

10-2016

Simple Soil Quality Tests and Organic Management Practices for Orchards in the Intermountain West

Esther Oline Thomsen
Utah State University

Follow this and additional works at: <http://digitalcommons.usu.edu/etd>

 Part of the [Soil Science Commons](#)

Recommended Citation

Thomsen, Esther Oline, "Simple Soil Quality Tests and Organic Management Practices for Orchards in the Intermountain West" (2016). *All Graduate Theses and Dissertations*. Paper 5050.

This Thesis is brought to you for free and open access by the Graduate Studies at DigitalCommons@USU. It has been accepted for inclusion in All Graduate Theses and Dissertations by an authorized administrator of DigitalCommons@USU. For more information, please contact dylan.burns@usu.edu.



SIMPLE SOIL QUALITY TESTS AND ORGANIC MANAGEMENT PRACTICES
FOR ORCHARDS IN THE INTERMOUNTAIN WEST

by

Esther Oline Thomsen

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Soil Science

Approved:

Jennifer Reeve, Ph.D.
Major Professor

Diane Alston, Ph.D.
Committee Member

Grant Cardon, Ph.D.
Committee Member

Mark McLellan, Ph.D.
Vice President for Research
and Dean of Graduate
Studies

UTAH STATE UNIVERSITY
Logan, Utah

2016

Copyright © Esther O. Thomsen 2016.

All Rights Reserved.

ABSTRACT

Simple Soil Quality Tests and Organic Management Practices
for Orchards in the Intermountain West

by

Esther Oline Thomsen, Master of Science

Utah State University, 2016

Major Professor: Dr. Jennifer R. Reeve
Department: Plants, Soils, and Climate

Soil quality problems such as erosion, depleted soil organic matter, salinity, depleted or excessive nutrient reserves and reduced water holding capacity are of increasing concern to farmers in the Intermountain West. Marginal soils require higher rates of fertilizers and other amendments to meet crop needs. As input costs rise and water resources are increasingly limited, simple and effective methods for evaluating and improving soil quality and fertility are of growing importance. Practices known to improve soil quality include reduced to no tillage, cover crop use- especially legumes, and addition of mulch and other carbon rich amendments. Comprehensive soil quality testing is often not routine, cost prohibitive, unavailable or confusing to interpret. The purpose of this study was to develop tools to help growers improve and monitor soil quality. Chapter 1 provides a general overview of the project. Chapters 2 and 3 discuss the effectiveness of simple soil tests that can be performed by growers on-site. The most

effective simple soil testing methods were found to be modified slake tests, the Solvita® respiration test kit, and soil organism biodiversity counts ($R = 0.88$, $R = 0.88$, $R = 0.68$ respectively). Simple nutrient test kits, correlated somewhat with laboratory results (the highest correlation was $R = 0.80$), however no simple test kit was accurate across all tests provided. Chapters 4 and 5 investigate organic nutrient management practices for peach orchards in the Utah, illustrating examples from: Capitol Reef National Park, Torrey, in southcentral Utah; and Utah State University Horticultural Research Farm, Kaysville, in northern Utah.

(122 pages)

PUBLIC ABSTRACT

Simple Soil Quality Tests and Organic Management Practices for Orchards in the Intermountain West

Esther O. Thomsen

Soil health is often overlooked as a long-term management strategy as growers face an increasing number of short-term management challenges in the Intermountain West. The costs of inputs are rising and water resources are becoming more limited. Soil with poor health typically requires more amendments and fertilizers to meet crop needs. Soil health tests can help reveal management practices that reduce soil health, as well as those that improve soil health. Practices known to improve soil health are reduced to no tillage, cover crop use- especially legumes, and addition of mulch and other organic materials. Soil health testing is not routine in most soil testing facilities, therefore is often cost prohibitive, unavailable or confusing to interpret. The purpose of this study was to help growers improve and monitor soil health. Chapter 1 provides an overview of soil health. Chapters 2 and 3 discuss the effectiveness of simple soil health tests that can be performed by growers on-site. The best simple soil testing methods were found to be modified slake tests, the Solvita® respiration test kit, and soil organism biodiversity counts. Simple nutrient test kits were found to be much less accurate in identifying pH or soil nutrient availability when compared to soil testing facility results. Chapters 4 and 5 investigate organic nutrient management practices for peach orchards in the Utah, illustrating examples from: Capitol Reef National Park, Torrey, in southcentral Utah; and

Utah State University Horticultural Research Farm, Kaysville, in northern Utah.

