil health is…not getting lost in the complexity of the issue and putting existing knowledge to use to manage soil health for specific end goals.
- Identifying a specific set of soil health indicators that can effectively be monitored and tied to production and sustainability outcomes.
- Quantitatively connecting economic and environmental outcomes to soil health indices.

Information Gaps

Effectively and rapidly translate the science/understanding of soil health to implementation. Innovative growers are often ahead of university researchers. Some of the best work that Extension can do is facilitating interaction with and between innovative growers (e.g., a former extension agent started a direct seed breakfast club and facilitated interaction between farmers that are innovators). It's very difficult for researchers to stay ahead of the farmer/rancher leaders as research funding is generally directed at the majority of the growers. Extension is an important component, with the majority of effort directed at keeping the middle of the pack moving forward.

Figure 7. Dryland wheat field after harvest. (Photo: Sullivan)

Barriers to Adoption

- The most critical barrier is the inherently complex nature of soils – and how little is actually known.
- The lack of clarity and consistency in terms of soil health metrics used across the region and cropping systems and inconsistency in measuring the benefit of improved soil management over time.
- Sociology/psychology of adoption: major barrier is the individual's mindset – particularly as it relates to the difficulty of correlating management investments with measurable outcomes.
- The economic incentive at the farm level is often unclear. We need to better understand return on investment (ROI) of soil management practices.
- The disconnect between producers and consumers as it relates to management of soils. Producers don't get paid to manage soils; they get paid for a crop.

Overcoming the Barriers

Research

- Stable funding pool to invest in soil health research.
- Long-term research that links soil health to environmental and economic outcomes.
- Capacity – human (new hires, cluster hires) and facilities.
- Taking on-farm and analyzing it in meaningful ways to develop regional best practices. (Though this should be seen as low hanging fruit, some clarity is needed about what the questions are first, think about a comparative score card approach?).

Outreach/Extension

- Create new partnerships in industry and cultivate better partnerships to reach a more diverse group of producers to effect change.
- Central website for information.

- Collaboration, resource pooling, and training: farmer-researcher collaborations and interactions (foster two-way influences), grower to grower mentoring, education and training for crop consultants.
- Communication plan reaching producers where they are with understandable language; Improvements in communications down the supply chain (potential tool example: potato sustainability project).
- Encourage ‘out of box’ work in extension and agriculture service.
- Risk assessment tool (e.g., Farm Assist or Home Assist programs established in the 80’s: guide a user through protecting water resources that can guide farms through sustainability decisions).
- Monitoring should always be part of the protocol for implementing new practices.
- Better communication from researchers to farmers about the practices that ARE making a difference.
- “Cultivating a pioneer culture” –identifying innovators.
- Long-term demonstration of proven ideas critical for grower buy in.
- Finance on farm research with research, growers, industry.
- Matching extension with growers willing to do large scale plots/demos.
- Development of meaningful soil health metrics, development and use of existing studies to better understand soil health metrics.

Education

- Add capacity to teach soil health-related courses.
- Need a broad base of knowledge, encourage cross-disciplinary training for students (no silos).
- Encourage training in more effective technical communication (e.g., among soil scientists).
- Re-introduce conservation ethics and add more training in social sciences part of soils courses and standard curriculum.

Soil Health Policies

- Cost-share programs that help reduce the risk of experimentation are critical. Especially, programs that offer direct payment for building soil organic matter.
- Soil health checkoff.
- Fertilizer tax.
- Carbon tax.
- Soil erosion tax.
- Invest in recognizing (award program), validating (replicated studies) and sharing practices that innovative producers are implementing successfully.

Resources/Tools/Opportunities

- “Sustainability audits” for various crops.
- Address the dwindling human capacity issue with good hires (i.e., research, extension, crop advisors, agency / Conservation District staffing).
- Focus on utilizing current resources and create a clearinghouse for new innovation.
- Enhance the research and technical support connectivity between researchers and innovative producers.
- Explore opportunities for accessing databases on soils collected by the private sector.
- Further evaluation of various soil health indicators / tests across cropping systems and the region.

Cropping System Specific Issues

- Lack of irrigation/limitations imposed by natural rainfall amounts and distribution may pose challenges to altering management practices.
- Limited options for economically viable crops and diversification of crop rotations (including cover cropping).
- Heavy reliance on synthetic nitrogen and other fertilizers with few off-farm sources of nutrients or organic matter amendments.
- Heavy reliance on glyphosate tied for reduced tillage.
- Increasing occurrence of herbicide resistant weeds coupled with few new options in terms of active ingredients and new herbicide modes of action.

Core Investments Areas

- “The goals of our consumers should be our goals”; Bringing more stakeholders (i.e., those who eat) to the table will ideally result in more money for research.
- Funding mechanisms are needed to support soil health over time (e.g., soil health checkoff, fertilizer tax, carbon tax, soil erosion tax). Establish public, private partnerships similar to those that have been successful in Midwest.
- Invest in recognizing (award program), validating (replicated studies) and sharing practices that innovative producers are implementing successfully.
- Invest in and fund long-term, on-farm, research and demonstration projects. Involve growers with operations of different scales, researchers, and industry.
- Invest in dedicated, multi-disciplinary soil health science positions. Fund a dedicated soil ecology center, endowed chairs, with state government leadership and industry support.
- Invest in a research and outreach team to collect stories on and market the benefits of soil health to producers and the public.

Resources

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Photo: McGuire

ENVIRONMENTAL COMMUNITY

Primary Author: Karen Hills and Chad Kruger

Summary

The Environmental Community views soil health from a very different perspective than other focus areas. Current soil health issues are related to many other ecosystem functions such as climate and flooding. This is highlighted by the emphasis of benefits (e.g., water quality, environmental resiliency) that come about as soil health improves. There was additional emphasis that this focus area perceives a win-win for both the farming community and the environment as soil health is protected and improved. This group noted that the farming community should get paid directly for undertaking practice that benefit soil health, but also agreed that there is a knowledge gap on how to assess this at scale. Importantly, this group emphasized the need to rely on entities that have *existing* relationships with the farming community rather than take the lead themselves.

Information Collection

Implementation of soil health practices in agricultural systems has the potential to not only improve soil function and agricultural productivity but also have positive impacts on other ecosystem services (e.g., water quality biodiversity). As a result, government agencies and environmental organizations have shown interest in better understanding the role soil health can play in improving the environment and promoting implementation of soil health management practices. However, barriers exist for the environmental community to effectively communicate with farmers in supporting the adoption of management practices that improve soil health. There is a general perception that environmental policies are often weaponized (e.g., costly regulatory compliance burdens and prohibitions) to damage rural and agricultural communities as the environmental movement has largely been urban-centric and often out of touch with rural / agricultural concerns. Because this perception that environmental and agricultural priorities often don't align and are sometimes in opposition with each other, this road-mapping process directly engaged participants with environmental perspectives in order to find opportunities for win-win scenarios for soil health.

To better understand these concerns and to help prioritize soil health research and education investments, a virtual listening session was held on August 18, 2020 with five participants representing the following organizations: American Farmland Trust, Carbon Washington, Sightline Institute, Washington Department of Natural Resources, and Washington State Conservation Commission. Additional organizations were invited to provide input and comment on the prioritization. Participants were invited based on their interest in the topic and existing involvement in issues in the nexus of agriculture and environment.

Current Situation

When asked what the most important soil health issues are in Washington State, participants responded with the following:

- *Climate Resiliency*. Understanding how soil health ties into climate resiliency – to what extent does soil health improve resiliency in the face of climate change.
- *Soil Organic Carbon*. Carbon storage can potentially lead to increases in yields while protecting our farmland from long-term climate impacts (e.g., increased water-holding capacity, thus increased drought resilience) and help to mitigate carbon emissions. However, much more research is needed on carbon storage in PNW agricultural soils.
- *Farm Economic Viability*. How does improved soil health affect the bottom line for farmers – either through internal benefits (improved yields and/or reduced costs for inputs such as irrigation, fertilizer, or fuel) or payments for external benefits (incentives).
- *Regulatory Compliance*. Improving soil health may be a tool to help farmers better comply with environmental protection regulations. Ideally, voluntary soil health investments could reduce the need for regulations on farmers.
- *Flood Mitigation*. There are questions that focus on the inter-relation of healthy soils (e.g., good soil structure) and water dynamics, including flooding and water inundation in certain environments (e.g., western Washington).
- *Topsoil Protection*. Participants mentioned improved soil health leads to protected topsoil, lower water and wind erosion, and overall improvements in water quality by reducing sedimentation and nutrient leaching.

Environmental Benefits that Could Result from Improved Soil Health

Participants ranked the following environmental benefits in order of importance (high to low).

1. Soil water-holding capacity
2. Climate benefits (e.g., carbon sequestration and greenhouse gas emission reductions)
3. Water health (water quality), reduced runoff
4. Ecosystem health (e.g., soil microbial community, habitat quality, biodiversity)
5. Resilience (economic)
6. Agro-economic growth
7. Resilience (ecosystem)
8. Reduced soil erosion
9. Air quality

Benefits can either be thought of as “internal” if they are captured on-farm (e.g., better yields) or “external” if they occur off-farm (e.g., carbon sequestration, reduced downstream pollution). Farmers are likely to be more motivated when the benefits of a soil health strategy accrue directly to the farmer than when the benefits accrue more broadly to the environment. Participants mentioned that there may be a need for marketplaces and incentives that recognize the external benefits to motivate farmers to move in that direction.

In the group discussion the idea of "stacked benefits" was as, or more, important than prioritizing the list of benefits. One respondent described the "layered cake analogy."

Participant Comment

"We want everyone to recognize all the layers of the cake. It's ok to talk about just the carbon layer, as long as we recognize that there's a water quality layer on top of it and an agricultural productivity benefit on top of that. We want everyone to be aware of all of the layers of the cake and get to a point where we can value the indirect [or external] layers of the cake as well."

Goals and Priorities

Priorities for moving forward in soil health improvement can be distilled into three major categories:

1. *We need to know more.* Much more research is needed. Initial research should be aimed at carbon storage, water management, and links between soil microbial activity/diversity and food nutritional quality. Crop-specific recommendations and soil health metrics specific to production systems are needed as well as faster, cheaper, and more robust verification methods.
2. *Make information more accessible.* There is a need for an open-source database with metrics for soil health improvement in the region that enables better sharing of data. There is also a need for effective communication of best practices for soil health to conservation districts so that information can be delivered to the producers to implement. Sustainable (long-term) funding sources are needed to help producers adopt practices using science-based information.
3. *Figure out how to pay people for it.* Implementing new practices involves cost and financial risk for farmers. Incentivizing soil health practices makes them more affordable to implement and reduces risk of trying something new. In some cases, the benefits of soil health investments may not accrue directly to the farmer, making incentives critical as a mechanism to support soil health investments by farmers. One idea that was raised is the development of a carbon marketplace that recognizes the contributions of soil carbon sequestration.

Additional comments:

- For public lands leased for agricultural use, the question of how to incorporate long-term stewardship of these lands for more sustainable management of the soil and maintain productivity was raised. Carbon sequestration provides a side benefit of soil health that is critical for the planet but isn't necessarily easy to include in a land lease.
- The linkage between rural economic development and positive climate contributions and

better land productivity needs to be explored.

- Resources should be targeted toward researchers to generate leading edge concepts to inform the entire system.
- Resources should be targeted toward encouraging field trials from early adopters who are using practices outside of an academic setting, or where the "study" portion of the grant is small in comparison to the funds to implement the practice.

Participant Comment

"There is an analogy to using an Instantpot that is relevant to soil health efforts. There needs to be a ramping up of awareness, communicating about the soil health roadmap and baseline assessment; growers providing soil samples and being on standby for when information on best practices is available. There needs to be a surge of activity now but then it has to be sustained at a level that people embrace as the maintenance level . . . [This effort] has to be ongoing and a permanent mindset moving forward."

Information Gaps

Participants ranked the following information gaps related to environmental benefits of soil health, in order of importance (high to low).

1. Data on soil health and crop productivity and quality (cost benefit analysis).
2. Data on practices that improve carbon sequestration and length of storage.
3. Could incentive-based soil health programs create jobs in Washington? Where? How many? What types of jobs?
4. Timing of relationship between management practices and measurable changes in soil health.
5. The under-valued importance of soil organic carbon levels for water retention and microbial growth in addition to climate benefits.
6. Need for most current information (regionally specific).
7. What types (payment levels) of incentives would encourage farmers to enroll in a voluntary program for soil health practices?
8. General lack of knowledge among scientists, legislators, farmers, the environmental community, and the general public on benefits of carbon sequestration.
9. Data on intercropping vs. cover cropping vs. crop rotation diversification and water use, especially for the inland PNW.

Other topics that were mentioned: What are the main barriers stopping farmers from enrolling in existing incentive-based conservation programs? Relationship between soil health and food quality; Better understanding of practices to affect carbon sequestration; Implications of soil health for nitrous oxide emissions (increase or decrease).

Milestones

Participants listed the following soil health milestones as priorities for Washington State.

- 100% of farms, reporting their soil samples, being financially recognized for the sequestration benefits they produce, funded by a revenue from a carbon tax on 100% of fossil-fuel based CO_2 emissions in the state. This type of program should be set up in such a way that protects farmers if things don't go as expected (five years).
- Leading the nation in soil health programming with opportunities to provide leadership using the diversity of Washington's agricultural systems to reach and influence other regions (five years).
- Dominant paradigm shift among agricultural producers involving soil health in which people who *aren't* thinking about soil health are outliers (10 years).
- Farmers include revenue from ecosystem services in their business plan (15 years).
- A 30% increase in enrollment of farmers and ranchers over the first five years in the Washington Sustainable Farms and Fields grant program for technical and financial support implementing soil carbon enhancement practices.
- A coordinated network of farms established to track short- & long-term improvements in soil health, environmental co-benefits, and economics.
- More education targeted to producers and the general public leading to more people who understand the value of soil health.
- Increased percentage of farms that use annual cover crops (western Washington), or intercrop (in inland PNW).
- Reduced rates of soil erosion.
- Accessible information on benefits, practices, and funding to support soil health practice implementation.
- Increases in soil organic carbon.
- Increases in the number of green jobs supported by soil health initiatives.
- The Voluntary Stewardship Program goals of Washington State have been met.
- Endorsement of soil health efforts by agricultural interest groups, environmental interest groups, tribes, and state and local governments.

Barriers to Adoption

The major barriers for agricultural producers to adopt soil health practices, from the perspective of participants were:

- Fear of diminished crop yields, loss of crop insurance, and uncertainty (i.e., producers want to know that a practice will work).
- Expense.
- Timing - how quickly it takes to get an economic return and see the positive impact.
- Lack of technical assistance/knowledge of what will work in a particular situation and metrics used to assess.
- Lack of a critical mass of implementation and demonstration projects (e.g., not seeing neighbors adopt practices).
- Need for promotion by leaders in the agricultural space.
- Resistance to the idea that climate action is needed.
- Reluctance to change, especially if doing so might imply that a long-term, conventional farming method has been "wrong" or "bad".

Overcoming the Barriers

As previously mentioned, the perception that environmental and agricultural priorities are in opposition can limit the capacity of the environmental community to effectively communicate with farmers in supporting the adoption of soil health practices. Solutions include advancing more successful programs that clearly demonstrate financial benefits for farmers and farm-related businesses rather than just academic research-related work. As such, it was felt that the environmental community should not be out front on this issue, but rather should support and engage with trusted groups (e.g., local conservation districts, WSU Extension staff, other land managers) and need to raise awareness in the general public about soil health and the benefits that agriculture can create for climate.

Education is needed in urban communities to foster a better sense of appreciation for rural landowners and land managers. It is important for rural participants to feel proud of their landscapes and have benefits of their landscapes and farming practices recognized by urban participants (e.g., innovative intensive grazing practices in beef cattle to benefit climate action).
Ecosystem services that land managers can provide should be compensated as a product in addition to the products they are harvesting.

The diversity of the state's production system is a challenge as there is a need for crop-specific recommendations and soil health metrics specific to diverse production systems to provide feedback to farmers. Likewise, there is a need to measure, report, verify impacts of soil health practices

The Sustainable Farms and Field Bill was successful because the bill's proponents were able to show that farmers and environmental groups have shared goals in this case. Agricultural producers want to be good environmental stewards**.**

Participant Comment:

> "We need to continue inviting [agricultural producers and environmental groups] to come together and have these conversations on their own turf instead of at the capital. Communication, understanding, and mutual respect are key to developing relationships between the environmental groups and farmers."

Some financial support could go towards a communications campaign to highlight the good work that farmers are doing and acknowledge the pressures and stress that farmers are trying to manage might help make those human connections easier.

Resources/Tools/Opportunities

When asked about current support mechanisms, participants mentioned opportunities to learn from what is underway in other states that could be applied in Washington State. For example, Healthy Soils programs exist in Maryland, California, New Mexico, and Colorado. Other relevant programs include: Maryland's Ag Water Quality Cost Share Program, Illinois Cover Crops Premium Discount Program, Iowa's Cover Crop Crop Insurance Demonstration Project, and Michigan's

Agricultural Environmental Assurance Program.

A consortium of groups (American Farmland Trust, Coalition on Agricultural Greenhouse Gases, U.S. Climate Alliance) published *Agricultural Solutions for Mitigating Climate Change: A Policy Toolkit for US Climate Alliance State Governments* (USCA 2020). Washington State is one of the 25 states within the U.S. Climate Alliance.

Participants also pointed out these possible future opportunities:

- Ecosystem Services Marketplace Consortium has launched a carbon ranching pilot program in Oregon
- Public-private partnerships
- COVID Economic Recovery Funds
- Participants mentioned that economic downturns can slow the momentum of efforts like the soil health initiative. The state of Washington needs to assure that economic recovery efforts and resources include efforts to sustain agricultural productivity and imprint resilience in our food system. This priority needs to take shape in the short-term (next 2-years) so that the positive long-term impacts have time to mature.
- The Washington Food Policy Forum recommendations to the legislature (Food Policy Forum 2019) included soil health in its recommendation to "Promote research and programmatic investments in agricultural viability, resiliency, and market development."

Current Soil Health Related Support Mechanisms

Participants named the following mechanisms and efforts available at either federal, state, or local levels.

Federal

NRCS Environmental Quality Incentives Program, federal loans, and other grants.
USDA cover crop and federal crop insurance (https://www.rma.usda.gov/en/Fact-Sheets/National-Fact-Sheets/Cover-Crops-and-Crop-Insurance)
Carbon markets (e.g., Nori, Ecosystem Services Market Consortium, Indigo Ag, Soil and Water Outcomes Fund), both voluntary and regulatory (within California)
Farming for the Future: A Forum Exploring Ecosystem Markets (webinar by American Farmland Trust with Illinois Sustainable Ag Partnership)
Ecosystem Market Information (handout with summary table of four markets)

State

Washington SB5947 – Sustainable Farms and Fields Bill, Washington Soil Health Initiative, Washington Soil Health Committee

Local

Conservation districts cost share and equipment loan programs (e.g., for no-till equipment) and technical assistance (e.g., use of cover cropping, manure, and composted amendments)

Other

PNW Direct Seed Association's Farmed Smart Certification (https://www.directseed.org/farmed-smart-certification)
Industry-led sustainability initiatives (e.g., Potato Sustainability Alliance)

Conclusions

The highest priorities for moving forward on soil health efforts were described as:

1. Research that produces convincing data that defines what practices improve or maintain soil health and how soil health benefits agricultural producers and the environment in general.
2. Leadership support of soil health efforts from the agricultural community.
3. Long-term funding to support implementation of soil health efforts across the state.
4. The installation of demonstration sites, specifically linking the economic benefits, shifting the concept from "XYZ *doesn't* work here" to "XYZ *does* work here."
5. The creation of a network community of practice that supports dissemination of information.
6. Raising awareness amongst all parties from rural farmer to urban legislator about the opportunities, both environmental and economic, for sequestering carbon in rural landscapes

It's important to make sure that soil health is tied to resiliency. For example, COVID-19 exposed many vulnerabilities in our agriculture and food system. Understanding how soil health is inter-connected with other aspects of our agriculture and food system is critical for creating a comprehensive effort. Participants emphasized that soil health efforts need to be aligned with issues that are currently of high priority that include food security, environmental justice, support for new farmers, underrepresented groups and prioritization of programs to help targeted groups.

References

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Photo: Griffin LaHue

IRRIGATED COLUMBIA BASIN

Primary Author: Andy McGuire and Karen Hills

Summary

Soil health related issues in the Columbia Basin vary based on crop, but most responses to a survey underscored issues related to the physical and biological portion of soil. Soils in this region are threatened by wind erosion and degraded soil physical quality. These soils are characterized by largely coarse texture, low organic matter content, low water and nutrient holding capacity, and production systems that rely on heavy use of tillage. Respondents frequently stated that the use of cover crops and alternative tillage strategies could help to overcome these issues. Challenges such as the economics of using soil health improving practices and the lack of ability to effectively monitor soil health changes were ranked high.

Overview

The Columbia Basin is one of the premier agricultural regions in the U.S. The semi-arid dry climate averages about 200 frost free days per year. It has abundant water from the Columbia River providing irrigation for nearly 700,000 acres. Over 70 different crops are grown, including tree fruit (apples, cherries, pears) vegetables (potatoes, onions, sweet corn, green peas) forage crops (alfalfa and timothy hay), and grains (corn and wheat). Cattle and dairy operations exist in the basin.

Information Collection

A survey was sent to the Irrigated Agriculture listserv managed by WSU Extension on February 13, 2020 and was closed on March 7, 2020. 147 crop growers/producers, 54 crop consultants and 16 livestock producers participated, for a total of 217 respondents across production systems.

Since soil health issues and approaches can vary substantially based on production system, survey responses were divided by primary crop identified by participants. Significant numbers of respondents represented tree fruit (60 respondents), grapes (23 respondents), and potatoes (32 respondents), cropping systems covered in other areas of this report. Here we focus on other crops of significance in irrigated Columbia Basin agriculture: blueberries or other small fruit (3 respondents), corn – grain or silage (6 respondents), hay or other forage crops (18 respondents), hops (4 respondents), seed crops (4 respondents), sweet corn, green peas or other vegetables (12 respondents), and wheat (9 responses). Overall results from the survey are presented in Appendix 1 of this report.

Current Situation

Wind Erosion

The Columbia Basin is prone to high wind events especially in the spring and fall, often when soils are not adequately covered with crops, plant residues or other vegetation. Wind erosion removes fine particles and organic matter from the topsoil which results in lower soil productivity, fertility, water-holding capacity, tilth, structure and water infiltration on dryland and irrigated soils. Unprotected sand, loamy sand and sandy loam soils are the most susceptible to wind erosion (McGuire 2011). Additionally, blowing dust can result in serious traffic accidents, loss of productivity, air quality issues, and respiratory problems in communities surrounding farmland. Efforts to control wind erosion are an ongoing challenge being addressed through the use of cover crops, high crop residue farming, and addition of manure and compost on the most prevalent wind-blown soils. Major efforts are continuing to improve soil health using multiple management strategies thus reducing soil deterioration.

Figure 8. Irrigated mustard cover crop emerging after sweet corn. (Photo: McGuire)

Climate Change and Water Supply

Although the supply of water from the Columbia River is forecast to increase slightly by 2030, the timing of peak supply will shift earlier in the calendar year (late-fall, winter and spring), away from the peak irrigation demands of mid-summer (Hall et al. 2016).

Blueberries or Other Small Fruit

There were three respondents (all producers) who listed blueberries or other small fruit as their main crop, though only two of the respondents answered the questions in full. The issue of greatest importance to this group is nutrient cycling. The most frequently mentioned soil health improving practices of interest are double cropping, relay cropping, intercropping, manure application and no-till. The importance of challenges to improving soil health were noted as high cost of soil improvement practices, short term land leases and lack of information. Both of the respondents in this crop group listed the importance of research or additional information in all four areas (economics, monitoring, benefits, and strategies for improvement) as “high.”

Table 3. Importance of issues related to soil health – Blueberries or other small fruit.

	High	Mod	Low
Nutrient cycling	100%	0%	0%
Soil organic matter (SOM) level	50%	50%	0%

Drainage, ponding, runoff	50%	50%	0%
Water-holding capacity	50%	50%	0%
Soilborne disease	50%	50%	0%
Parasitic nematodes	50%	50%	0%
Wind erosion	0%	50%	50%
Water infiltration	0%	100%	0%
Soil tilth	0%	100%	0%
Compaction	0%	100%	0%
Crusting	0%	100%	0%

Table 4. Interest in soil health improving practices – Blueberries or other small fruit.

	High	Mod	Low
Double cropping	50%	0%	50%
Relay cropping	50%	0%	50%
Intercropping	50%	0%	50%
Manure application	50%	0%	50%
No-till	50%	0%	50%
Cover crops	0%	100%	0%
Green manures	0%	100%	0%
Compost application	0%	100%	0%
Strip-till	0%	0%	100%
Reduced tillage	0%	100%	0%
Livestock integration	0%	50%	50%

Table 5. Importance of challenges to improving soil health – Blueberries or other small fruit.

	High	Mod	Low
High cost of soil improvement practices	50%	50%	0%
Short term land leases	50%	50%	0%
Lack of information	50%	50%	0%
Low residue crops	0%	50%	50%

Required tillage	0%	100%	0%
Logistics of using soil improvement practices	0%	50%	50%
Managing high levels of crop residue	0%	50%	50%
Rotation restrictions	0%	100%	0%
Sandy soils	0%	100%	0%

Table 6. Importance of research or additional information – Blueberries or other small fruit.

	High	Mod	Low
Economics of soil health	100%	0%	0%
Monitoring soil health	100%	0%	0%
Benefits of soil health	100%	0%	0%
Strategies for improving soil health	100%	0%	0%

Corn – Grain or Silage

There were six respondents (four producers, two crop consultants) who listed grain or silage corn as their main crop. The importance of issues related to soil health that were most frequently mentioned as being of high importance for this group were soil organic matter (SOM) level and soilborne disease. Cover crops, double cropping, green manures, no-till, and reduced tillage were identified as issues of high importance by the 50% or more of respondents. The most important challenges identified by this group were short term land leases, high cost of soil improvement practices, managing high levels of crop residue, rotation restrictions, and low residue crops. The areas of research that were most frequently identified as being of high importance for this group were monitoring soil health and strategies for improving soil health. One grower in this group offered the following comment:

Figure 9. Irrigated sweet corn in the Columbia Basin. (Photo: Waters)

> "Soil variation occurs on every unit often to extreme degrees and often is managed to the mean. Cost efficacy always an issue. Tilth [is] a clumsy and lowbrow hand waving umbrella term for complex biome."

Table 7. Importance of issues related to soil health – Corn, grain or silage.

	High	Mod	Low
SOM level	100%	0%	0%
Soilborne disease	100%	0%	0%
Water infiltration	83%	17%	0%
Compaction	83%	17%	0%
Drainage, ponding, runoff	83%	17%	0%
Wind erosion	67%	33%	0%
Water-holding capacity	67%	33%	0%
Nutrient cycling	67%	33%	0%
Parasitic nematodes	60%	40%	0%
Soil tilth	50%	50%	0%
Crusting	50%	50%	0%

Other responses: salt accumulation, pH and nutrition

Table 8. Interest in soil health improving practices – Corn, grain or silage.

	High	Mod	Low
Cover crops	67%	17%	17%
Double cropping	67%	33%	0%
Green manures	50%	33%	17%
No-till	50%	50%	0%
Reduced tillage	50%	50%	0%
Relay cropping	40%	40%	20%
Intercropping	40%	40%	20%
Compost application	33%	50%	17%
Manure application	33%	50%	17%
Strip-till	33%	50%	17%
Livestock integration	33%	33%	33%

Other responses: legume inoculation, compost tea and other “snake oils”

Figure 10. Researchers showcasing cover crop trials at a field day. (Photo: McGuire)

Table 9. Importance of challenges to improving soil health – Corn, grain or silage.

	High	Mod	Low
Short term land leases	83%	17%	0%
High cost of soil improvement practices	80%	20%	0%
Managing high levels of crop residue	67%	17%	17%
Rotation restrictions	67%	33%	0%
Low residue crops	60%	20%	20%
Logistics of using soil improvement practices	40%	40%	20%
Sandy soils	33%	50%	17%
Lack of information	20%	60%	20%
Required tillage	20%	60%	20%

Table 10. Importance of research or additional information – Corn, grain or silage.

	High	Mod	Low
Monitoring soil health	83%	17%	0%
Strategies for improving soil health	83%	17%	0%
Economics of soil health	67%	17%	17%
Benefits of soil health	50%	33%	17%

Other responses: nitrogen availability relative to organic fraction and binding, technical data for extended-release fertilizers, microbiome management - the frontier of knowledge, balancing application rates with plant use.

Hay or Other Forage Crops

There were 18 respondents (13 producers, five crop consultants) with hay or other forage crops as their main crop. The issues of highest importance for this group were soil tilth, soil organic matter (SOM) level, nutrient cycling, water infiltration, and water-holding capacity. Practices that garnered the greatest level of interest were no-till, green manures, reduced tillage, cover crops, and manure application. At least half of the respondents in this group listed the high cost of soil improvement and lack of information as challenges of high importance for improving soil health. The areas for more research that were identified as being of the highest importance were benefits of soil health, strategies for improving soil health, and economics of soil health. Other comments offered by respondents in this group were:

"Soil health is something I've really focused on the last five to ten years or so. My main strategy has been cover crops and implementing minimum tillage. Have tried flying wheat seed into standing grain corn August 15."

"Overall status of rotational cropping in the Columbia Basin and new approaches for better soil maintenance as the Odessa/Ritzville Reclamation takes place in the next few years."

Table 11. Importance of issues related to soil health – Hay or other forage crops.

	High	Mod	Low
Soil tilth	80%	13%	7%
SOM level	75%	25%	0%
Nutrient cycling	69%	25%	6%
Water infiltration	56%	44%	0%
Water-holding capacity	53%	47%	0%
Compaction	47%	47%	7%
Drainage, ponding, runoff	47%	33%	20%
Soilborne disease	47%	40%	13%
Wind erosion	40%	47%	13%
Parasitic nematodes	40%	27%	33%
Crusting	29%	50%	21%

Other responses: correct fertilizers, crop rotation benefits

Figure 11. Researchers obtaining soil samples a part of soil health evaluation. (Photo: McGuire)

Table 12. Interest in soil health improving practices – Hay or other forage crops.

	High	Mod	Low
No-till	64%	21%	14%
Green manures	60%	33%	7%
Reduced tillage	60%	40%	0%
Cover crops	56%	44%	0%
Manure application	56%	31%	13%
Double cropping	47%	47%	7%
Strip-till	46%	46%	8%
Livestock integration	40%	47%	13%
Compost application	38%	44%	19%
Relay cropping	14%	50%	36%
Intercropping	14%	36%	50%

Other responses: legume rotation, nematode restriction

Table 13. Importance of challenges to improving soil health – Hay or other forage crops.

	High	Mod	Low
High cost of soil improvement practices	73%	13%	13%
Lack of information	57%	21%	21%
Logistics of using soil improvement practices	47%	47%	7%

Sandy soils	47%	13%	40%
Managing high levels of crop residue	36%	57%	7%
Short term land leases	33%	67%	0%
Required tillage	29%	57%	14%
Rotation restrictions	15%	54%	31%
Low residue crops	14%	64%	21%

Other responses: cost of equipment

Table 14. Importance of research or additional information – Hay or other forage crops.

	High	Mod	Low
Benefits of soil health	73%	20%	7%
Strategies for improving soil health	73%	20%	7%
Economics of soil health	64%	21%	14%
Monitoring soil health	47%	47%	7%

Other responses: impacts of compaction

Hops

Four respondents (one producer, three crop consultants) listed hops as their primary crop. Soil organic matter level was the issue of greatest importance to this group, with cover crops, green manures, compost and manure application all listed as practices of high interest to 50% or more of respondents in this group. The high cost of soil improvement practices is the most important challenge identified by this crop group. Strategies for improving soil health is the research area of greatest importance identified by this group.

Figure 12. Hop field in Columbia Basin (Photo: Benedict)

Other comments offered by respondents in this group:

"It is becoming a bigger deal each and every year."

"Tillage is the main inhibitor to soil health in our system. We remove residues due to potential disease carryover, but I would like to learn more about that."

"I believe this is a very important topic which needs attention, especially in perennial crops like I deal with. It isn't as easy to amend soil health in perennial crops and not all people are willing to spend the $$ to improve it without actually seeing a measurable way to justify it."

Table 15. Importance of issues related to soil health - Hops.

	High	Mod	Low
SOM level	50%	50%	0%
Water infiltration	25%	50%	25%
Soil tilth	25%	75%	0%
Compaction	25%	75%	0%
Nutrient cycling	25%	75%	0%
Parasitic nematodes	25%	50%	25%
Wind erosion	0%	25%	75%
Drainage, ponding, runoff	0%	100%	0%
Water-holding capacity	0%	100%	0%
Crusting	0%	50%	50%
Soilborne disease	0%	33%	67%

Table 16. Interest in soil health improving practices - Hops

	High	Mod	Low
Cover crops	75%	25%	0%
Green manures	75%	0%	25%
Compost application	50%	50%	0%
Manure application	50%	50%	0%
No-till	25%	25%	50%
Reduced tillage	25%	25%	50%
Livestock integration	25%	0%	75%
Double cropping	0%	0%	100%
Relay cropping	0%	0%	100%
Intercropping	0%	0%	100%
Strip-till	0%	0%	100%

Figure 13. Hop trellis system. (Photo: Benedict)

Table 17. Importance of challenges to improving soil health - Hops.

	High	Mod	Low
High cost of soil improvement practices	100%	0%	0%
Short term land leases	25%	0%	75%
Required tillage	25%	25%	50%
Logistics of using soil improvement practices	25%	50%	25%
Rotation restrictions	25%	0%	75%
Lack of information	0%	25%	75%
Low residue crops	0%	25%	75%
Managing high levels of crop residue	0%	50%	50%
Sandy soils	0%	67%	33%

Table 18. Importance of research or additional information - Hops.

	High	Mod	Low
Strategies for improving soil health	100%	0%	0%
Benefits of soil health	75%	25%	0%
Economics of soil health	50%	50%	0%
Monitoring soil health	50%	50%	0%

Other answers offered by respondents: soil health in grass-based rotations

Seed Crops

Four respondents (all producers) listed seed crops as their primary crop. The issues that were identified as being of high importance by this group were wind erosion, soil tilth, water-holding capacity, soilborne disease, water infiltration, compaction, and nutrient cycling. Reduced tillage was the one soil health improvement practice considered to be of high interest by 50% of respondents. The challenges this group identified as most important were low residue crops, high cost and logistics of soil improvement practices, and sandy soils. Research areas that were of greatest interest to this group were monitoring of soil health, benefits of soil health, and strategies for improving soil health.

Table 19. Importance of issues related to soil health – Seed crops.

	High	Mod	Low
Wind erosion	100%	0%	0%
Soil tilth	75%	25%	0%
Water-holding capacity	75%	25%	0%
Soilborne disease	75%	0%	25%
Water infiltration	50%	0%	50%
Compaction	50%	25%	25%
Nutrient cycling	50%	50%	0%
Parasitic nematodes	33%	0%	67%
SOM level	25%	75%	0%
Crusting	25%	50%	25%
Drainage, ponding, runoff	0%	25%	75%

Table 20. Interest in soil health improving practices – Seed crops.

	High	Mod	Low
Reduced tillage	50%	25%	25%
Green manures	25%	75%	0%
Cover crops	25%	50%	25%
Livestock integration	25%	50%	25%
Compost application	25%	25%	50%
Double cropping	0%	50%	50%
No-till	0%	50%	50%
Manure application	0%	25%	75%
Strip-till	0%	25%	75%
Relay cropping	0%	0%	100%
Intercropping	0%	0%	100%

Table 21. Importance of challenges to improving soil health – Seed crops.

	High	Mod	Low
Low residue crops	75%	0%	25%
High cost of soil improvement practices	50%	25%	25%
Logistics of using soil improvement practices	50%	25%	25%
Sandy soils	50%	25%	25%
Short term land leases	25%	75%	0%
Required tillage	25%	0%	75%
Rotation restrictions	25%	25%	50%
Lack of information	0%	75%	25%
Managing high levels of crop residue	0%	50%	50%

Table 22. Importance of research or additional information – Seed crops.