ACKNOWLEDGMENTS

This research was supported through grants from the Western Sustainable Agriculture and Research Education (WSARE) program, the Organic Agriculture Research and Extension Initiative (OREI) of the U.S. Department of Agriculture National Institute of Food and Agriculture (USDA NIFA), and the Utah Specialty crop Block Grant program (SCBGP). I would like to thank my committee members who have been an invaluable support and guidance for this project: Drs. Diane Alston and Grant Cardon; I would like to especially thank Dr. Jennifer Reeve, my major professor. This research would not have been possible without her efforts, support, patience, sense of humor, enthusiastic nature and guidance. I would like to thank Dr. Mae Culumber, a fellow graduate student, from whom I have gained a tremendous amount of knowledge and support. I would like to thank Susan Durham for her statistical support with interpreting this data. I would also like to thank Thor Lindstrom, Research Associate, whose tremendous support at the Utah State Horticultural Research Farm in Kaysville have been so valuable to this project, and whose helpful nature has also been greatly appreciated. Special thanks to Kareem Adeleke, Gaia Nafziger, Alicia Campbell, Leanna Hayes, and my husband Nithya Shanti, who have all spent countless hours with me in the lab and in the field working with soil sample tests. I'd like to also thank the commercial orchardists for their willingness to be a part of this study and openmindedness to experiment with new techniques: Jeff Mitchell, Ian Adams, Jordan Riley, Chris Riley, Wayne Hanks, Susan Oler, and Annie Baczek. I also owe a lot of gratitude to my family

and friends whose support and love through all of this have meant so much. I've learned so much from this process, more than this thesis could ever adequately portray. Thank you all so much; this research was made possible because of all of your support.

Esther O. Thomsen

CONTENTS

	Page
ABSTRACT.....	iii
PUBLIC ABSTRACT	v
ACKNOWLEDGMENTS	vii
LIST OF TABLES	x
LIST OF FIGURES	xi
CHAPTER	
I. GENERAL INTRODUCTION	1
II. SIMPLE SOIL TESTS FOR ON-SITE EVALUATION OF SOIL QUALITY IN ORCHARD SYSTEMS	10
Abstract.....	10
Introduction	11
Methods	15
Results and Discussion.....	24
Summary and Conclusion.....	34
References	35
Tables and Figures.....	40
III. SIMPLE SOIL TESTS FOR ON-SITE EVALUATION OF SOIL HEALTH IN ORCHARDS. FACTSHEET	63
IV. STRATEGIES FOR MANAGING SOIL FERTILITY AND HEALTH IN ORGANIC ORCHARDS. FACTSHEET	72
V. ZERO INPUT METHODS FOR MANAGING MATURE PEACH ORCHARDS IN CAPITOL REEF NATIONAL PARK: A CASE STUDY. FACTSHEET	89
VI. GENERAL CONCLUSIONS.....	100
VII. APPENDICES	102

LIST OF TABLES

Table		Page
1	Pearson Correlations between in field biological tests and laboratory biological tests in 2014 and 2015	40
2	Pearson Correlations between in field physical tests and laboratory biological and physical tests 2014 and 2015	41
3	Pearson Correlations between in field chemical tests and laboratory chemical tests on both conventional and organic soils in 2014 and 2015	42
4	Growers' perceptions of what healthy soil means	43
5	Growers indicate why they test their soil.....	44
6	Growers indicate why they don't test their soil	45
7	Growers perceptions on what could be improved with modern testing methods..	46