	High	Mod	Low
Monitoring soil health	100%	0%	0%
Benefits of soil health	100%	0%	0%
Strategies for improving soil health	75%	25%	0%
Economics of soil health	25%	75%	0%

Sweet Corn, Green Peas, and Other Vegetables

This group encompasses a number of vegetable crops, including sweet corn and green peas and consisting of 12 respondents (nine producers, three crop consultants). At least half of the respondents in this group listed the following issues as being of high importance: soil tilth, water-holding capacity, nutrient cycling, water infiltration, compaction, drainage, ponding, runoff, soilborne disease, wind erosion, and SOM level. The practices of greatest interest to this group for improving soil health are compost application, cover crops, green manures, reduced tillage, and intercropping. The high cost of soil improvement was the challenge identified as being of high importance by the majority of respondents in this group. This group expressed significant interest in each of the four areas for potential research.

Other comments offered by respondents in this group were:

> "I would like to see plots on ways to reduce weed seed banks in organic fields. Also, what crop or cover crop affects organism health in soil."

"We have already implemented many soil health practices: strip till, reduced till, compost application, cover crops, livestock integration, etc. my main interest is in soil health practices to reduce soil fungal pathogens."

"Importance of organic matter and the soil on Columbia Basin."

Figure 14. Root system of strip tilled corn (left) and full tilled corn (right). (Photo: McGuire)

Table 23. Importance of issues related to soil health – Sweet corn, green peas, other vegetables.

	High	Mod	Low
Soil tilth	84%	11%	5%
Water-holding capacity	79%	16%	5%
Nutrient cycling	79%	21%	0%
Water infiltration	74%	16%	11%
Compaction	68%	21%	11%
Drainage, ponding, runoff	68%	16%	16%
Soilborne disease	63%	32%	5%

Wind erosion	58%	11%	32%
SOM level	58%	37%	5%
Crusting	47%	37%	16%
Parasitic nematodes	47%	53%	0%

Other responses: fungal diversity

Figure 15. Strip tilled onions. (Photo: McGuire)

Table 24. Interest in soil health improving practices – Sweet corn, green peas, other vegetables.

	High	Mod	Low
Compost application	94%	0%	6%
Cover crops	78%	22%	0%
Green manures	67%	28%	6%
Reduced tillage	56%	44%	0%
Intercropping	53%	35%	12%
Livestock integration	44%	19%	38%
Manure application	41%	29%	29%
No-till	41%	24%	35%
Relay cropping	31%	44%	25%
Double cropping	29%	57%	14%
Strip-till	22%	56%	22%

Other responses: ridge till

Figure 16. Strip till planting of sweet corn into green cover. (Photo: McGuire)

Table 25. Importance of challenges to improving soil health – Sweet corn, green peas, other vegetables.

	High	Mod	Low
High cost of soil improvement practices	61%	28%	11%
Lack of information	47%	41%	12%
Required tillage	47%	35%	18%
Logistics of using soil improvement practices	47%	53%	0%
Sandy soils	35%	53%	12%
Managing high levels of crop residue	29%	59%	12%
Short term land leases	28%	33%	39%
Rotation restrictions	28%	61%	11%
Low residue crops	24%	71%	6%

Figure 17. Cucurbits grown in the Columbia Basin. (Photo: Waters)

Table 26. Importance of research or additional information – Sweet corn, green peas, other vegetables.

	High	Mod	Low
Strategies for improving soil health	94%	6%	0%
Benefits of soil health	89%	11%	0%
Economics of soil health	83%	17%	0%
Monitoring soil health	67%	28%	6%

Figure 18. Columbia Basin sweet corn. (Photo: Waters)

Wheat

Nine survey respondents (five producers and four crop consultants) listed wheat as their main crop. Over half of respondents in this group listed the following as high importance issues related to soil health: water infiltration, SOM level, soil tilth, water-holding capacity, nutrient cycling, and soilborne disease. The practices with the greatest level of interest for wheat producers were no-till, reduced tillage, and cover crops. The greatest challenges to improving soil health for wheat systems were identified as the high cost and logistics of using soil improvement practices. All areas of potential research (strategies, economics, benefits, and monitoring) were of high importance to a majority of respondents in this group. Dryland wheat production is covered elsewhere in this report.

Other comments offered by respondents in this group:

"As a grower and a business leader of an enterprise that serves growers, I think it important to build upon substantial progress made--reducing waterborne soil erosion 85%, reducing dust 6-fold, reducing stubble burning 22-fold. A fine foundation to build upon. A major contribution to habitat restoration for salmon."

"Very complicated. Not well understood."

"Tissue testing looks like an important tool, along with the forms of the nutrients being applied."

Figure 19. No-till drill planting a cover crop into wheat stubble. (Photo: McGuire)

Table 27. Importance of issues related to soil health - Wheat.

	High	Mod	Low
Water infiltration	89%	11%	0%
SOM level	89%	11%	0%
Soil tilth	78%	22%	0%
Water-holding capacity	78%	22%	0%
Nutrient cycling	78%	22%	0%
Soilborne disease	67%	22%	11%
Wind erosion	44%	33%	22%
Compaction	44%	56%	0%
Drainage, ponding, runoff	44%	44%	11%
Crusting	33%	56%	11%
Parasitic nematodes	22%	56%	22%

Other answers offered by respondents: pH, falling number, soil organisms

Table 28. Interest in soil health improving practices - Wheat.

	High	Mod	Low
No-till	78%	22%	0%
Reduced tillage	78%	11%	11%
Cover crops	56%	22%	22%
Green manures	44%	11%	44%
Double cropping	44%	11%	44%
Relay cropping	44%	22%	33%
Livestock integration	44%	44%	11%
Intercropping	33%	44%	22%
Compost application	33%	22%	44%
Strip-till	33%	33%	33%
Manure application	11%	22%	67%

Other answers offered by respondents: microbial amendments, micronutrients, Rhizobacters, noxious weed management.

Figure 20. Mustard green manure coming through wheat stubble. (Photo: McGuire)

Table 29. Importance of challenges to improving soil health - Wheat.

	High	Mod	Low
High cost of soil improvement practices	89%	11%	0%
Logistics of using soil improvement practices	67%	22%	11%
Lack of information	33%	67%	0%
Required tillage	33%	22%	44%
Managing high levels of crop residue	33%	44%	22%
Rotation restrictions	33%	44%	22%
Low residue crops	22%	56%	22%
Short term land leases	11%	56%	33%
Sandy soils	11%	33%	56%

Other responses: yield protection, microorganism interactions

Table 30. Importance of research or additional information - Wheat.

	High	Mod	Low
Strategies for improving soil health	100%	0%	0%
Economics of soil health	78%	22%	0%
Benefits of soil health	78%	22%	0%
Monitoring soil health	56%	44%	0%

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Photo: Waters

IRRIGATED POTATO PRODUCTION IN THE COLUMBIA BASIN

Primary Authors: Matthew Blua, Andy Jensen, and Andy McGuire

Current Situation

Currently, there are approximately 160,000 acres of mostly processing potatoes grown annually in the Columbia Basin with ~10,000 acres of fresh market potatoes grown in northwestern WA. At an average of over 30 tons per acre, the yield of potatoes in the Columbia Basin is the highest in the world. Ninety percent of WA potatoes are grown for processing including for french fries, with the remainder grown for fresh market sales, chipping, or dehydration. Net profits for potato growers are low relative to past years yet demand for potatoes is strong and increasing. Because processors in WA are increasing capacities, the demand for more potatoes will continue into the foreseeable future. Although there are nearly one million irrigated acres in Eastern and Central Washington, many acres are under permanent crops and are therefore not available for potato growing. Potatoes here are generally grown under a 3 to 4-year rotation, which is usually required in contracts with processors, presumably because potato cultivation is disruptive to soil and time is required to re-generate soil that will support high potato yield and quality after a prior potato crop. Thus, given available farmland and rotations, the acres under annual potato production will not increase unless more irrigated farmland becomes available, or rotations are reduced without compromising yield and quality. In addition, to fulfill demand, management of potato production will need to improve to maximize yields on all acres under cultivation. Soil health issues are complicated by the use of fumigants, currently necessary to reduce soilborne pathogens and nematodes and attain those high yields. Fumigation is the most expensive single operation in potato production.

Potato production involves several key factors that interact to reduce soil health, including the substantial tillage required by a potato crop for bedding and harvest that disrupts soil horizons and aerates soils causing oxidation of organic matter, and the fact that potato leaves relatively little plant residue behind to control wind erosion. But the most important issue regarding potato soils involves the buildup of important soilborne pathogens and nematodes, particularly *Verticillium dahliae* which induces Verticillium wilt, and *Meloidogyne chitwoodi*, the Columbia root-knot nematode.

Figure 21. Researcher obtaining potato root samples to evaluate the soil-root microbiome. (Photo: Sarpong)

Soil Health Issues

1. Soilborne pathogens and nematodes
2. 2. A system that requires increased production while depending on leased farmland which discourages tenant and landlord investment in soil health-building practices
3. 3-4 year rotations due to 1 (above) leading to 2 (above)

Causes of Soil Health Issues

1. Soilborne pathogens and nematodes, particularly *Verticillium dahliae* which induces Verticillium wilt, and *Meloidogyne chitwoodi*, the Columbia root-knot nematode, persist through rotations at levels that cause economic damage
2. Fumigation, bedding, harvesting, and other tillage operations

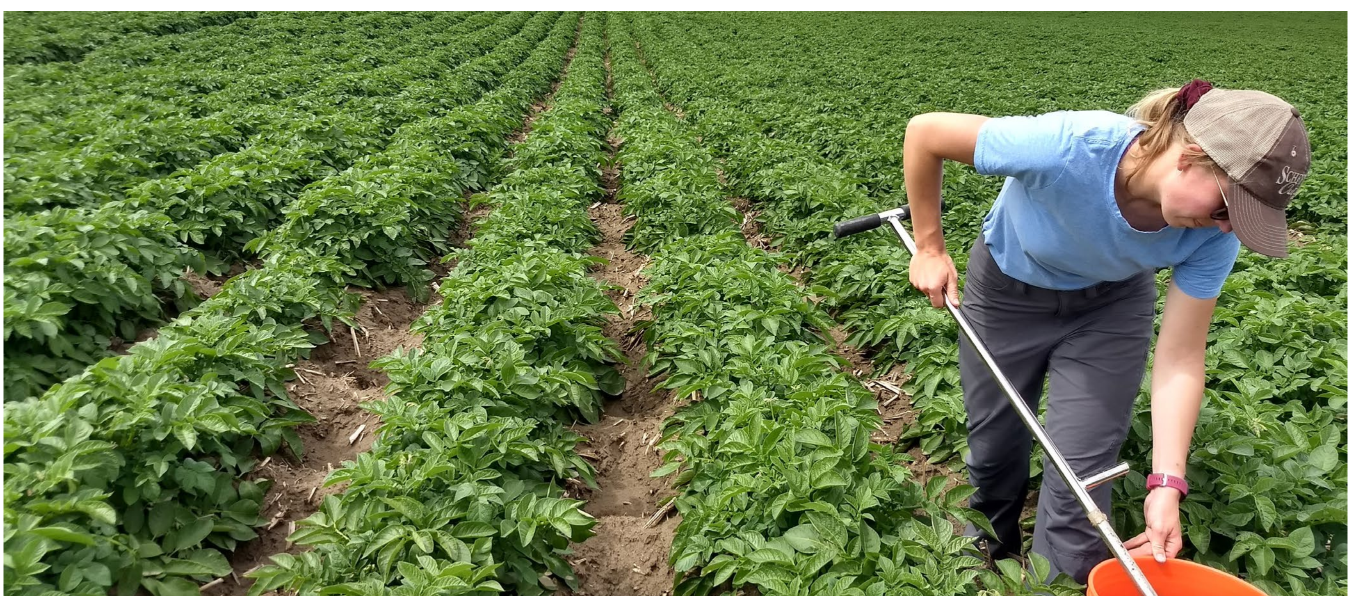

Figure 22. Researchers taking soil samples to evaluate soil health in Columbia Basin potato fields. (Photo: Griffin LaHue)

A survey was sent to the Irrigated Agriculture listserv managed by WSU Extension on February 13, 2020 and was closed on March 7, 2020 (Appendix 1). 147 crop growers/producers, 54 crop consultants and 16 livestock producers participated, for a total of 217 respondents across production systems. Here we focus on the results from respondents who selected potatoes as their main crop. Thirty-two respondents listed potatoes as their main crop (16 producers, 16 crop consultants). Relevant responses are shown in tables throughout this focus area.

Table 31. Importance of issues related to soil health - Potatoes.

	High	Mod	Low
	Potato		
	High	**Mod**	**Low**
Soilborne disease	82%	14%	4%
Parasitic nematodes	78%	22%	0%
Water infiltration	66%	31%	3%
Soil tilth	61%	39%	0%
Compaction	59%	41%	0%
SOM level	54%	36%	11%
Wind erosion	52%	34%	14%
Nutrient cycling	50%	50%	0%
Water-holding capacity	46%	39%	14%

Other answers offered by respondents: beneficial microbes, pesticide residues, microbial activity, rotation, carbon sequestration

Goals and Priorities

The potato community in Washington would like to move towards decreasing or eliminating fumigation and reducing years of rotations without compromising grower profits, and potato yield and quality. This would enhance sustainability, fulfill the demand for WA-grown processing potatoes, reduce the potential of off-site impacts of fumigation, and promote a more robust microbiome that potentially could buffer impacts of soilborne pathogens and nematodes.

Long Term Goals

1. Increasing acreage that is available for potato production by reducing rotations without compromising yield and quality
2. Increasing yield on lower producing fields
3. Reducing inputs of broad-spectrum biocides that manage soil-borne pathogens and nematodes in favor of other mean of management
4. Supporting the use of soil-building practices on leased land.

Top Five Priorities

1. Keeping population densities of soilborne pathogens and nematodes lower than economic thresholds, or developing soils that suppress them.
2. Reducing or finding alternatives to fumigation
3. Target-specific pesticides to manage soilborne pathogens and nematodes
4. Decreasing years of crop rotations between potato cropping
5. Rotating with crops that are profitable, enhance soil health metrics, and reduce soilborne pathogens and nematodes

Knowledge Gaps

1. Ecology of soilborne pathogens and nematodes
2. Understanding the nature of "suppressive soils"
3. Understanding why new soils or soils not producing potatoes for many years are relatively highly productive, and if not, understanding why
4. Measurable indicators of soil health that are reliable and that can suggest management practices in WA irrigated agriculture

Quotes from survey respondent:

"What is soil health? Everyone has a different definition. I think you can define soil health as sustainable farming, rather than some long winded version of biodiversity."

"We need a consensus on what soil health is and how it is defined. This is the first major hurdle. Also, growers need to make money from the land each year, that has to be strongly considered with any future recommendations."

Milestones

1. Reduction in length of rotations from 3-4 years to 2-3 years within 20 years
2. Economically viable alternatives to soil fumigation within 10 years
3. An updateable "Best Practices" document for potato soil management within 2 years

Barriers to Adoption

The only practices that improve soil health that are used consistently are 3-4 years of rotation and fumigation, the later having negative impacts on beneficial soil microbes, nematodes, and soil-dwelling insects. Barriers to adopting soil health practices primarily are knowledge gaps regarding soil ecology and how it could be manipulated to decrease the impact of soilborne pathogens and parasitic nematodes.

Another barrier involves low levels of blemishes acceptable due to nematodes. For fresh-market potatoes various soilborne pathogens cause cosmetic damage that reduces quality and value. Currently, these issues are managed with fumigation. There is substantial pressure on growers to maximize yields. High yields are necessary for a profit under the terms of processing contracts. For several decades soil fumigation for disease control has successfully and consistently maximized yields.

Figure 23. Researchers taking soil bulk density samples to evaluate soil health in Columbia Basin potato fields. (Photo: Sarpong)

Table 32. Importance of challenges to improving soil health - Potatoes.

	High	Mod	Low
High cost of soil improvement practices	67%	30%	4%
Rotation restrictions	65%	23%	12%
Low residue crops	56%	26%	19%
Short term land leases	52%	30%	19%
Required tillage	52%	37%	11%
Logistics of using soil improvement practices	48%	37%	15%
Sandy soils	48%	48%	4%
Managing high levels of crop residue	44%	52%	4%
Lack of information	43%	24%	33%

Other answers offered by respondents: yield protection, microorganism interactions.

Overcoming the Barriers

Overcoming these barriers requires research directed at improving our understanding of the soil ecosystem, including biotic and abiotic interactions among potatoes and soil organisms with a goal of enhancing our ability to reduce soilborne pathogens and parasitic nematodes to levels lower than economic thresholds. Also, developing a means to profitably process tubers with exterior blemishes might allow Columbia root-knot nematode to be managed with nematicides, rather than broad-spectrum fumigants that more completely manage nematodes but negatively impact beneficial organisms as well.

Quote from survey respondent:

"Soil health tactics must be scalable and have direct economic benefits in order to be adopted. Growers understand that some benefits aren't realized in year 1, but incentives for improving long term health of rented ground are low. Results of soil health research must be replicated and repeatable."

"Soil biology and the interactions between beneficial and pest organisms has largely been neglected. The organic movement has become a leader in this understanding. Conventional agriculture needs to keep up."

Table 33. Interest in soil health improving practices - Potatoes.

	High	Mod	Low
Green manures	56%	41%	4%
Cover crops	54%	38%	8%
Compost application	37%	44%	19%
Reduced tillage	33%	52%	15%
Double cropping	30%	45%	25%
Manure application	27%	54%	19%
Strip-till	23%	27%	50%
Intercropping	22%	26%	52%
Livestock integration	18%	36%	45%
Relay cropping	17%	29%	54%
No-till	15%	38%	46%

Soil Health Policies

It is not clear that state policies could increase adoption of management practices that improve soil health without reducing profitability by growers and processors.

Resources/Tools/Opportunities

The Columbia Basin Potato Soil Health Workgroup, a coalition of growers, processors, and registrants have recently generated over $3 million in support of an Endowed Chair at Washington State University. Candidates for this position are being interviewed in July 2021. With recent interest in soil health throughout the US, particularly in Washington, this creates an opportunity for WSU, and the state to take a leadership role in research and extension in soil health.

Research, extension symposia, workshops, demonstrations showing best soils management practices, and a decision-making guide on potato soil-health management would advance soil health goals for the potato community.

Cropping System Specific Issue

Potatoes cannot be grown without extensive tillage, if only because they require hilling and harvesting. This compromises soil quality. Importantly, the harvested product is underground and thus subject to exploitation by soilborne organisms, and even minor damage is important to product quality. Finding alternatives to fumigation to manage soilborne pathogens and nematodes will be challenging.

Core Investments Areas

Washington State University should invest in researchers who have the capacity to study microbial and nematode ecology and interactions in irrigated agricultural ecosystems, and the infrastructure to do so. Ideally, this researcher should be placed in the Columbia Basin.

Table 34. Importance of research or additional information - Potatoes.

	High	Mod	Low
Strategies for improving soil health	85%	15%	0%
Economics of soil health	70%	30%	0%
Monitoring soil health	63%	30%	7%
Benefits of soil health	63%	37%	0%

Photo: Sullivan

JUICE AND WINE GRAPES

Primary Authors: Gwen Hoheisel, Michelle Moyer, and Markus Keller

Summary

Juice and wine grape growers have distinct soil health needs. Nutrient cycling and soilborne pests were listed as the biggest issues. Potential solutions to these issues include the use of rootstocks; a topic that needs more research. The industry noted a need for an increased investment in public university research capacity in the form of additional faculty and improved facilities.

Overview

Washington is the second-leading wine grape (*Vitis vinifera*) producing state in the nation. The state has 16 American Viticultural Areas (AVA[1]), up from only five a decade ago. Wine grape acreage exceeds 60,000. The number of wineries in Washington State has more than quadrupled in the past 15 years, from 240 to over 1000. The Columbia Valley AVA comprise 94% of the state's total wine grape acreage (NASS 2019, WA Wine Commission 2020). Ninety-nine percent of Washington State's wine grapes are produced east of the Cascade Mountains, where production is dependent on the use of irrigation. Vineyards west of the Cascade Mountains represent a small part of the state's wine grape industry. The vineyards in this cooler climate have historically been small in acreage but are increasing in number, focusing on northern European varieties suited for the climate (Moyer and O'Neal 2014). Eastern Washington is also the nation's leading producer of juice grapes with nearly half of the tonnage produced in the US. However, there is a downward trend in juice grape production with now less than 200,000 tons annually and an annual reduction of 7-10% in acreage and tonnage for the last five years. The price of juice grapes has recently fluctuated between $110 and $230 per ton and an acre can produce on average between 8 and 15 tons depending on age of the vines and farming practices (WA State Concord Grape Research Council). In contrast, Washington wine grape production was increasing until recently with annual yields between 200,000 and 270,000 tons in the past five years. The price of wine grapes is highly variable ranging from $800 to over $4,000 per ton and dependent on specific cultivar, location grown, and fruit quality.

[1]areas determined by the Alcohol and Tobacco Tax and Trade Bureau to have unique climate, soil structure, and physical features distinguishing them from surrounding areas.

Current Situation

A survey on soil health sent through WSU's Irrigated Ag listserv in early 2020 had 23 respondents listing grapes (wine or juice) as their primary crop. Of a variety of issues listed, nutrient cycling was rated as an issue of high importance by the greatest number (77%) of grape respondents. The soil improving practices of greatest interest in grape production are cover cropping and compost application. Topics for research or additional information that were considered highly important by grape respondents included strategies for improving soil health (85%), benefits of soil health (73%), monitoring soil health (67%), and economics of soil health (65%). The full survey results are detailed in Appendix 1.

The term 'soil health' can vary in meaning to many in the grape industry. Historically, soil research and priorities have focused on nutrient management/deficiencies, soil structure and irrigation, and terroir as it relates to a specific AVA. The industry has funded decades of research on nutrient management and Concord foliar chlorosis as well as irrigation practices and their effects on vine vigor and grape quality. Other major soil issues include nematodes, phylloxera, and replant disease. Recently in Concord grapes, the industry has explored functional microbe ecology to improve nutrient uptake, but that work is not yet conclusive. Despite the long-term reliance on irrigation in this arid climate, including the use of deficit irrigation for wine grapes since the mid-1990s, salinity is not yet considered a concern among industry members.

Figure 24. Researchers soil sampling to evaluate soil health in vineyards (Photo: Sullivan)

Goals and Priorities

Juice and wine grape grower priorities differ based on the factors influencing the price of grapes. The juice grapes must meet a minimum sugar content (Brix level) but then profit is based almost entirely on tonnage. Juice grape farmers try to maximize yields per acre. Wine grape farming goals are rarely driven by maximum yield but rather by berry attributes desired by a winemaker, and include qualities such as Brix, various fruit chemistry attributes, berry size, and color. In fact, many wine grape sale contracts limit the allowable yield far below the vine capacity. Therefore, the function of soil health would have different goals in each commodity. However, two common goals would be: 1) to improve soil health that maximizes nutrient uptake to minimize nutrient input under specific irrigation strategies, and 2) to improve control methods for soilborne pests (plant parasitic nematodes and the insect pest phylloxera) and replant disease without detrimentally affecting soil health and beneficial nematodes, fungi, and bacteria.

The Washington State Wine Commission and the Concord Grape Research Council identify priorities annually. Those specifically related to soils involve nutrient, water, and pest management and are listed below:

Viticulture Production Efficiency and Profitability

- Improve water use efficiency/water savings to optimize grape production and wine flavors.
- Understand impact of water quality (e.g., salinity, alkalinity) on vine health.
- Develop nutrient management for optimal vine health.
- Explore strategies for iron chlorosis, particularly in juice grapes.

Pest Management (including sustainable and organic)

- Develop/refine strategies for all pests (e.g., insects, weeds) of economic impact potential, with emphasis on stable, biological systems.
- Develop nematode management strategies (i.e., efficacy of control measures, economic thresholds, resistant rootstock).

Management of plant parasitic nematodes and newly discovered populations of phylloxera can have a direct negative impact on soil health as chemical strategies have non-target impacts on soil biology. New plantings are particularly susceptible to pest pressure and can be difficult to establish without some control mechanism. Unfortunately, all registered pesticides used at standard rates essentially suppress, rather than eliminate, pest populations. The hope is to minimize populations long enough to allow newly planted, young vines enough years to become established and basically tolerate pest populations as they increase. Long term control options and research have focused on use of rootstocks and green manures like mustards planted prior to vineyard establishment. Rootstock research has been conducted worldwide since the late 1800s and in Washington since the late 1990s, and there are many viable choices that are resistant to both nematodes and phylloxera. Rootstocks can also have an impact on horticultural parameters like growth patterns, yield and fruit composition, water and nutrient uptake, and winter survival. An understanding of the performance of specific rootstock-scion combinations in various soils and microclimates will only occur through long term research and extension projects and knowledge gained from grower plantings.

Iron-induced chlorosis is a yellowing of leaves due to high soil pH and the lack of plant-available iron. Symptoms are relatively common in heavily irrigated Concord grapes; they can be seen on a single vine or entire sections of a vineyard and often lead to reduced grape yield and quality due to a lack of photosynthesis. Own-rooted (ungrafted) juice grapes are more susceptible than wine grapes, due to their natural preference for low pH soils. Anything minimizing photosynthesis, which produces energy and carbohydrates for the plant, can be a problem for juice grapes given that they are grown for maximum yield. Years of work on iron chlorosis has been funded, yet it persists as a problem with Washington juice grape growers. Looking at the role of soil health, microbes, and microbe function has been listed as a priority in juice grapes.

Figure 25. Grape plant exhibiting chlorotic symptoms. (Photo: Sullivan)

Cover cropping to prevent soil erosion and aid in weed management is critical. Grapes are drip irrigated so there is minimal moisture mid-row. Growers are often concerned that cover crops compete with water and nutrient resources for grapes and may possibly decrease berry quality. Yet research has shown that in the right conditions it can be a powerful tool to help control vine vigor and assist with canopy management (Tesic et al. 2007). Volunteer plants can easily establish as cover crops mid-row, but intentional establishment of specific cover crops can be more challenging with the limited water. More than a decade ago, there was research on testing different grasses and legumes as cover crops. There has also been research on native plants used to attract beneficial insects and cover crop use, but it has not been widely adopted. Current research is focusing on the use of Litchi Tomato, oilseed radish, clover, and/or brassicas as a pre-plant cover crop with the intent of baiting nematodes. Of interest to viticulturists is the use of complementary cover crops that mitigate soil erosion, weeds, and possibly fix nitrogen.

Figure 26. Juice grapes with no ground cover (left) and with grass cover (right). (Photo: Sullivan)

Milestones

Many milestones have already been accomplished. In particular, a 30% reduction in irrigation water use and pumping costs is attributed to WSU research on deficit irrigation strategies for red wine grapes to control canopy growth and improve fruit quality. Improving nutrient and pest management strategies continue to be priorities. However, significant knowledge must be gained on rootstock-scion combinations in various mesoclimates and soils to meet the demands of new plantings and replant situations as the wine grape industry is embarking on large-scale vineyard replanting in the face of ongoing or increasing pest pressure. Some Washington studies have shown minimal effects of rootstock on grape quality yet some effects on growth and yield of different rootstock-scion combinations (Harbertson and Keller 2012; Keller et al. 2012). Juice grape production is a struggling industry with a narrow profit margin and producers would benefit from nutrient management strategies that optimize production.

Barriers to Adoption

Grapes are a perennial crop meaning that it is at least three years until full production with plantings lasting 30 to more than 50 years, and replanting is a significant economic decision. Likewise, many modifications or improvements to soil health need to be conducted after plant establishment. Soil modifications pre-plant are an option, but that only serves the grower for a short period in the life of a vineyard and a small part of the industry.

Figure 27. Mowed ground cover between juice grape rows. (Photo: Sullivan)

Resources/Tools/Opportunities

Both wine and juice grapes have an engaged industry that has funded research and is very well organized. There is a dedicated set of researchers in pathology, entomology, and horticulture. A Viticulture and Enology (V&E) major was created in 2002 for undergraduates, and the V&E extension certificate for industry members was created in 2003. In 2006 a V&E building was constructed at the WSU Irrigated Agriculture Research and Extension Center (IAREC) in Prosser, and in 2015 the Ste. Michelle Wine Estates WSU Wine Science Center (WSC) opened at WSU Tri-Cities. The program is supported by vineyards at IAREC and WSC, a research and teaching winery at the WSC, and specialized laboratories at the WSC and IAREC. The program's national and international reputation continues to grow, and the working relationship between its faculty and the industry is exemplary.

Figure 28. Soil scientists sampling soil bulk density in vineyards to quantify soil health. (Photo: Sarpong)

Recently, federal Specialty Crop Research Initiative funds and WSDA Specialty Crop Block Grant funds were awarded. The goal is to improve precision irrigation and nutrient management as well as conduct a statewide soil health assessment of seven specialty crops including wine grapes. These efforts, led by a WSU viticulturist, WSU soil health specialist and the WSDA Natural Resources Assessment Section, hope to improve metrics for evaluating and tracking soil health as well as management in Washington wine grape systems.

Washington State University no longer has dedicated weed or soil scientists working in grapes or perennial fruit crops. In 2021, USDA Agricultural Research Service hired a soil scientist located in Prosser, Washington, and his research focus on soil microbial communities is a collaboration opportunity for scientists working in related disciplines. There is a strong relationship between industry and research scientists and extension educators. Some industry members participate on national boards, like the National Grape Research Alliance, that bridge state and national issues and opportunities.

WSDA also supports and cooperates with the grape industry. The industry has continually asked for quick and assertive registration of new products that allow for proper rotation of chemistries to minimize pesticide resistance. In addition, WSDA has developed regulations related to the import of plant material. Continued industry engagement and input is essential in making these regulations function well for the industry while protecting it from invasive pests, diseases, and viruses.

Core Investment Areas

The WSU Viticulture & Enology (V&E) strategic plan (http://wine.wsu.edu/2021/09/01/ve-strategic-plan/) prioritized many research, teaching, and Extension needs. However, those related directly to soil health are included here. Despite the infusion of five new faculty positions in 2003 and expanding facilities, the V&E Program has been unable to keep pace with the tremendous growth of Washington's grape-related industries to more than 70,000 acres and nearly 1000 wineries and juice processors by 2019. Compared to other V&E programs in different states, we have half the number of faculty fully engaged in the V&E program. Prioritized faculty positions related to the Washington Soil Health Initiative would include soil and weed scientists specializing in irrigated soil management in perennial crops as well as a plant biochemist/molecular biologist to progress knowledge in fundamental grapevine biology and the plant's interaction with the biotic and abiotic environment. Support positions include a vineyard and greenhouse manager for WSU Prosser and Tri-cities as well as permanent funding for technicians who support research and Extension.

There is a need for additional core facilities and other infrastructure that are crucial to achieve the strategic goals of the V&E Program. These include greenhouses for year-round pot experiments in viticulture (2100 ft^2), bird-proof screen house (2100 ft^2) for outdoor pot experiments, two plant growth rooms, expansion and support of research vineyards (10 acres) to permit alternating field trials under homogeneous conditions, upgrades and maintenance of vineyard and laboratory equipment, and a mechanical harvester and pruner to reduce labor costs.

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Photo: Griffin LaHue

NORTHWESTERN WASHINGTON ANNUAL CROPPING SYSTEMS

Primary Authors: Deirdre Griffin LaHue, Gabe LaHue, Karen Hills, Chris Benedict

Summary

In northwestern Washington, crop rotations are diverse but largely driven by the high value of fresh-market potatoes that result in short rotation lengths. Participants mentioned issues associated with intensive tillage and soil pH. Some growers are investigating alternative tillage strategies and changes to rotations. Future research needs to be directed toward quantifying the beneficial value of rotational crops and cover crops and providing better tools to assess changes in soil health. Better understanding of soil biology was also emphasized. Core investments are needed that include biophysical and sociological research related to soil health, standardizing soil health indicators, and long-term monitoring of commercial fields.

Information Collection

The majority of the following information was gathered at a roundtable event in December 2019 held at WSU's Northwestern Washington Research and Extension Center (NWREC) in Mount Vernon. There were 22 participants, including growers (14), consultants/agronomists (3), WSDA staff (2), and researchers (3) representing the potato, flower bulb, vegetable seed, small grain, and dairy industries. The event began with the larger group together to go through a retrospective and visioning exercise. Participants were then divided into three smaller subgroups to facilitate discussion. The groups came back together towards the end of the event to go over each subgroup's discussion and identify priorities and next steps. A follow-up meeting to confirm primary goals and milestones was held in February 2021 with an advisory group of 6 growers representing the potato, bulb, dairy, and vegetable seed industries in northwestern Washington.

Current Situation

Northwestern Washington's annual cropping systems are focused in Skagit, Snohomish, and Whatcom Counties. Crop rotations in the region are frequently driven by fresh-market potatoes, the most commonly grown high-value annual crop. Additional high-value annual crops include tulip and daffodil bulbs, vegetable seed crops (beet, spinach, and cabbage seed), and fresh-market vegetables (broccoli and Brussels sprouts). However, the largest acreage rotational crops (e.g., forages, small grains, silage corn) yield low returns.

Figure 29. A soil health roadmapping listening event with local producers held at WSU Mount Vernon Northwestern Washington Research and Extension Center. (Photo: Benedict)

At the roadmapping event, the group discussed major issues of soil compaction and maintaining soil structure that result from the nature of the potato-driven system that necessitates there are no hard soil clods that cause blemishes or misshapen potato tubers. Therefore, growers routinely till the soil until all soil clods are broken up. The resulting loss of soil structure may lead to issues with saturated and flooded fields from fall to early spring due to poor drainage and may cause issues with reduced water-holding capacity (from reduced porosity) in the summer.

The growers also mentioned that profit margins are very tight and, while preferred, “resting” fields in cover crops or forages for multiple years is difficult between potato crops. Growers also mentioned that there is not enough land base for a five-year rotation, so potatoes are grown every three to four years, which is recognized to have significant detrimental effects on the soil. To assist with this, growers need a rotational crop with good economic viability. This could be achieved by developing mechanisms to value rotational crops (e.g., grasses, alfalfa, cover crops, forages) in terms of the soil health and environmental benefits they are providing.

Participants also outlined issues with soil pH. In potato systems, ideal pH is below 6.0 to prevent issues with scab (*Streptomyces scabes*). However, spinach seed crops (that are rotated with potato crops) are regularly limed to mitigate Fusarium wilt pressure, which is exacerbated at low pH. Previously, there was tighter integration of annual crops with dairy operations and therefore more manure applied to fields. The organic matter additions in the manure were beneficial as they helped to buffer soil pH changes and led to higher yields. Growers identified that with fewer dairies in the area, there is not enough dairy manure available and therefore less organic matter inputs than there were previously. However, some growers also associated raw manure additions with increased scab on potatoes.

Current Understanding of Soil Health

Growers discussed that when a soil is healthier, it makes the growing process easier the whole way through and that they find that the healthier soil is easier to work in preparation for planting, requires fewer irrigation events, and produces higher yields and higher quality products. They described knowing a good or healthy field as an innate feeling based on look and feel but were interested in improved metrics to confirm their observations. Regenerative agriculture was also mentioned and associated with needing fewer chemical inputs. Participants also associated soil health with high functioning of soil organisms.

Definition and Components of Soil Health

Participants associated soil health with soil organic matter, fertility, pH, biology, and tilth. One subgroup was particularly curious about soil biology and wanted more information outlining ways to help soil biological activity and "not hurt it." They thought of this particularly in terms of tillage, asking how one tillage event vs. several events affects soil organisms and whether there is a threshold at which microbial communities are "harmed." Participants discussed physical (e.g., workability), chemical (e.g., pH, soil organic matter), and biological (e.g., decomposition, competition with pathogens) aspects of soil health.

Important Functions of Soil Health

Growers identified the most important functions of soil health as:

- Increasing resilience against the uncertainty of water availability.
- Improving root growth to allow roots to access water deeper in the soil profile and perhaps improve capillary rise of water toward the soil surface.
- Buffering against pH changes, which would help manage soil fertility and pathogen pressures.
- Allowing for better soil workability and fewer tillage passes.

Goals and Priorities

Most Important Soil Health Issues

The primary issues for producers in this region are related to soil physical properties, including soil compaction, affecting root growth, drainage, and water-holding capacity, and poor soil structure, which causes poor water infiltration, hard surface crusting, increased tillage, and issues with seed germination and growth. Additionally, producers have issues with pathogen pressure, which is in part driven by challenges with managing soil pH, as described above.

Causes of Soil Health Issues

Issues with soil physical properties are caused by the intensive tillage and equipment traffic necessitated by the potato-driven rotation, and the fact that traffic often occurs at times when the soils are very wet due to spring and fall precipitation. Occurrence of tillage and harvests when soil moisture is higher than ideal for field traffic exacerbates issues with soil compaction and crusting and further drives issues with drainage and flooded fields. Several growers are working to reduce disturbance in the rotation by including grasses or other cover crops in the rotation to allow the soil to "rest" from potatoes, but limited land and tight profit margins make this challenging. Growers also recognize that soil organic matter and soil biology play a role in helping to reduce issues with compaction and water management and are working to find ways to increase organic matter inputs to the soil.