LIST OF FIGURES

Figure		Page
1	Solvita® Respiration correlated with microbial biomass 2014.....	47
2	Solvita® Respiration correlated with microbial biomass 2015	48
3	Earthworm Abundance test correlated with dehydrogenase enzyme assay as measured by reduction of triphenylformazan per hour per gram of soil in 2014.....	49
4	Biodiversity test correlated with laboratory measured soil basal respiration 2015.....	50
5	Soil surface test correlated with microbial biomass 2014	51
6	Soil surface test correlated with microbial biomass 2015	52
7	Hose test correlated with microbial biomass 2014	53
8	Rapidtest N test correlated with laboratory N.....	54
9	Lamotte N test correlated with laboratory N	55
10	Lamotte K test correlated with laboratory K in the organic orchard	56
11	Mosser N test correlated with laboratory N.....	57
12	Growers' perceptions of their soil testing knowledge	58
13	Soil tests growers use to test their soil	59
14	Growers indicate the usefulness, affordability and ease of current soil testing strategies.....	60
15	Percent of respondents interested to learn from researchers on soil quality tests.....	61
16	Growers indicate which simple soil tests they would most likely use	62

CHAPTER I

GENERAL INTRODUCTION

Soil quality is typically defined as the ability of soil to function while maintaining or improving water and air quality and supporting biota, and is assessed using a suite of physical, chemical and biological tests. Measuring soil quality can be difficult to standardize as parameters vary over location and circumstance. However, maintaining soil quality is essential for the long-term prosperity of a farm or other land-based-system (Wienhold et al. 2004). Six percent of agricultural land requires major capital investment to be restored to its original productive state (Doran et al. 1996). Moderate to severe erosion occurs on about 80 % of the world's agricultural land (Pimental 2006). In the US, cropland loses an average of 6 tons of soil per acre, per year (Pimental 1995). Maintaining soil quality can prevent loss in system productivity while also improving financial outcome for farmers in the short term. Farmers in Iowa were able to increase yield by 3-12 % by maintaining soil quality. Additionally, they were able to reduce costs from inputs by 41-79 % (Liebman et al. 2003).

Despite attempts, little progress has been made in increasing farmer involvement in maintaining soil quality (Herrick 2000). Even when farmers are interested in learning more about soil quality, soil quality tests are not always available, affordable, reliable or feasible (Friedman et al. 2001). While farmers are often observant of overall soil function, these observations fall short in assessing long-term viability of management practices (Andrews et al. 2003). In a study by Andrews et al. (2003), the farmer's

understanding of soil quality lab results were limited without thorough interpretation. Yet, even with thorough explanation, farmers expressed concern over the local relevance of the baseline data used to assess their soil quality, as well as an interest in long-term soil quality trends of their farming practices (rather than mere values), and the connection between economic viability and soil quality. The lab analyses were inadequate to fully address these concerns.

The goal of this study was to support growers in their orchard soil quality needs by providing accessible information, such as how soil quality can be improved and the easiest, most affordable methods for testing soil quality. This thesis will discuss simple on-site tests for measuring soil quality, and explore simple strategies that growers can use to improve soil fertility and quality.

On-site tests gained popularity in the 1980's, especially for corn-belt farmers determining pre-plant side-dress nitrate levels (Allan et al. 1997). National Resource Conservation Service (NRCS) soil test kits include biological, physical and chemical tests, allowing farmers and landowners to conduct a reasonably accurate evaluation of soil quality properties on-site (Evanylo 2005). Evanylo (2005), did find inaccuracies with the pH meter readings from the test kit. Questions concerning the accuracy of on-site chemical tests in general remain. Other simple on-site test issues for farmers include time expectations (Friedman et al. 2001), technical application and interpretation (Dilley 2006).

The soil test kit also measures two biological components in the soil, earthworms and soil respiration. Soil organisms are important indicators of soil health as they are rapidly responsive to shifts in management practices (Pankhurst et al. 1997). However,

earthworm abundance and soil respiration tests may not be useful in every situation. As earthworms are not native to all soils and respiration is highly affected by weather, these parameters can be unreliable predictors of biological activity of a specific soil (NRCS 2001).

Litter bag tests are commonly used in ecological studies to measure decomposition rates of organic matter, but are less commonly used for agricultural applications. However, they may provide farmers with an easier, cheaper and more reliable option for determining soil microorganism activity than completing a soil respiration test. Litter bag tests can quantify decomposition rates over a longer period of time rather than being limited to current field conditions. (Keuskamp 2013).

The NRCS test kit also includes a slake test. Slake tests measure aggregate stability. Aggregates are combinations of primary soil particles (sand, silt, clay) that bind together in a soil system. Aggregate stability is the ability of soil particles to remain attached under disruptive forces. These tests are useful in addressing a soil's potential for erosion, in particular, comparing soils from different management systems (Kemper and Rosenau 1986).

Multiple variations of slaking tests have been developed. The earliest work on aggregate stability was conducted using a series of various sized tubes to separate different aggregate sizes (Kemper and Koch 1966). The soil producing the largest sized aggregates, are recorded as having the greatest aggregate strength. As larger aggregates require more "stability" in order to remain together. Yoder (1936) identified inaccuracies with this method and modified a wet sieve procedure created by Tiulin (1928). This method utilized a nest of six sieves suspended in a container filled with water to

mechanically separate soil aggregates. Fifty grams of air-dried soil was placed on the upper sieve, and the sieves were lowered into the water to cover the soil. A mechanical action would raise and lower the sieves into the water for 30 minutes. A mean weight diameter was chosen to categorize differences of different soils. The greater the mean weight diameter the greater the indication of aggregate strength (Kemper and Koch 1966).

In 1997, a slaking test was developed by Field et al. (1997), which involved immersing soil aggregates into a petri dish and rating the level of cloudiness which surrounded the aggregate on a scale of 0-4. Then 0.01 M calcium chloride was added and the measurement taken again after two hours. Plasticity tests were conducted on any aggregates that scored zero. Soils were remoulded into 3-5mm soil formations at a water content just above their plastic limit. Soil formations were placed into a petri dish with deionized water to record the amount of dispersion after two and twenty hours. All scores were added up, for a total maximum points of 16, with 0 meaning no dispersion and 16 meaning severe dispersion.

The slaking test kit used by the NRCS is a slight modification of a version developed by Herrick et al. (2001). Herrick et al. (2001), developed a stability test kit that could be made inexpensively with simple tools. It was made to test up to 18 samples in 10 minutes. The kit is essentially made of two boxes (21 x 10 x 3.5 cm) with eighteen equal sections that each contain a 2.5 cm sieve (mesh size equals 1.5 mm). The rating system is based on a scale of 1-6, with one indicating weakest soil aggregate structure and 6 indicating strongest soil aggregate structure. This test has been found to be highly sensitive to a variety of plant and soil conditions (Herrick et al. 2001). The NRCS

modified test uses one tray with 18 compartments each with a sieve. It uses the same aggregate rating scale of 1-6. The compartments in the tray are filled with water, a dry soil aggregate is placed into the sieves which are placed into the compartments filled with water. The aggregates soak in the water for 5 minutes, followed by a slow and steady immersion of the sieves repeated four times. The ratings are recorded as the masses disintegrate.

A persistent criticism of slaking tests is that disintegrating forces used in laboratory settings are arbitrary. No laboratory tests can exactly replicate forces experienced in the field. Additionally, in any lab test, soils are handled (e.g., dried) prior to testing, and are subject to react differently than under field conditions. Despite these shortcomings, aggregate stability tests are especially useful for comparing the potential erodibility of soils under different systems of management (Kemper and Koch 1966).

On-site slake tests often make use of a visual assessment of the soil. There are several other methodologies for visually assessing the soil, that are typically combined with soil health cards such as the visual soil assessment (VSA) (Shepherd 2009) and visual soil structure and evaluation method (VESS) (Ball et al. 2007). These assessments are helpful tools for farmers that indicate soil quality, however are usually used as complimentary tools in addition to quantitative methods. Visual assessments of soil can be time consuming to teach and subjective (Munkholm et al. 2012; and Ball et al. 2007).

A major benefit of conducting soil quality tests over a period of time or in comparison to a reference soil – a soil of the same soil type but in a more undisturbed state - is that they may provide an indication of soil quality status; whether soil quality is: 1) improving, 2) deteriorating, or 3) maintaining initial levels, possibly due to the land

management practices. Soil quality results can then be used in the management decision-making process.