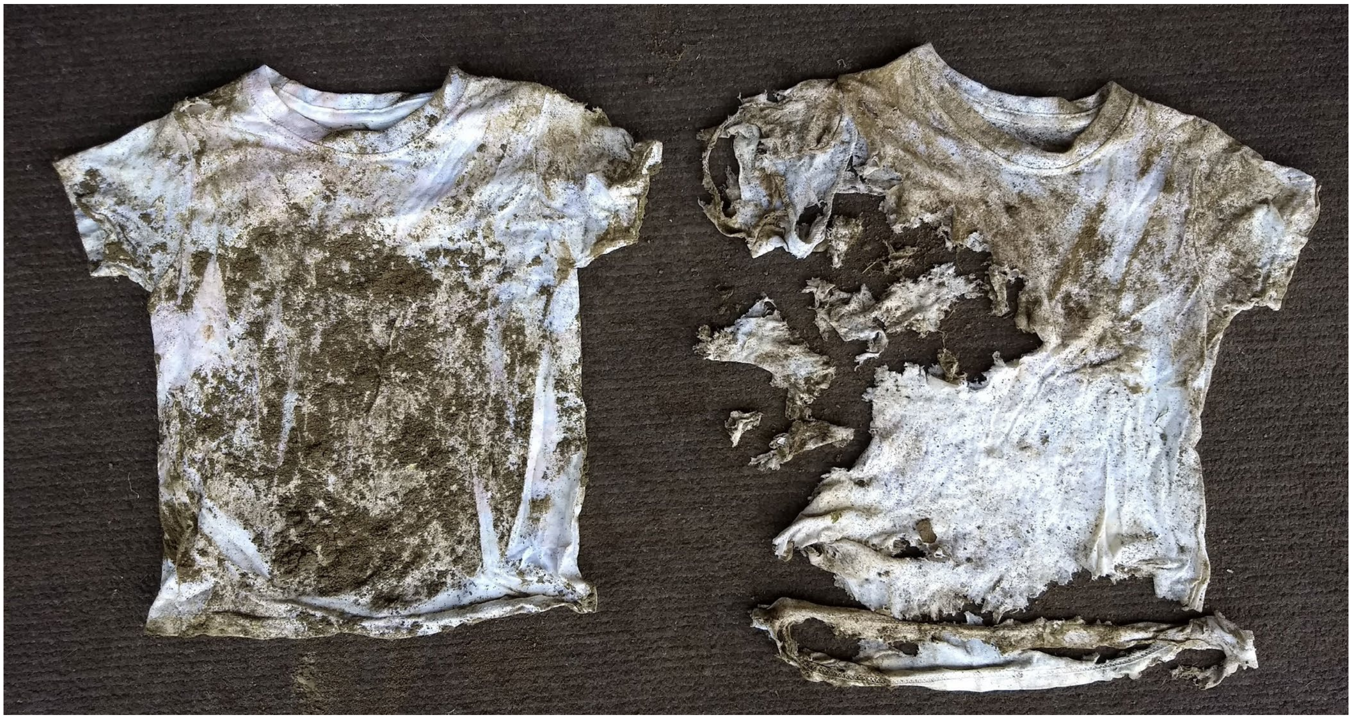

Figure 30. Results after two cotton t-shirts were buried in a regularly tilled field (left) and a field that had not received tillage for eight years (right). Higher soil microbial activity broke down the t-shirt on the right more quickly. (Photo: Griffin LaHue)

Soil Health Benefits

Participants stated that improved soil health would lead to reduced compaction, which would in turn would improve soil workability or tilth (requiring fewer tillage passes to prepare fields for planting), as well as soil moisture management with better water infiltration and drainage. Growers stated that they currently have challenges managing soil moisture, with flooded fields much of the year and moisture-stressed fields in the summer, and that improving soil health would make it easier to manage water throughout the year.

Key soil health research priorities for agriculture in Northwestern Washington include:

- Quantifying the incremental benefits gained by keeping a field out of potatoes each year (lengthening the rotation).
- Investigating which aspects of virgin soils (not previously cultivated, particularly with potatoes) lead to such high yields with the first potato crop, and how non-virgin soils can be managed to achieve similarly high yields. Deciphering the connection between the high productivity of virgin soils, soil biological communities, and soil fertility (micronutrients).
- Optimizing cover crop management including termination methods and timing. For example, whether it is better to terminate cover crops while vegetation is green or brown, whether chopping a green cover promotes more root exudation and benefits microbes, timing of nutrient availability if you let a grain crop “rot back into the ground,”, and the degree to which cover crops are nutrient scavenging and preventing nutrient loss while they are growing.

- Better understanding of the functions of soil biology and how soil biological communities are affected by soil management.
- Improving water management with soil health by determining whether improved soil health can increase rooting depth and capillary rise of water from the water table, thereby reducing the need for overhead irrigation.

Information Gaps

In addition to the research priorities listed above, information gaps that are critical to improving soil health for this system include:

- Quantifying the value of services provided by rotational crops and cover crops, such as fertility, increased water-holding capacity (fewer irrigation events), and carbon storage, in order to create a structure for generating economic gains when using longer rotations.
- Lack of standardization of methods for measuring soil health, availability of simple measurement tools, and understanding of the meaning behind these measurements (e.g., soil microbial communities).
- Elucidating mechanisms and organisms driving disease-suppressing vs. disease-enhancing soils.
- Better understanding of the options for optimizing tillage in this system, including equipment options to reduce the number of passes needed and knowledge of how the timing of existing tillage operations is affecting the soil.

Milestones

Growers in this region expressed wanting to get to a point where they have rebuilt the soil organic matter that has been lost over decades of cultivation and to ensure that "no further harm" is being done to the soils, for example by stopping oxidation of organic matter by tillage. Rather than setting a quantifiable milestone, they want to know that their management is moving soils in the "right direction," one where soil organic matter is accumulating over time, soil structure is more resilient, water dynamics (e.g., drainage, water-holding capacity) are improved.

Barriers to Adoption

Cover crops: The ability of cover crops to either introduce (through untested or low-quality seed) or harbor disease (through living biomass or stubble) was cited as a significant barrier to adoption/use, most obviously in the case of brassica cover crops that are grown in proximity to vegetable seed crops and fresh-market brassica crops. Other barriers include poor germination with low-quality cover crop seed, seed predation pressure from migratory birds, seed cost, and insufficient growing degree days to get good establishment after late harvested crops (which increases susceptibility to bird pressure).

Crop rotations: Land trading is very common in the area due to complex rotations but can stifle investment in the land. Economic considerations force producers to shorten the rotation (there is not enough land or other income to do a 5-year potato rotation) and practices that can shorten rotations (e.g., liming) are always appealing since they allow producers to get more out of their own ground (vs. leasing it out).

Reduced tillage and leaving residue: Participants stated that some crops, such as corn, can handle residue and that incompletely incorporating residues can help reduce soil crusting but also create problems with plant disease survival. Furthermore, hard clods can cause misshapen potatoes, so marketable high-quality potatoes typically require many tillage passes.

Organic amendments: It can be challenging to incorporate amendments (e.g., compost) in the sheer quantity needed during the busiest times of year (before planting and after harvest). Previous experiences with low quality organic amendments have created perception barriers to their use, including mill waste that had grass seed and "sewage sludge" that left a field unable to be planted. The expense of many organic amendments limits their use (e.g., compost needs to be on a field going into a high-value crop, biochar has been produced locally but at too high a price), and dairy manure is in limited supply and can't be economically transported more than a few miles from the farm. Lastly, organic amendments bring concerns about plant diseases (e.g., scab), food safety risks, and public perception.

Overcoming the Barriers

While no one solution can completely overcome these barriers, the need that workshop participants stressed repeatedly was for financial incentives for land stewardship. These could take several different forms, such as: 1) Valuation of the economic benefits of management practices to build soil health, 2) Inclusion of stewardship requirements in leases and other contracts (some contracts have stipulations pertaining to nutrient levels), or 3) Direct payments for certain management practices to help producers overcome constraints of tight profit margins. Other solutions specific to particular barriers include using cover crops that are less susceptible to bird damage and well-adapted to late planting and access to high-quality organic amendments at reduced cost.

Soil Health Policies

As mentioned above, financial incentives for management practices that build soil health would be a key policy solution. For example, carbon credits could be offered for keeping fields in perennial grass or sod, allowing producers to lengthen their rotations (or for other practices that build soil organic carbon). Access to irrigation water was also raised as an area where policy solutions are needed, possibly because uncertainty can stifle investment. It was emphasized that "soil health is a public resource" and as such, needs to be incentivized appropriately.

Resources/Tools/Opportunities

Resources and tools that provide technical guidance for specific management practices and especially, for standardized measurement of a key suite of soil health indicators, would be important to advancing soil health in northwestern Washington. Participants stressed the importance of standardizing the metrics for monitoring soil health (and other soil properties, such as soil moisture), so that producers can compare with their neighbors and reliably compare their baseline conditions to future measurements.

Cropping System Specific Issues

Northwestern Washington, and Skagit and Snohomish Counties in particular, have diversified annual crop rotations in peri-urban areas, which carry several important challenges. First, complex crop rotations and land trading are an integral part of the system, creating complications for adopting certain management practices and, in some cases, disincentivizing investment in land stewardship. Second, irrigation water access for many growers is subject to minimum in-stream flows, which creates uncertainty for growers and may limit investment (previously described). Lastly, the peri-urban nature of the agricultural system makes it subject to high land values and development pressure, mostly eliminates flooding from the river (and its associated costs and fertility benefits), and increases public scrutiny of agriculture.

Core Investments Areas

While this question was not specifically raised with stakeholders, several needs that directly translate to key investments were discussed. First, there is a need for biophysical and socioeconomic research to 1) quantify the ecosystem services and societal benefits provided by improved soil health, 2) inform policies that monetize the value of soil health and incentivize practices to build soil health, and 3) develop best management practices for specific soil health interventions and guide the implementation of these practices. Second, the importance of standardizing soil health indicators and educating stakeholders on how to use and interpret these indicators was stressed repeatedly, which will require some additional research and significant outreach and education efforts. Lastly, long-term monitoring of soil health in producers' fields was identified as a key need, so that producers know whether their soil health is improving or declining. The aforementioned efforts will require interdisciplinary funding sources, and though the facilities and expertise to conduct this research exists within WSU, some additional investment in human resource capacity may be required.

Photo: DuPont

TREE FRUIT

Primary Authors: Tianna DuPont and David Granatstein

Summary

While there is great interest in soil microbiology, soil health is generally not well understood by the tree fruit industry. Soil health related issues include fruit quantity and quality issues as well as soilborne diseases and soils with low water-holding capacity. Replant disease is ranked highly as a research topic by the industry as well as ways to improve soil organic matter, soil health testing, and testing of various inputs. Identified milestones include but are not limited to education/awareness of soil health, improved soil health indicators, adoption of soil health practices, and improved orchard health and productivity. The industry noted barriers that include lack of definition of soil health, clear cohesive best management practices (BMPs), and lack of knowledge. Listed investments included long-term research, soil health indices, soil health outreach, and strategic hiring in the soil microbiology arena.

Challenges related to soil type include:

- Lack of uniformity
- High pH
- Low water-holding capacity
- Low or excess nutrient availability
- Restricted root growth resulting from soil hardpans, impermeable soil layers, physical barriers, and shallow rocks.
- High salinity in soils irrigated with well water or soils that are overfertilized.

Information Collection

In 2020 feedback was collected via in person and online survey as well as focus groups from 37 individuals representing more than 8,170 acres of apples, pears and cherries, the predominant types of tree fruit grown in Washington State (Appendix 2). Participants included orchardists and consultants representing small acreage (13 respondents < 80 acres), mid-sized (20 respondents, 100-250 acres), and large (four respondents > 1,000 acres). This survey builds upon a previous needs assessment survey in 2015, Washington Tree Fruit Research Commission research priorities, and research and extension surveys of organic growers in 2016 (focus group of nine growers) and 2017 (104 survey respondents). Additional needs assessment was conducted as part of an Orchard Soil Health Workshop held November 4 and 5, 2020 which facilitated feedback from 92 participants through discussion groups and a follow up survey (Appendix 3,4).

Figure 32. Soils from a gala block. (Photo: DuPont)

Current Situation

Knowledge and Definition of Soil Health

In general, soil health is not well understood in the tree fruit industry. Some growers are unfamiliar with the term. Of those who think about soil health many associate soil health with microbial activity and soil life. Others think more about the ability of the soil to provide nutrients. Some growers are very aware and interested in soil health, for example, defining it as "the ability of the soil to provide an environment conducive for the healthy development of plants with an abundant and thriving rhizosphere" (DuPont 2020). Lack of understanding of basic soil fertility is considered a problem. Some industry professionals also point out that many orchardists follow the supplement recommendations of the commercial representatives who have a vested interest without other unbiased information.

Soil Health Issues

Many of the important challenges voiced by industry representatives focus on how soil health is related to tree health, productivity and fruit quality:

- Fruit quality problems related to nutrition (e.g., bitter pit);
- Low yields;
- Low fruit quality (packout);
- Replant disease, nematodes and soilborne pathogens;
- Light/ droughty soils;
- Soils with lead/arsenic toxicity;
- Compaction.

Figure 31. Soil compaction in tree fruit leads to reduced water infiltration. (Photo: Sallato)

Soil types in the Central Washington tree fruit growing region contribute to the challenges. Soils are notoriously patchy with individual fields sometimes composed of multiple soil types resulting in a lack of uniformity throughout the field. In some areas caliche (hardened calcium carbonate) soils result in layers which constrict root growth and water movement and contribute to increased pH, buffering capacity and nutrient imbalances. The soils in the growing region also tend to have a high pH, which can limit micro-nutrient availability.

Additionally, perennial cropping systems have both advantages and disadvantages related to building and maintaining soil health. Because plantings are semi-permanent (13 to 30 years) there are few opportunities to incorporate large amounts of organic matter and few opportunities to rotate for disease management. Cover crops other than grass generally cannot be grown because of the high amount of traffic from equipment down the drive rows and potential to host viruses. Apples, pears, and cherries also do not export very high amounts of phosphorus and so yearly compost applications are not advised as they would lead to build-up of phosphorous levels which contribute to fruit disorders. Recycling of wood material after trees have been removed requires costly machinery for chipping, therefore, most growers prefer to burn the wood instead of incorporating it into the soil.

Goals and Priorities

Research Priorities

In organic grower focus groups, replant disease has been cited as the number one challenge (Dupont 2016a and 2016b). In the 2020 Washington Tree Fruit Research Commission Apple Crop Research Priorities, soil health improvement priorities including testing of available biostimulants was listed as high priority and developing standard operating procedures for alternative controls for replant disease was a medium priority (Hanrahan 2020). The 2016 and 2020 surveys identified a range of research needs including soil biology, soil health testing, replant disease and input testing (DuPont 2020, DuPont 2016a and 2016b). Specific soil health research needs identified by survey participants are listed below.

- Investigate soil biology in relation to disease suppression, nutrient uptake, nutrient availability, and microbiome interactions.
- Identify soil health analysis with simple action steps to rectify deficiencies.
- Analyze non-synthetic and microbial inputs (e.g., mycorrhizae, green manures, biostimulants, microbial inoculants).
- Identify how to improve organic matter (e.g., from wine/ hop residue, compost, green manures).
- Research soilborne disease mitigation (replant, crown rot, and nematodes).
- Investigate ways to conserve water, improve water holding ability, manage water across uneven soil types, and buffer from stress.
- Look at interactions between herbicides and soil health.
- Examine how cultivation practices in organic production impact soil organic matter, soil biology, and soil health.
- How to interpret soil tests, fertilize optimally, correct nutrient imbalances, and optimize timing.

Knowledge Gaps

There is great interest in the soil biology and the "microbiome". There is a general feeling that soil biology is key, but growers want to know more about what microorganisms there are, and how to help it to enhance nutrient cycling and absorption, improve root-health and increase water uptake. Soil biology and health as well as nutrition were top areas where growers wanted to learn more according to the 2016 needs assessments and 2020 soil health surveys (DuPont 2020, DuPont 2016, DuPont et al. 2020). Growers understand that nutrition is not the only limiting factor and want ways to test, diagnose and manage for limiting factors related to soil biological and physical properties. While fertility and nutrition have been studied for many years, orchardists still feel there are many knowledge gaps in this area (DuPont 2020, DuPont 2016, DuPont et al. 2020). Nutrition is particularly key for organic growers with fewer options and was first or second priority in non-pest related needs for organic growers in 2017 (DuPont and Granatstein 2017).

Knowledge gaps include:

- What makes quality soil?
- How to build healthy soil?
- Information on soil biology (microbiome) how it can extend the life of an orchard, enhance nutrient cycling, improve root health.
- Testing of 'natural' products, bio-stimulants and microbial inoculants.
- Increased understanding of soil fertility and soil chemistry.
- Correlating soil health to fruit pack outs and fruit storage.

Figure 33. Sweet cherry intensive cropping systems. (Photo: Sallato Camona)

Milestones

Short-term (1 to 5 years)

- Provide education (extension) on soil health basics including nutrition and soil biology.
- Increase awareness of the importance of soil health.
- Increase understanding of the biological, and physical as well as chemical properties of soil.
- Understand economics of soil health related practices as they relate to yield, fruit quality, tree health, efficiency, reduction of losses, integration into production system.
- Hire Washington State University Endowed Chair in tree fruit soils.
- Implement new research projects investigating soil biology in orchards.
- Identify a suite of soil health tests/indicators that relate to yield and fruit quality in orchards which can be used to test for limiting factors and track soil health gains.
- Implement new research projects looking at long-term sustainable approaches to managing replant disease.
- Initiate research projects on soil health to conserve water and buffer environmental stress in the face of climate change.

Medium-term (5 to 10 years)

- Build a database of soil tests and fruit quality so we can look at correlations.
- Soil health testing available to growers through university or commercial labs.

- Establish program of soil health education (extension) helping growers understand and apply new research on soil biology, replant disease, soil health testing, nutrition, and climate change mitigation.
- Growers using refined soil health test/ indicators to identify limitations and track soil health building practices.
- Establish best practices and standard operating procedures for optimal soil health.
- Reduce variability in orchards with organic matter amendments or other soil health building practices.
- Reduce bitter pit and other disorders related to nutrient uptake and water/plant stress.