The goal of this research is to provide information on soil nutrient management and options for convenient, affordable and accurate soil quality testing methods appropriate to orchardists in the Intermountain West. Chapter 2 describes on-site simple soil quality tests and how they compare to laboratory tests, in addition to farmer's feedback on their impressions of soil quality and the tests. This chapter will be submitted to the Communications in Soil Science and Plant Analysis and has been formatted accordingly. Chapter 3 highlights the simple soil tests that were found to be the most effective, and is presented in the form of a factsheet. Chapter 4, also written as a factsheet, covers strategies for organic fertility management suitable for use in orchards in the Intermountain West. Strategies that can help growers improve soil health are highlighted, and demonstrated using examples from conventional, integrated and organic peach orchards at the Utah State Horticultural Research Farm in Kaysville, UT. One demonstration orchard was organically certified and included six understory treatments, primarily three of which were used for the soil quality tests: 1) tillage in the tree row with a grass alleyway (industry standard), 2) straw mulch in the tree row with a legume (bird's-foot trefoil) alleyway, 3) straw mulch in the tree row with a grass alleyway. All treatments had paunch manure compost applied at a rate of 136 g N per tree in 2014 and 2015. In the tillage plot the compost was applied under the drip line, in the straw mulched plots the compost was applied to a tillage strip. There were two conventional demonstration orchards. One orchard was integrated and conventional with four understory treatments, with one understory treatment primarily used for the soil quality

tests: 1) Conventional fertilizers (N-P-K) plus herbicide in the tree row with a grass alleyway. The conventional fertilizers included 16-16-16 which was applied at a rate of 28.8 g N per tree and 46-0-0 which was applied at a rate of 130 g N per tree in 2014. All treatments were replicated four times.

The 5th chapter covers an organic strategy to help manage soil fertility in a zero input situation. Capitol Reef National Park is used as a case study, an historic heritage site where no fertilizer was used. Chapter 5 is written as a fact sheet, and outlines a simple strategy to enhance tree growth and yield through managing soil health and fertility. The terms, 'soil quality' and 'soil health' are used interchangeably throughout the document. The term 'soil health' has been used in the public abstract and in Chapter 3, as it is a more recognized term among growers. The term 'soil quality' is used largely throughout the rest of the thesis, as it is the most commonly used term in technical documents when referring to the long-term assessments of the three major properties of soil: biological, physical and chemical. While in technical documents, the term 'soil health' is used largely to describe soil biology.

In summary, the aim of this thesis is to support growers in the assessment of their sustainable management practices for the benefit and maintenance of soil fertility and health.

References

Andrews, S.S., C.B. Flora, J.P. Mitchell, and D.L. Karlen. 2003. Growers' perceptions and acceptance of soil quality indices. *Geoderma* 114 (3-4): 87–213.
doi:10.1016/S0016-7061(03)00041-7

- Ball, B.C., T. Batey, L.J. Munkholm. 2007. Field assessment of soil structural quality – a development of the Peerlkamp test. *Soil Use Manage* 23:329–337.
- Bryant, J.C., T.W. Bedixen, and C.S. Slater. 1948. Measurement of the water stability of soils. *Soil Science* 65: 341-345.
- Dilley, C. 2006. Transferring information from research lab to farm field: evaluation of on-farm soil quality test kits for grower use in sustainable strawberry production. Grants and education to advance innovations in sustainable agriculture. Sustainable Agriculture Research and Education.
- Doran, D.W., and T.B. Parkin. 1996. Quantitative indicators of soil quality: a minimum data set. *In Methods for Assessing Soil Quality*, eds. J.W. Doran and A.J. Jones, 25-38. Madison, Wisconsin: SSSA.
- Evanylo, G. 2009. Agricultural management practices and soil quality: measuring, assessing, and comparing laboratory and field test kit indicators of soil quality attributes. Virginia Cooperative Extensive. Retrieved from: <http://pubs.ext.vt.edu/452/452-400/452-400.html>
- Field, D.J., D.C. McKenzie, and A.J. Koppi. 1997. Development of an improved vertisol stability test for SOILpak. *Australian Journal of Soil Research* 35: 843-852
- Friedman, D., M. Hubbs, A. Tugel, C. Seybold, and M. Sucik. 2001. Guidelines for soil quality assessment in conservation planning. NRCS. USDA, Jan. 2001. Web. Jan. 2014.
- Herrick, J.E., 2000. Soil quality: an indicator of sustainable land management? *Applied Soil Ecology* 15 (1): 75–83.
- Herrick, J.E., W.G. Whitford, A.G. de Soyza, J.W. Van Zee, K.M. Havstad, C.A. Seybold, and M. Walton. 2001. Field soil aggregate stability kit for soil quality and rangeland health evaluations. *Jornada Experimental Range* 44: 27-44.
- Kemper, W.D., and E.J. Koch. 1966. Aggregate stability of soils from the western portions of the United States and Canada. Washington. D.C.: USDA Technical Bulletin 1355. U.S. Government Printing Office.
- Kemper, W.D., and R.C. Rosenau. 1986. Aggregate stability and size distribution. *In Methods of soil analysis*, eds. A. Klute. Part 1 2nd ed. 425-442. Madison, Wisconsin: ASA and SSSA.
- Keuskamp, J.A., B.J. Dingemans, T. Lehtinen, J. Sarneel, M., and M.M. Hefting. 2013. Tea bag index: a novel approach to collect uniform decomposition data across