Long-term (10 to 20 years)

- Growers and consultant have tools and knowledge to examine limiting factors beyond nutrients AND fix them.
- Growers using practices which build and sustain large, active biological communities in their soils which support healthy trees and nutritious, high-quality fruit.
- Orchard health, productivity, and fruit quality improved.
- Orchard ability to conserve water and provide environmental benefits improved.

Barriers to Adoption

- Lack of a definition of soil health for perennial fruit crops and lack of consensus on how to measure it.
- Lack of clear cohesive BMPs for soil health in perennial tree and vine crops.
- Lack of knowledge by producers about what soil health is, its importance and how to manage it.

Core Investment Areas

- Long term research plot for tree fruit to look at BMPs for soil health over time including organic practices.
- Research on soil health indices and BMPs.
- Funding for creating soil health outreach and training materials such as videos, animations, illustrations, demonstrations.
- Research/ extension faculty position focused on soil microbiology in perennial crops.
- Engineering solutions for soil health monitoring (data analysis, integration of data collection and sensors, image technology), and/ or solutions for pesticide/weed management. Incentives or restrictions to burning, while economic alternatives to processing residues/compost.

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Photo: Benedict

WESTERN WASHINGTON DIVERSIFIED FARMING SYSTEMS

Primary Author: Doug Collins

Summary

Current understanding of soil health is strong with this group as it is a principle of organic production. Challenges were described as reliance on tillage, soil fertility, and farm flooding. Goals included reduction in off-farm inputs, improved understanding of carbon sequestration, better management of soilborne diseases, and creation of policies to increase access to NRCS funding. Gaps in information focused on carbon sequestering, soil biology, successful methods to reduce tillage, soil management, use of cover crops, and other innovative solutions. Lack of local capacity in Extension offices and better incentive program design were both listed as barriers to adoption. Education, technical assistance, and funding could help to overcome these barriers. Changes in existing policy was listed as a way to alleviate these barriers as well funding for on-farm experimentation. Investment in key personnel at WSU with extension appointments to provide technical support was listed as a key investment area.

Information Collection

Eighteen farmers representing 16 farms in nine counties of Western Washington participated in three virtual listening sessions held March 2-3, 2020. These individuals were nominated by agricultural professionals in the region or self-nominated.

Current Situation

In general, organic growers in western Washington have a good basic understanding of soil health, in part because it is an important tenet of organic agriculture. Producers following organic standards are expected to be fostering soil health, per the soil fertility and crop nutrient management practice standard (National Organic Program). These producers are interested in the aspects of soil health that allow them to produce quality crops (sufficient nutrients, low pest/disease pressure), but many are also interested in less tangible functions of soil health (e.g., carbon sequestration, fostering biological diversity, water quality). Many see themselves as stewards of the soil and would welcome additional focus and resources toward an aspect of agriculture to which they are already paying attention. A focus on soil health by consumers and policy makers would highlight the work of organic growers who are already implementing a host of soil health practices. There is interest in this group in moving away from granular fertilizer and towards cover crops for soil fertility, allowing the reduction of off-farm inputs.

Figure 35. Researchers gather soil samples in organic fertilizer trial. (Photo: Collins)

Soil Health Issues

The most common soil health issues faced by western Washington organic producers are described below.

Tillage

Tillage is used to prepare ground for planting and is an important method of weed suppression in organic production. However, tillage can lead to a loss of organic matter and is detrimental to soil microbial populations. Reducing tillage is challenging in organic systems, especially for annual vegetable production as tillage is also typically used to prepare ground for, terminate, and incorporate cover crops. Participants observed an increase of wireworm and symphylans when tillage is reduced. Producers see obvious trade-offs between production and reducing tillage. For example, one participant mentioned using precision direct seeders, which can improve stands and reduce seed costs, but noted that this equipment requires even better bed prep, thus more intensive tillage of soil.

Figure 34. Researchers evaluating strip tillage as a means to protect soil health. (Photo: Collins)

Soil Fertility

Producers using organic methods have more limited options to provide adequate nutrients for crops than those using conventional methods. One option is the use of bulky organic amendments such as compost or manure that benefit soil health as well as provide nutrients. Participants mentioned issues with sourcing compost or animal manure from off-farm in areas where these are in short supply. Some growers are worried about potential herbicide contamination of compost. While incorporating livestock into the farming operation would be one way to supply manure, the animal aspect of the farm is not always profitable, and growers are challenged to add another facet to already busy and diverse operations. Some growers struggle to find affordable organic fertilizer for lower value crops (e.g., hay) where return on investment is limited. Estimating nutrient availability for plants (particularly nitrogen), can be challenging in organic production. Likewise, nutrient, organic amendments and cover crop management were mentioned to be challenging to implement effectively with a diverse portfolio of crops grown.

Soilborne Pests

Soilborne pests were discussed as issues for these growers, including insect pests (e.g., wireworm, root maggot/cabbage maggot, flea beetles, and symphylans); weeds (particularly grasses such as barnyard grass and cockspur grass); and diseases (e.g., club root, white rot, downy mildew). Participants emphasized that alterations to the production system to improve soil health can have unintended consequences, particularly with regard to increasing pressure from some soilborne pests. More specifically, increases in damage from wireworm and symphylans in reduced tillage situations, increased wireworm populations after cover crop incorporation, and one participant reported onion stunt caused by a bloom in Rhizoctonia after plowing in a cereal cover crop. These types of unintended consequence are not unique to organic agriculture, but growers following organic practices have fewer options for addressing the issues.

Flooding

Much of western Washington's fertile farm ground lies in flood plains. Flooding benefits soil fertility through mass deposition of micronutrients and silt, but leads to difficulty maintaining cover crops, permanent beds (important in reduced tillage systems), and washing away of expensive soil amendments such as compost. Likewise, flooding can impact profitability by shortening the season, cause damage to overwintering crops (e.g., brassicas), and decreased summer production in parts of the field that are wet during the winter.

Figure 36. Researchers gather soil samples in organic fertilizer trial. (Photo: Jobe)

Other specific challenges identified by this group include suburbanization and land use changes around these farms, many of which are in peri-urban areas lacking strong agricultural infrastructure; knowing how to maximize soil health for the diversity of crops on each farm is challenging; growers' ability to experiment is limited by finances and time.

Goals and Priorities

- Reduction of off-farm inputs.
- Moving toward cover crops and away from granular fertilizers.
- Incorporation of soil health into planning, development, and policy considerations at the county and state levels.
- Growers understanding and implementing practices resulting in carbon sequestration, following needed research in these areas.
- Accessible soil health metrics specific to diversified organic production systems in western Washington.
- Growers understanding and effectively managing soilborne disease, a common issue for small acreage producers growing many high demand crops on small acreage.
- Paradigm shift from reframing question: "Why do my plants/soil have unbalanced pest pressure?" instead of "How do I get rid of these pests?"
- Policy that provides cost share and encourage access to NRCS to increase soil testing, cover crop seed costs, revolving loan programs to assist beginning farmers would all be good programs to invest in that provide immediate support where it matters; to make investments into soil fertility and building carbon reserves.

Information Gaps

The following were identified as important information gaps related to soil health:

Sequestering carbon and building soil organic matter

- More information is needed on best ways to sequester carbon in the soil, thereby building organic matter as well as targets for soil organic matter levels to reach and how to successfully incorporate soil-building practices into production systems.

Soil biology

- A better understanding is needed of how the biological health of soils impacts a crop's ability to access nutrients and how soil health affects the nutritional quality of the resulting crop.

Strategies for successful reduced tillage in organic production

- Management of perennial weeds and pest problems in reduced tillage systems, including non-tillage weed control for paths in perennial berry fields.
- Management of early crops in the spring in a

Figure 37. Transplanting squash into cover crop residue. (Photo: Collins)

no-till situation (e.g., how to get soil warmed up and introduce oxygen without tillage).

- How to ameliorate impact from tillage that is needed for seedbed preparation.
- Identifying rotations that are compatible with reduced tillage.
- How to achieve high-quality, good-looking produce in a reduced tillage situation (e.g., carrots that aren't knobby).
- More information on the pros/cons of various kind of tillage for organic farming.

Cover crops

- Trying to figure out what works best for understory cover cropping.
- Cover crop combinations and timing/methods of cover crop termination.
- Effective strategies for use of winterkill cover crops for soil nutrients and early spring plantings (e.g., timing, density).
- Fine tuning use of leguminous cover crops for providing nitrogen, particularly in soils with high phosphorus levels.

Management

- Best practices shifting from pasture to annual crop production (especially for managing pH and compaction).
- More information on managing wet soils, managing unused ground to maintain fertility, and soil testing.

Other innovative solutions

- Perennial vegetables as a method for soil health improvement (or other innovative production practices).
- More information on terminating cover crops.
- Information on how to scale up innovative solutions coming out of small farms.
- How to incorporate larger livestock (larger than chickens) with vegetable production.

Figure 38. Diversified vegetable farmscape common in western Washington. (Photo: Benedict)

Barriers to Adoption

Recent decades have seen significant erosion in public funding for WSU Extension agents that has affected all agricultural producers, including diversified growers in western Washington. There is a need for both more *technical support* in the form of agricultural staff in local WSU Extension offices, and for more *researchers* paying attention to the problems of organic vegetable producers at this scale.

Many farmers report operating on very thin margins and while many have interest in trying innovative strategies, they often don't have the funds necessary for on-farm experimentation. These growers mention the need for *financial support* both for the time and resources needed to implement soil health practices. The practice of cover cropping can result in taking an area out of production, sometimes for two to four years, which represents significant loss of revenue. While cost-share programs (e.g., through NRCS or Conservation Districts) can help defray costs, growers expressed that currently cost-share programs do not reflect the reality of costs, including the time spent managing funds. Growers use of cost-share programs often need to invest their own money, with sometimes a lag of several months before receiving payment, which can be financially difficult. Growers in this group are often challenged to find affordable equipment that is suitable for the scale of their operations. Many of the practices for improving soil health (e.g., reduced tillage, cover crop incorporation) may require investment in expensive, specialized equipment that they do not currently own.

Related are the barriers involving the *time and effort* needed to access resources and existing information and figuring out how to apply the research to their own farm. Further complicating the effort involved are the facts that the variability in crops grown is substantial, especially for market farms, resulting in significant recordkeeping needs.

Overcoming the Barriers

Direct *technical assistance* is needed to help growers navigate the complexities of their farming operations and to assist with planning and application of soil health strategies.

> "Since we don't have a specific agricultural person to go to, we just share among farmers. It would be nice if we had one place where we knew where to look."

Education is needed, including 1) education to help growers understand their soil health and effects of practices over time, including a centralized place to look up information on soil health and translation of scientific information into some usable information for farmers; and 2) education of non-growers, specifically of policy makers and the general public to help them understand the need for soil health and the links between soil health, productive farmland, and organic practices. Several participants expressed that it is important to change *customer expectations* (e.g., seasonal availability) as a part of addressing soil health concerns.

“If we are going to adopt a no-till truly sustainable system, maybe we have to retrain our customers not to expect a wide variety of crops over a long season.”

Funding for time and resources necessary to implement soil health practices that are available and should be provided up front, and at a level that realistically reflects the cost of such practices.

There is a role for plant breeders to work with growers *to develop locally adapted crop varieties that do well in no-till systems.*

Figure 39. Researchers evaluating novel cover crop termination methods for use in organic farming. (Photo: Collins)

Soil Health Policies

Incentives for soil health practices are needed to reward farmers who implement practices that improve soil health (e.g., overwintering cover crops) including payments to growers for sequestering carbon in their soils, and incentives for practices that preserve the health of waterways and Puget Sound. Participants specifically mentioned that a policy supporting biochar could provide a win-win for fire resiliency and agricultural soil health.

Technical assistance and education were mentioned by growers as important ways to overcome barriers to improving soil health.

Funding for on-farm experimentation to try different practices and document how they affect soil health and crop production. One participant noted that “the key is that the money has to come firs

Photo: DeVetter

RED RASPBERRY

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Summary

Soil fertility, compaction, and soilborne pathogen and nematode management have been identified as key soil health concerns by growers and crop advisors. Viable solutions are yet to be identified. The industry is interested in long-term soil health research, but availability of suitable land in Whatcom County is a limitation.

Overview

Northwest Washington produces most of the US processed raspberries and comprises 99% of Washington's raspberry production. The industry is concentrated in Whatcom County with 62 growers cultivating raspberry on ~8,800 acres.

Current Situation

A focus group of raspberry growers and Washington State University, USDA, and private researchers was held in April 2022. A follow-up survey and one-on-one discussions with raspberry growers were held in the Summer of 2022. These events were leveraged to inform this chapter and catalyze future research and outreach efforts on soil health in raspberry systems.

Growers are observing declines in raspberry planting longevity and are associating this decline to soil health and adaptation of cultivars. Soilborne pathogens including plant-parasitic nematodes and Phytophthora root rot are the primary biotic factors impacting raspberry production. Despite fumigation, some growers continue to struggle with managing these soilborne pathogens. Abiotic soil health, particularly soil compaction, was another topic of concern among growers. Cultivation and harvesting entails use of heavy equipment that compacts alleyway soils, which can reduce drainage and may limit root growth. Maintaining or increasing fertility was also highlighted by growers. Most growers apply synthetic fertilizers to meet plant nutrition goals, but industry-specific guidelines on timing, rates for specific cultivars, application techniques, and achieving uptake of key nutrients (e.g., calcium) are lacking. An additional constraint is suitable land for raspberry production is limited and costs for external inputs are increasing. Research has been conducted on soilborne pathogen management, alleyway cover cropping, and compaction through industry support. However, the industry and perennial nature of the crop requires a more concerted effort to address key soil health issues to ensure the long-term viability of the Washington raspberry industry.

Goals and Priorities

During the information gathering process, three goals of the raspberry industry related to soil health were identified: 1) improved control methods for soilborne pests (plant-parasitic nematodes and Phytophthora root rot) without detrimentally affecting other aspects of soil health, 2) methods to reduce soil compaction, and 3) practices that improve or maintain soil fertility. The Washington Red Raspberry Commission (WRRC) identifies priorities annually. The industry has identified four research priorities related to soil health: 1) development of cultivars that are disease resistant, including resistance to soilborne diseases, 2) understanding soil ecology and soilborne pathogens and their effects on plant health and crop yields, 3) soil fumigation techniques and alternatives to control soilborne pathogens, nematodes, and weeds, 4) and improved nutrient and irrigation management.

Primary soil health goals:

- Improved management of soilborne pathogens that maintains or improves soil health
- Methods to reduce soil compaction
- Implement practices that improve or maintain soil fertility

Improve soilborne pest management

The industry almost exclusively relies on soil fumigation for soilborne pest management prior to replanting. Post-plant fungicides and nematicides are also used. Soil fumigants, fungicides, and nematicides tend to be broad spectrum biocides that not only suppress target organisms but also many nontarget organisms. There is currently no long-term vision for how soilborne pathogens will be managed in raspberry without soil fumigation. While there is a raspberry breeding program at WSU that focuses on breeding for resistance to Phytophthora root rot, such an effort does not exist for plant-parasitic nematodes. Improving soil biology and use of beneficial organisms to suppress diseases is an area of interest among growers. However, there has been little research on how to promote suppressive soils in raspberry and that effort would require a long-term commitment from the industry and researchers.

Reduce soil compaction

Soil compaction is also common in raspberry production due to the many passes that are required for applying pesticides for crop protection and harvest activities. Compaction leads to issues with drainage and the need for extensive soil remediation upon the removal of a planting. Practices such as deep ripping have negative long-term effects on soil health. Cover crops have received attention by growers and researchers; however, they are not commonly planted. Expanding the use of alleyway cover cropping through research and education focusing on soil health may increase adoption.

Improving soil fertility

Raspberry requires annual application of fertilizers to maintain growth and productivity. Current nutrient management recommendations are from Oregon State University and are not cultivar specific. Growers are also increasingly applying liquid and foliar fertilizers to meet nutrition goals and there has been little research on the application of these fertilizers. Revising nutrient management recommendations for the Washington industry and relevant cultivars will take concerted research efforts and industry support.

Milestones

Part of the 10-year strategic plan for the Washington raspberry industry involves environmental stewardship, which includes soil health. Part of this plan is to build healthier soils that are free from economically destructive soil borne pathogens leading to less reliance on current fumigation practices. This vision would reduce a costly component of producing raspberry leading to increased profits to growers. It would also result in a balanced soil biotic system with the ability to self-regulate soilborne pathogens and potentially improve nutrient cycling. Methods to reduce soil compaction, such as cover cropping, would reduce the need for soil disturbance that are extremely detrimental to long-term soil health and sustain gains that might be realized in creating suppressive soils. Increasing or maintaining soil fertility through more targeted fertility programs would improve plant uptake for sustained crop production while minimizing environmental and financial costs .

Significant knowledge must be gained on long-term strategies to reduce the impact of soilborne pathogens and compaction and address soil fertility concerns. The establishment of a long-term soil health research site within the main raspberry production area of Whatcom County would facilitate this type of research.

Figure 40. A young raspberry transplant planted into black plastic. (Photo: DeVetter)

Barriers to Adoption

The relative lack of economically sustainable rotational crops reduces the use of crop rotation to improve soil health. Long-term rotations would likely reduce Phytophthora root rot pressure, but very few crops can be grown profitably enough to offset the high land costs where raspberries are grown. The relatively small base of well-drained land with appropriate weather conditions also limits crop rotation.

Soil fumigation is essential to current raspberry production systems; without it, plants do not establish successfully, and soon succumb to Phytophthora root rot or nematodes. However, it can also negatively affect the overall soil microbial community, potentially killing some beneficial organisms and preventing the establishment of stable, disease-suppressive populations.

Figure 41. Raspberries grown for processing in Whatcom County. (Photo: DeVetter)

Due to the high cost of production, raspberry growers can be risk-adverse when it comes to adopting changes that have a high potential to negatively impact production. Expensive inputs, hand labor, and equipment costs combined with highly valuable land are required for commercial production. Any choice that risks a loss of production is very expensive. Practices that improve soil health need to be at least neutral to productivity, and this must be demonstrated to growers. Uncertainty around regulations that could impact fertilization, fumigation, and other soil management practices is also a concern.

Resources/Tools/Opportunities

The raspberry industry in Washington State is well positioned to address the soil health issues that are commonplace. First, WRRC has provided research funds to address issues. These funds are largely considered to be seed funds to begin investigations and to be leveraged for larger grant opportunities. However, projects are funded on a year-by-year basis which prevents long-term projects that are needed to evaluate soil health. Second, the raspberry industry is supported by a research community that extends beyond the state of Washington. Researchers from British Columbia, California, and Oregon have historically addressed the soil health issues through basic and applied research. Third, beyond the support the WRRC provides, many producers within the raspberry community play an active role in supporting research on their farms. These collaborations and connections continue to lead to co-creation of knowledge related to soil health. This strong industry-research community connection underscores a unique opportunity to undertake long-term, on-farm research focused on soil health.