- ecosystems. *Methods in Ecology and Evolution* 4 (11): 1070–75.
doi:10.1111/2041-210X.12097.
- Liebman, M., M.J. Helmers, L.A. Schulte, and C.A. Chase. 2013. Using biodiversity to link agricultural productivity with environmental quality: results from three field experiments in iowa. *Renewable Agriculture and Food Systems* 28 (02): 115–28.
doi:10.1017/S1742170512000300.
- McGrath, D., S. Campbell, S. Seiter, and C. Seybold. 2002. Participatory evaluation of farmer based soil quality assessment cards. Grants and Education to Advance Innovations in Sustainable Agriculture. Sustainable Agriculture Research and Education.
- Munkholm, L.J., R.J. Heck, B. Deen. 2012. Long-term rotation and tillage effects on soil structure and crop yield. *Soil & Tillage Research* 127 (2013) 85–91.
- Pimentel, D., C. Harvey, P. Resosudarmo, K. Sinclair, D. Kurz, M. McNair, S. Crist, L. Shpritz, L. Fitton, R. Saffouri, and R. Blair. 1995. Environmental and economic costs of soil erosion and conservation benefits. *Science*. 267 (24): 1117–1122.
- Pankhurst, C.E., B.M. Doube, and V.V.S.R. Gupta. 1997. Biological indicators of soil health: synthesis. In *Biological Indicators of Soil Health*, eds. C.E. Pankhurst, B.M. Doube, and V.V.S.R. Gupta, 419-435. New York, New York: CAB International.
- Shepherd, T.G. 2009. Visual Soil Assessment, Field Guide for Pastoral Grazing and Cropping on Flat and Rolling Country, second ed., vol. 1. Horizons Regional Council, Palmerston North, New Zealand, 119.
- Tiulin, A.F. 1928. Question on soil structure II: aggregate analysis as a method of determining soil structure. *Permanent Agricultural Experiment Station Division Agricultural Chemistry Report 2*: 77-122
- Van Bavel, C.H.M. 1950. Mean weight diameter of soil aggregates as a statistical index of aggregation. *Soil Science Society America Proceedings* 14: 20-23.
- Wienhold, B.J., S.S. Andrews, and D.L. Karlen. 2004. Soil quality: a review of the science and experiences in the USA. *Environmental Geochemistry and Health* 26 (2): 89–95. doi:10.1023/B:EGAH.0000039571.59640.3c.
- Yoder, R.E. 1936. A direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. *American Society Agronomy Journal* 28: 337-351

CHAPTER II

SIMPLE SOIL TESTS FOR ON-SITE EVALUATION OF
SOIL QUALITY IN ORCHARD SYSTEMS¹

Abstract

Standard commercial tests typically quantify soil nitrogen, phosphorus, potassium, pH and salinity. These factors alone are not sufficient to predict the long-term effects of management on soil quality. The goal of this study was to assess the effectiveness and use of simple chemical, biological, and physical soil quality indicator tests that can be completed on-site. Analyses were conducted on soil samples collected from two experimental peach orchards located on the Utah State Horticultural Research Farm in Kaysville, Utah. All simple tests were correlated to comparable lab analyses using Pearson's correlation. The highest positive correlations were found between Solvita® respiration and microbial biomass ($R = 0.88$), followed by the modified slake test and microbial biomass ($R = 0.83$). The highest correlation among simple chemical tests was the Mosser simple nitrogen test and the laboratory measured nitrogen ($R = 0.80$). The weakest correlation among simple chemical tests was the Lamotte simple test and the laboratory measured nitrogen ($R = -0.21$). Overall, simple chemical tests were weak indicators of soil nutrient concentrations compared to laboratory tests. Modified

¹ Coauthored by Thomsen E.O., J.R. Reeve, C.M. Culumber, G. Cardon, R. Newhall, D. Alston

slake tests, Solvita® respiration and soil organism biodiversity counts may be efficient and cost effective tools for monitoring soil quality on-site.