Core Investment Areas

The core investment identified by the industry is the need for land in Whatcom County that can be utilized for long-term research to address soil health issues in raspberry. The land must be in Whatcom County due to the specific requirements for commercial production and environmental conditions that the area provides. This research site would provide the opportunity for growers and researchers to implement and evaluate long-term strategies to promote soil health as well as to evaluate new raspberry genotypes produced from breeding programs. Funding is also required for a farm manager to coordinate and maintain a long-term research effort in raspberry.

Photo: Sullivan

CROSS-CUTTING RESULTS FROM ROADMAP EFFORTS

Each focus area unearthed different perspectives and feedback, but there were common themes between focus areas, detailed below. Additionally, across focus areas there was a common emphasis on the need for production system-specific research, outreach and technical support, optimization of soil health metrics, and incentive programs.

Research Priorities

The top five soil health related research priorities for this group are:

- © Develop better tools and strategies for managing challenging soilborne pests.
- © Develop strategies to effectively use reduced tillage in organic production.
- © Develop metrics for measuring soil health (including carbon sequestration).
- © More research on cover crop combos and termination methods.
- © More information needed on managing common soil issues in western Washington: soil compaction, wet soils, soil pH.

Goals and Priorities

Description: Positive soil health outcomes achieved through action.

- Soil health measurements and metrics that are standardized, inexpensive, and easily deployed.
- Easy access to equipment that maintains soil health (e.g., no-till seeder).
- Improved knowledge of soil health specific to production systems.
- Improved information dissemination to agricultural professionals and producers.
- Greater valuation of soil health in the marketplace.
- Protection of existing soil organic matter, and future increase in soil organic matter levels.
- Tillage is minimized where applicable and is well-timed and strategic.
- General public understands and values soil health.

Soil Health Issues

Description: Prioritized soil health issues.

- Soil pH.
- Soil tilth.
- Soil compaction.
- Nutrient cycling.
- Wind and water erosion of soils.
- Water-holding capacity.
- Soilborne plant diseases.
- Tillage requirements for certain crops limit that ability to reduce soil disturbance.
- Poor soil structure that results in drainage issues/flooding and limits field access.

Milestones

Description: Specific metrics that gauge progress towards the above listed soil health goals.

Short-Term (1 to 5 years)

- Establish a network of soil health research sites across the state that generate and disseminate soil health information.
- Identify management practices to increase soil water holding capacity.
- Increase landowner incentive programs by 30%.
- Increase knowledge of soil health by farmers, agricultural professionals, and the public.
- Hire three soil health-focused researchers for tree fruit, grapes, and Columbia Basin irrigated systems.
- Increase enrollment in incentive programs that pay landowners to utilize management practices that sequester carbon.
- Increase soil carbon levels.
- Reduce soil erosion rates.
- Position Washington as the preeminent state deploying soil health efforts and providing guidance to other states to follow suit.

Medium-Term (5 to 10 years)

- Identify production system specific practices production system specific practices that build soil health on farms with degraded soils.
- Allow farmers and consultants to efficiently track soil health conditions through production system specific metrics.

Long-Term (10 to 20 years)

- Rebuild soil organic matter levels to pre-tillage levels.
- Reduce soil erosion rates to represent pre-cultivation rates.
- Increase adoption of practices that suppress or provide resistance to soilborne diseases particularly in perennial production systems.
- Farmers can deploy targeted soil health practices to overcome problems based on production

systems specific metrics.

- Improve nutrient cycling.

Information Gaps

Description: Gaps in soil health understanding and knowledge.

- Several respondents across focus areas noted the lack of a universal definition for soil health. Agencies such as the NRCS has provided a definition that is used widely. Either there is a lack of the awareness of this definition, or respondents that made this comment don't agree with it, or soil health metrics are perceived as a definition of soil health.
- Understanding of soil biology.
- Information to *translate* the current state of soil health knowledge to practical agronomic decisions.
- Understanding of soil health in overall ecosystem function.
- Relationship between soil health and food quality.
- Return on investment (ROI) of soil health practices.

Barriers to Adoption of Soil Health Practices

Description: Barriers prevent the adoption of actions (e.g., management practices, policies) to protect or improve soil health.

- Soils are inherently complex.
- Lack of clarity and consistency of soil health sampling and metrics. Soil health metrics and expected measurement values vary across geography, production systems, and users.
- There is often a weak connection between soil health indicators and economic and environmental outcomes.
- Soil health-promoting practices can lead to unintended consequences (e.g., increased weed pressure and herbicide resistance).
- Producers do not have a good understanding of return on investment of deploying soil health practices.
- Lack of local technical support to deliver production system-specific recommendations.
- Producers are paid to produce crops not to undertake soil health practices, especially in commodity markets.
- Complex, time-consuming incentive programs.
- Complexity of crop rotations.
- Difficulty of investing in soil health practices for leased land.
- Costs associated with soil health practices.
- Logistics of using practices that improve soil health.
- Difficulty of incorporating soil health practices in perennial production systems.

Overcoming the Barriers

Description: Actions (e.g., incentive programs, policy) that would help to overcome the previously listed barriers to adoption.

- Financial incentives for soil health practices that appropriately cover costs.
- Stable, long-term research that connects economic and environmental benefits.
- Increased agency and University capacity and expertise in soil health.
- Implementation of soil health practices needs to be coupled with monitoring.
- Education efforts should simultaneously target K-12, College/University, and landowners and emphasize technical communication.

Soil Health Policies

Description: Are there specific state policies that could increase adoption of management practices that improve soil health?

- Incentive programs that reduce the risk for farmer experimentation, provide direct payments for practices that are known to improve soil health, and are not complex or burdensome to farmers.
- Resources available for farmers to try soil health practices.
- Taxes on fertilizers, carbon, and soil erosion.

Resources, Tools, and Opportunities

Description: Resources/tools/opportunities that could help advance soil health goals.

- Evaluation of soil health indicators across production systems.
- Coordination with other states and regions.
- Grant dollars from Federal, State, and commodity commissions.
- Technical support with expertise in soil health.

Investment Areas

Description: Strategic investments (e.g., personnel capacity) that could improve soil health knowledge and/or adoption.

- Quantify the value of services provided by soil health improving practices (e.g., crop rotations, cover crops, amendments).
- University research and extension capacity in soil health.
- Funding for long-term experiments that evaluate soil health practices.
- Reliable, simple, universal soil health assessment tools.
- An effective tool to assess soil carbon at scale.
- Inclusion of socioeconomic aspects in soil health research.

Photo: Kruger

EXPECTED IMPACTS AND OUTCOMES

Assuming widespread adoption of agricultural practices that protect or improve soil health, several impacts and outcomes are expected. In the coarse textured soils typically found East of the Cascades, an increase in the use of practices contributing carbon to the soil (e.g., cover crop use, application of organic amendments, maximizing plant residues, reduce tillage/no-till) will lead to increases in soil organic matter content. Resulting from this change, increases in soil water and nutrient holding capacity. This is especially important in the dryland farming regions, but also for the irrigated systems as timing of peak flow of the Columbia River shifts (e.g., Hall et al. 2016). Adoption of soil-building practices and subsequent increases in soil organic matter also will benefit agricultural production in western Washington. As stated in the Northwestern Washington Annual Cropping Systems focus area, growers realize the important role that soil organic matter plays in reducing issues with compaction and water management.

As outlined across several of the focus areas, use of soil health improving practices can result in several other ecosystem benefits. Reducing erosion and runoff will benefit water and air quality across the state. As documented in the Irrigated Columbia Basin focus area, issues around wind erosion have negatively impacted farmer's bottom line in addition to the air quality impacts to the non-farming population. In western Washington, water quality issues have detrimental effects on the fishing and shellfish industries, recreation, and to the overall functions of ecosystems.

Making changes to improve soil health in Washington's agricultural systems will also improve the resiliency of the food system across the state. Food system resiliency has been described and defined by many (e.g., Schipankski et al. 2016, Tendall et al. 2015) and contains many facets including production. As the past year has revealed, we are experiencing a changing climate. Greater temperature and moisture fluctuations and increases in the frequency of extreme weather events can be expected in the future. These expected changes highlight the importance of building the resilience of Washington's food production systems.

The potential for soils to store carbon varies, but taken as a whole, soils can act as major sink for atmospheric carbon (Lal et al. 2007). Widespread deployment of soil health practices can lead to increases in soil carbon, mitigating climate change impacts, and offering a potential source of revenue for landowners as carbon markets mature. With statewide programs such as the

Sustainable Farms and Fields Program recently funded, landowners have increased options to undertake soil health improving practices.

Washington State's agriculture is extremely diverse producing over 300 different commodities (USDA NASS 2019). 63% of the total value of agriculture products come from exports that rely on access to water and healthy soils. Threats to this sector can be witnessed during windy spring conditions as fields are prepared and wind erosion events take place or during heavy precipitation events as eroded soils enter adjacent waterways.

Healthy soils can positively influence agricultural production while protecting vital natural resources. More specifically, factors that reduce yield can be mitigated through practices that improve soil health leading to increased economic benefits to farmers. As this occurs, farmland can sequester carbon, and protect air and water quality. The State of Washington is at the beginning of the Washington Soil Health Initiative that will utilize an integrated approach to improve the health of soils in the state. With widespread education and adoption of practices that maintain or improve soil health, this effort will be a win-win-win situation for farmers, environmental advocates, and the residents of Washington State.

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APPENDIX 1: RESULTS FROM 2020 IRRIGATED AGRICULTURE SOIL HEALTH SURVEY

Information Collection

A survey was sent to the Irrigated Agriculture listserv managed by Washington State University Extension on February 13, 2020 and was closed on March 7, 2020. 147 crop growers/producers, 54 crop consultants and 16 livestock producers participated, for a total of 217 respondents across production systems.

Crop Grower/producer	147
Crop consultant	54
Livestock producer	16
TOTAL	**217**

Since soil health issues and approaches can vary substantially based on production system, survey responses were divided by primary crop identified by survey participants. Results by crop type are detailed elsewhere in this report.

	Total	% of total	Crop Grower/ producer	Crop consultant
Tree fruit	60	31%	48	12
Blueberries or other small fruit	3	2%	3	0
Grapes, wine or juice	23	12%	21	2
Hops	4	2%	1	3
Potatoes	32	16%	16	16
Sweet corn, green peas or other vegetables	12	6%	9	3
Hay or other forage crops	18	9%	13	5
Corn, grain or silage	6	3%	4	2
Wheat	9	5%	5	4
Dry beans	2	1%	2	0
Other (multiple crops, onions, bareroot perennials, horticultural crops, onions, carrots, Douglas fir trees, hemp, Kentucky bluegrass)	26	13%	2	4
TOTAL	**195**		**124**	**51**

Importance of issues related to soil health – All respondents

	High	Mod	Low	High	Mod	Low
	Totals			Percentages		
Nutrient cycling	133	55	3	70%	29%	2%
SOM level	128	60	6	66%	31%	3%
Soil tilth	117	63	13	62%	34%	5%
Water infiltration	117	64	9	61%	33%	7%
Water-holding capacity	112	68	10	59%	36%	5%
Soilborne disease	107	63	19	57%	33%	10%
Compaction	95	80	15	50%	42%	8%
Parasitic nematodes	84	71	33	45%	38%	18%
Drainage, ponding, runoff	79	76	35	42%	40%	18%
Wind erosion	69	66	53	37%	35%	28%
Crusting	48	87	52	26%	47%	28%

Interest in soil health improving practices – All respondents

	High	Mod	Low	High	Mod	Low
	Totals			**Percentages**		
Cover crops	107	66	14	57%	35%	7%
Compost application	104	57	26	56%	30%	14%
Green manures	89	64	32	48%	35%	17%
Reduced tillage	68	65	44	38%	37%	25%
Manure application	64	58	61	35%	32%	33%
No-till	63	52	66	35%	29%	36%
Double cropping	47	52	79	26%	29%	44%
Livestock integration	44	49	80	25%	28%	46%
Intercropping	39	49	83	23%	29%	49%
Strip-till	32	61	80	18%	35%	46%
Relay cropping	23	46	99	14%	27%	59%

Importance of challenges to improving soil health – All respondents

	High	Mod	Low	High	Mod	Low
	Totals			**Percentages**		
High cost of soil improvement practices	113	57	16	61%	31%	9%
Logistics of using soil improvement practices	83	75	25	45%	41%	14%
Lack of information	56	88	38	31%	48%	21%
Rotation restrictions	51	57	68	29%	32%	39%
Sandy soils	51	57	68	29%	32%	39%
Required tillage	48	69	60	27%	39%	34%
Short term land leases	47	53	80	26%	29%	44%
Managing high levels of crop residue	44	72	61	25%	41%	34%
Low residue crops	41	72	62	23%	41%	35%

Importance of research or additional information – All respondents

	High	Mod	Low	High	Mod	Low
	Totals			**Percentages**		
Strategies for improving soil health	157	24	7	84%	13%	4%
Benefits of soil health	133	41	11	72%	22%	6%
Monitoring soil health	124	56	9	66%	30%	5%
Economics of soil health	119	58	9	64%	31%	5%

APPENDIX 2. TREE FRUIT INDUSTRY RESPONSES TO 2020 SOIL HEALTH INITIATIVE SURVEY

37 respondents representing more than 8,170 acres of apples, pears and cherries.

How would you define soil health?

- Diverse microbial life, abundant organic matter, good water-holding capacity/soil structure, ability to sequester carbon
- Good
- The state at which available nutrients are readily available to the plant
- Group of soil characteristics that enable the sustained growth of trees, organisms and life
- Microbial diversity and abundance.
- Healthy soil feeds itself through a diverse microbiome. The healthiest soils require minimal inputs, other than replenishment of organic material.
- The ability of the soil to continuously maintain a healthy population of diverse beneficial soil microbes and flora to suppress pathogens and mineralize/produce nutrients for the crop.
- Good - but that is an uneducated assessment
- Somewhat okay
- Soils ability to retain and deliver nutrients for healthy crop production.
- sufficient nutrients in the right chemical state, maintained by the biological community in the soil to feed the plant at its optimal desire.
- Balance of nutrients and microbes to allow us to grow good fruit/ plants
- Not affecting fruit quality
- The virility and vitality of soil environment.
- Good soils would have a active microbial population. For what I grow in it a mid 6 pH is desired. Minerals available.
- Productive healthy living soils
- Poor
- The ability of the soul to provide an environment conducive for the healthy development of plants with an abundant and thriving rhizosphere.
- How well the tree is able to extract nutrients out of the soil, how well it holds water and moisture, biologicals available in the soil.
- humus, PH, texture (sand gravel Loam) microbes, the balance of these with necessary elements.
- Microbial activity is an indicator of soil health.
- How erodible soil is. Microbial activity. Water holding ability. Ability to provide water and nutrients.
- How soil benefits the growth of the trees. Biodiversity.
- Soil that can support plants. Soil holds the tree in place and holds nutrients and water.
- Good organic and microbial population.
- Organic matter.

What are the most important challenges from low soil health to our industry's orchards?

- Replant disease
- Diseases and therefore huge expenses due to outside inputs, low nutrient dense fruit
- PH
- The ability to quickly, inexpensively and accurately diagnose the issue with the soil health and what specifically to do to achieve a desired outcome.
- Productivity
- Restoring carbon and life to the soil.
- System approach and demands of industrial agriculture ROI push farmers to high input, super high-density systems. These systems are designed to extract resources from the soil, not replenish them.
- Reduced yield potential, seriously reduced fruit quality, increased soil pathogens and diseases, reduced tree health, reduced nutrient efficiency & utilization, all "requiring" more conventional fertilizers and 'crop protection' which increases the problems rather than correcting them.
- Pests and nutrient depletion
- it may be organic material in the soil
- Poor industry understanding of basic soil chemistry that has been foisted on industry for generations
- They are not defined and are hard to see..... do they exist
- Rethinking there is more to soil health than just enough nitrogen
- Supplement testing by university.
- Compaction. Infusion of organic matter (lack of).
- What to correct.
- Chemicals for everything
- Developing consistent and uniform crops.
- There are farmers that need to learn to take soil samples and analyze what is happening to their soil, instead of just pumping tons of nitrogen because it is common practice.
- nutrient availability with proper water level and PH.
- Light soils. Can't incorporate cover crops into the system because of the traffic from sprayers etc. Too much compost can lead to high K. There is not enough biomass available to add for carbon. We can't just add compost because of the P&K.
- Bitter pit. Low yields. Replant disease. Variability in blocks.
- With weak varieties we can't afford to let them stop growing, they need to make it to the top wire.
- Nutrient retention and biodiversity.
- Nutrient build-up possibilities.
- Production on hillsides.
- Old lead [arsenic] soil.

What are the most important functions/benefits soil health can provide for our industry's orchards?

- Cycling nutrients
- Healthy trees that need little ag inputs to resist disease and pest pressures, producing fruit that tastes great and has nutritional value.
- Good tree health by keeping nutrients available to the trees.
- To increase profitability back to the land and create sustainability for generations to come.
- Nutrients, water, mineralization, support, filtering
- Fertility and moisture absorption/retention. Natural fertility.
- The question is backwards - the question is what can our industry's orchards do for the soil. Different systems (rootstock selection, design/layout) are likely required to optimize for soil health. We've worked very hard for the past century towards driving costs down and packout up for financial performance. Permanent crop farming has the potential to build soil much more quickly with far less inputs, if addressed properly.
- Increased tree health, especially the root systems. Increased efficiency of nutrient uptake and utilization, significantly reduced disease and pathogen pressures. All allowing reduction of commercial fertilizer rates and pesticide usage. Significantly increased fruit quality, uniformity, and more consistent reliable yields. Increased storage life and retail shelf life of fruit. Increased nutritional content of the fruit as well.
- This is all conditional on proper pursuit and methods of increasing soil health.
- Stronger, healthier soil will strengthen trees and produce and simultaneously replenish nutrients
- Less stress on the trees and a better crop
- Soils are foundation for producing nutrient rich nutritious food. Current emphasis is on volume and cosmetics...
- nutrients out of balance can cause fruit quality problems
- Provide long term benefits to soil and grower so that with good soil balance there is less need for fertilizer, water and pesticides
- HIGHER PROFITS. NO A PROFIT !!
- Reduction in use of fertilizers and other synthetic amendments. A more naturally produced product.
- Productivity and quality
- Learning demonstrations and education
- Healthy plants and trees should be more productive
- Less water consumption and usage. Having healthy soil eliminates the need to constantly irrigate and replenish moisture and nutrients. When you over irrigation you move nutrients out of the roots profile zone. It would lead to better quality fruit too.
- Better tree health will produce better quality fruit and higher production.
- Yield. Fruit quality. Optimum fruit size. High pack out (quality).
- Promote good plant growth.
- Reduce fertilizer, pesticide and irrigation use.
- Improved production.
- Save on inputs.

What are the most important functions soil health provides to the environment?

- Health trees more clean breathable air and quality fruit available to people on earth.
- Sustainably
- Water holding and movement
- Carbon sequestration and retention. Reduced soil erosion. Larger healthier crops. Natural disease resistance.
- Orcharding in particular has the potential to perform quite well in terms of carbon sequestration. Also, more opportunities for cross-functional use: interstitial cropping, orchard grazing, etc. These provide additional opportunities to improve soil health and reduce inputs. Storing more carbon, while reducing input costs (also carbon-intensive) is an attractive proposition to weigh.
- Increased water efficiency & uptake, reduced runoff, reduced commercial fertilizers and pesticides. More truly sustainable, regenerative crop eco systems.
- Naturally cleaning water and air while providing a more effective nutrient for trees
- Longevity, many years of providing food with lots of nutrients.
- Balance. Hard to do when it's being used as dumping ground by urban areas in Western Washington…I.e. municipal sludge.
- I think it is not defined.
- Basically same as above.
- So it does its part.
- Healthy fruit that isn't on drugs
- Proper reading of nutrients so that we are not over applying fertilizer or nutrients and leaching them into drinking or river water.
- Erosion control. Reduction in leaching.
- Plants that harbor beneficials.
- Low toxicity.
- Clean air. Clean water.

What are some information gaps related to soil health in our industry?

- What makes quality soil? How does one attain healthy soil?
- If information is available it is not communicated in an effective manner. If the information is not available then it needs to be researched.
- Correlation with productive parameters
- Unsure
- Microbiology - the microbiome is not well understood. We have done a great job of evaluating tree nutrient needs by leaf assays. We can quickly, cheaply and easily sample the soil to determine which elements are missing. But the microbiome is an incredibly powerful ally that we've largely killed with chemical application (including fertilizer). Specifically the mycrorrhizal interactions.
- Industry suppliers, consultants, agronomists, and academics are highly resistant to any information from "alternative" (non-university) sources. Insistent on years of replicated trials before considering anything outside of the conventional status quo. Many of the soil health/crop health answers they "seek" have been well established and even researched by previous generations of academics for many years. One of the biggest problems is lack of research $ for "natural" product trials because the chemical companies provide most of the research funding. Why would they want affordable natural competition to their expensive patented products?
- For me it is how to replenish the nutrients in my small orchard's soil

- Understanding what to do in small areas.
- Once again... piss poor fundamental soil chemistry, biochemistry and plant nutrient practices. Seems to be a lot of fairy dust being marketed to growers.
- Are we doing things that we think are good which are bad.
- Beneficial Microbes and how they improve yield and disease resistance
- How to keep it balanced/correct while growing tree fruit crops. How to avoid replant issues.
- How to improve and maintain soil health. Understanding the definition of soil health and how to determine it in a quantitative way.
- Not fully understanding what is happening with nutrient uptake. Also the research to be a lot more clearer for farmers to understand.
- Water systems and application especially in gravelly sandy locations with areas of heavier soils in the same row.
- We need to know what is below ground. How does transition to organic effect health, specifically not using herbicides?
- Correlating a soil test with a fruit analysis. Correlating soil health to fruit pack outs and how well fruit stores.
- How long to organic amendments last, e.g. compost, fertilizers?
- Testing opportunities and results.
- How soil works.
- Soil testing.
- Getting information out to growers.

What are your top research priorities related to soil health?

- Keeping soil health so it strengthens the trees.
- Cheap soil analysis that can be done in the field by the farmer or foreman with simple action steps to take after analysis show deficiencies.
- Amendments that can improve organic matter from different sources; residues from wine, hop, juice etc
- Unsure
- Optimization of ectomycorrhizal networks in orchard systems. Carbon sequestration potential. Biochar - impact on tree health, nutrient buffering, fungal biome health, etc.
- Academic proof that green manure crops, bio-stimulants, & beneficial microbial inoculants do significantly improve soil & crop health, fruit quality, and reduce chemical input requirements, providing increased grower ROI. I have personally seen this in many different crops but sadly “proof” by academics is needed for alternative practices to be seen as legitimate programs.
- A better balance between natural soil health and controlling damaging pests while still producing healthy trees and safe produce; without simply taking nutrients out.

- Not sure
- Developing improved soil tilth which encompasses a process of implementing amendments which support nutrient cycling, soil microbiology and in my case irrigation water quality for the benefit of plant growth
- Show the difference between good and poor soil health
- More work done on crown rot- where is it coming from and how to prevent/ treat
- How plants and soils
- How to create a healthy
- Moisture, nutrient uptake and the plants health.
- For me water application in an area of mixed sandy and heaver loam soil in the same row, how do I apply enough in one end of the row without shorting the other end.
- How do the herbicides we use effect soil health? What are the effects of the tillage we use in organics (how much damage to microbiome)? More information on the critters that live in the duff?
- Education about soil types and how to manage them.

What core investments should be made to move the goals and priorities of your industry forward?

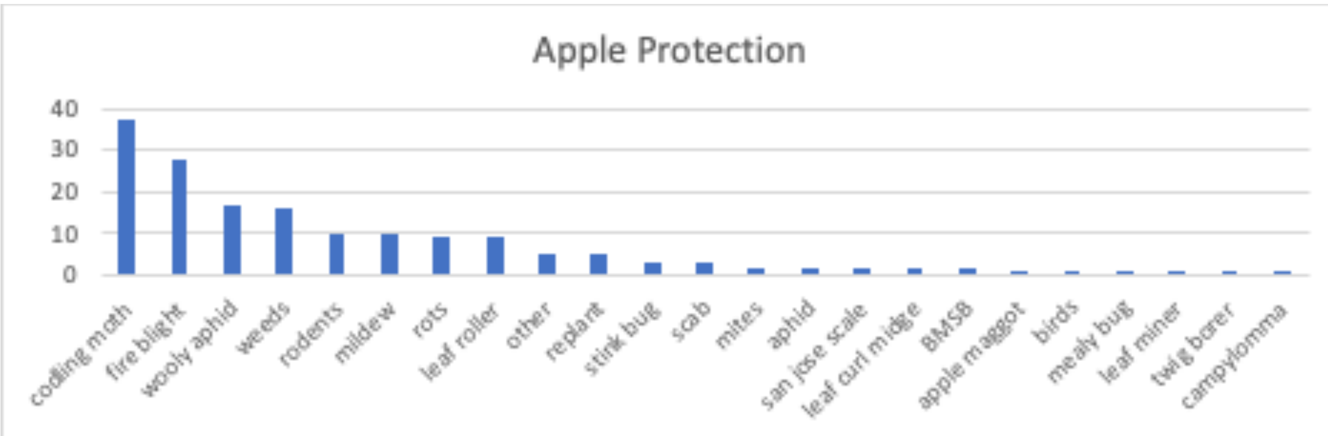
- Continuing education and lab testing to maintain healthy Orchards!
- Not sure where the research is at this point to give a good recommendation
- Funding for competitive projects for long term studies
- Unsure
- Field trials - more research.
- Significant research needs to be done on more 'natural' alternative materials and programs instead of on the latest chemical "tools".
- Buyers should be willing to pay a premium for higher quality fruit to reward growers who invest in systems that increase fruit quality, nutrient levels, shelf life, etc..
- Education to change the cycle of stripping the soil and replacing with chemical fertilizers and defolients.
- Put back in the soil what is needed
- Not enough space here...
- Researchers to do the work
- More crop diversity and sustainable practices
- Need a nation-wide apple promotion program to increase per capita apple consumption. Growers must have a realistic chance of achieving their full cost of production before they can afford to further enhance, both society and the environment.
- How to fortify nutrients to plants/fruit that soils are unable to provide as environmental changes occur.
- Hire the Endowed Chair in Rhizoshphere Ecology that is already funded.
- Show the benefits for everyone when you watch soil health. How taking care of your soil can have a big impact on your yields, costs ect.
- Have a test which will really indicate what is going on with soil health.

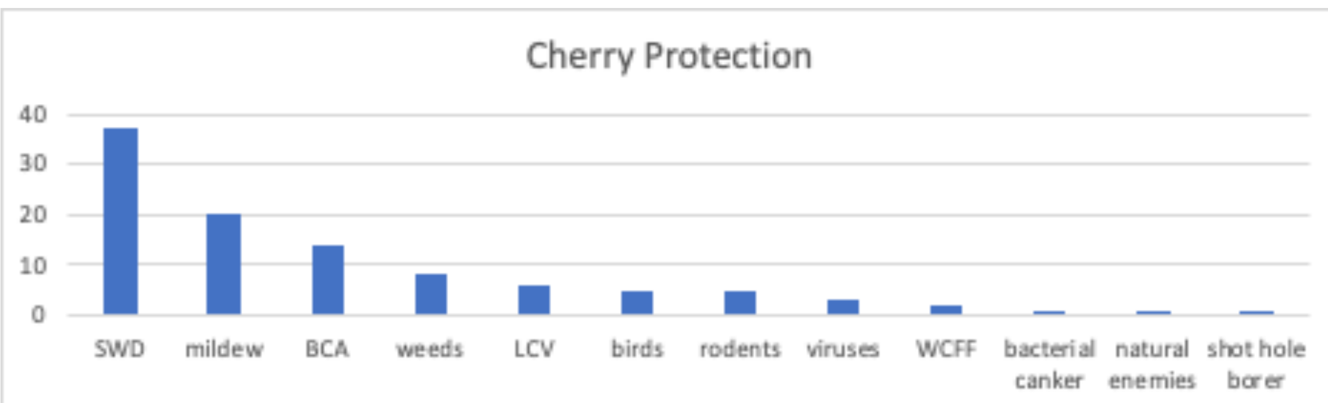
What are our three important milestones we should reach as an industry and how long would you expect each to take (5, 10 , 20 years for example)?

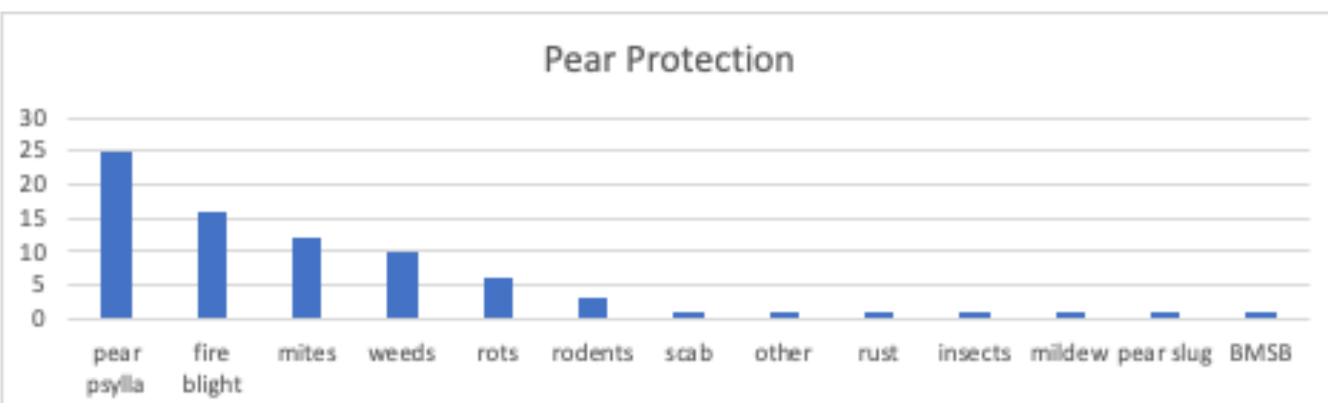
- PH-7
- Minerals in balance
- Fertilizers and leaf feeds that keep soils and trees healthy
- Not enough knowledge to give accurate milestones
- Unsure
- Reducing chemical input application by 50% or greater. Rootstock research - deeper rooted trees would help with nutrient uptake and irrigation expense (dry farming will be more important as climate changes). Working to identify climate change pressures on industry (pest, temperature/drought, chill hours, etc.) - what shifts will be required. Apple orcharding in W. WA - limited resources compared to E. WA climate. Cider apple production system approaches (may be substantially different than dessert apple)
- As one who has been teaching/coaching soil/ crop health for over 30 years, I am at a loss how to answer this. It has been agonizingly slow to see any progress in this direction until very recently and now most seminars on 'soil health' are so basic and simplistic it is sad. Reams of research on the subject has been done many decades ago and has continued around the world to this day. For some 'unknown' reasons, it does not disseminate across American agriculture except for a few consultants and small independent companies who produce exceptional 'alternative' products & programs.
- I have no idea how long it will take established eco-agriculture principles to reach any mainstream modern research or industry acceptance.
- Education (as a new orchardist I need this the most)1-4years
- Return to a Natural process of pest control and fertilization - don't know timeline
- Return more acreage to plant production and reclaim pasture land
- Not sure
- 1). Understand soil chemistry 2). Understand soil microbiology 3). Understand irrigation water quality and it's impact on soil health
- we have soils in tree fruit for over 130 years. is it depleted or sick??? we need a definition
- Don't know
- Full cost of production returns from the market place. 5 years.
- Replant disease issues……Keeping soils healthy……How to be better producers
- Hire Endowed Chair- immediately. Awareness of importance by the industry-5 years.
- Establishment of best practices and SOP's for optimal soil health-15.
- Water conservation, especially with recent past issues of drought and not enough snow fall. 5 years.
- Proper soil analysis, test your soil and understand what is happening so that you do not over apply fertilizers and spend extra money. 20 years.
- Pesticide use to avoid killing natural occurring biologicals in the soil that keep the soil healthy. 10 years.
- Soil tests which take into account the biology in the soil. Building a database of soil tests and fruit quality so we can look at correlations. Make sales not commission based (on fertility) so they are looking at long term benefits. In 20 years be able to look at limiting factors other than just nutrients AND fix them.

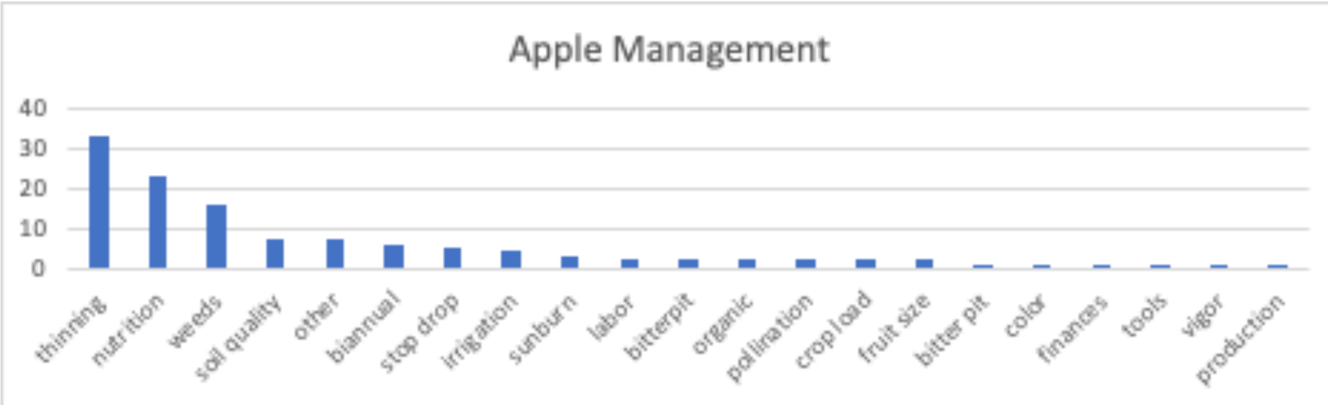
APPENDIX 3. ORGANIC TREE FRUIT PRODUCERS NEEDS ASSESSMENT 2017

A survey of organic tree fruit producers was conducted in January to March 2017 by the WSU Tree Fruit Extension team. Producers were asked to list the most challenging issues they face for each organic crop they grow in the areas of crop protection and crop management. Listed below are preliminary results of this survey which had 104 individual respondents.





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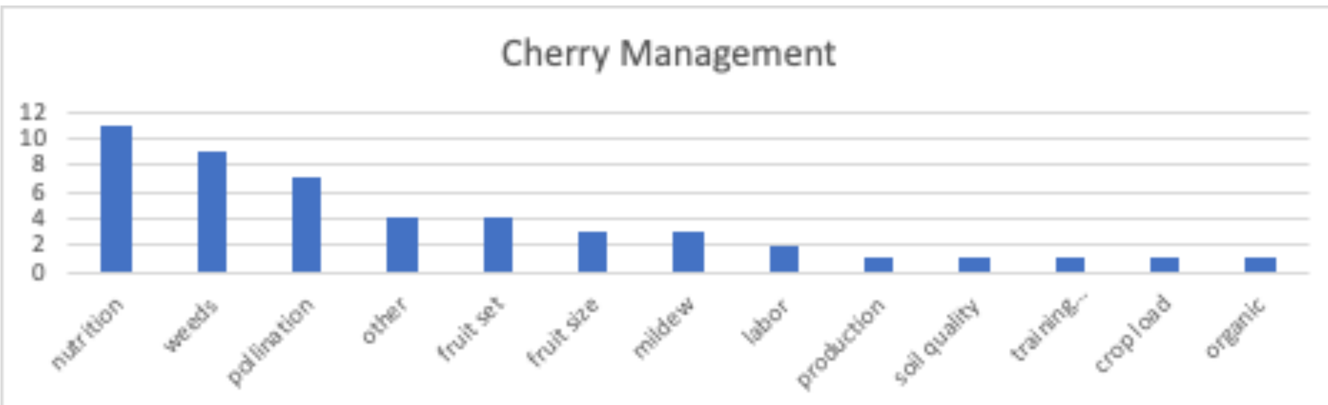
Cherry Management
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other
fruit set
fruit size
mildew
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production
soil quality
training...
crop load
organic


Pear Management
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irrigation
pollination
weeds
soil quality
thinning
labor
culture
pruning
cover crop
fruit size
education
production