Introduction

Soil quality is typically defined as the ability of soil to function while maintaining or improving water and air quality and supporting biota, and is assessed using a suite of physical, chemical and biological tests. Maintaining soil quality is essential for the long-term prosperity of a farm or other land-based system (Wienhold et al. 2004). In the US, cropland loses an average of 7 tons of soil per acre, per year (Sullivan 2004). Maintaining soil quality can prevent loss in system productivity while also improving long-term financial outcome for farmers. For example, growers in Iowa were able to increase yield by 3 % - 12 % and reduce costs from inputs by 41 % -79 % (Liebman et al. 2003). Despite attempts, little progress has been made in increasing grower involvement in maintaining soil quality (Herrick 2000). Soil quality tests are not always available, affordable, reliable or feasible for interested individuals. (Friedman et al. 2001).

Numerous simple soil health tests have been developed over the years, in particular, soil health cards and test kits such as the NRCS soil quality test kit. Soil health cards provide a visual conversational tool between soil health professionals and growers. However, soil health cards alone can be a subjective soil evaluation tool. (Friedman et al. 2001). The NRCS test kit is one of the most comprehensive soil quality test kits available, yet many of the tests are time consuming and confusing for someone new to soil testing (Friedman et al. 2001). Submitting soil samples to an analytical laboratory is the most straightforward testing method for growers. However, most laboratories don't offer biological and physical tests, and when they do, it is often cost prohibitive

(Friedman et al. 2001). There are a few innovative U.S. laboratories that offer affordable soil quality tests. For example, there is one soil lab in the Intermountain West offering Solvita® respiration tests, and at least 20 others in the U.S. (Solvita® 2014). The Cornell Soil Health Testing Laboratory offers a complete soil quality test for \$50-\$140 per sample (Cornell Soil Health 2015). Sample shipping costs and soil quality deterioration during shipment can be limitations.

Soil quality tests include the assessment of biological, physical and chemical parameters of the soil. The specific type of tests will vary based on the laboratory and the common soil problems of that region. There is no set list of soil quality tests. A few common laboratory soil quality measurements include: aggregate stability, texture, organic matter, nitrogen (N), potassium (K), phosphorus (P), pH, soil respiration and enzymes. One of the most important aspects of physical soil quality is aggregation. Aggregate stability is the ability of primary soil particles to remain attached under disruptive forces. Researchers have largely focused their efforts on laboratory aggregate stability tests, and improvements in their reproducibility. A main criticism of aggregate stability tests is that there is no universally accepted method to measure soil structure (Pulido Moncada et al. 2013; Diaz-Zorita et al. 2002). There are generally three categories of aggregate stability tests: 1) ease of dispersion by turbidimetric techniques (Emerson 1967), 2) evaluation of aggregate strength based on raindrop impact (Bruce-Okine and Lal 1975), and 3) aggregate stability by wet sieving (Yoder 1936). Cornell's aggregate stability test uses a rainfall simulator on soil aggregates in sieves. After 5 minutes of impact, soil particles that have fallen through the sieve are measured as the unstable soil aggregates (Gugino et al. 2009). All three categories of soil aggregate tests

have on-site versions. As rainfall simulators are often bulky and complicated to build, the most effective on-site aggregate testing options for growers are turbidimetric tests or wet sieving/slake tests. The NRCS incorporated a modified version of a slake test developed by Herrick et al. (2001) into their field test kit. Herrick et al. (2001), developed a stability test kit that could be made inexpensively with simple tools. It could test up to 18 samples in 10 minutes. The kit was made of two boxes (21 cm x 10 cm x 3.5 cm) with eighteen equal sections. There were also 18 2.5-cm sieves (1.5 mm) for placing the soil aggregates. The rating system was based on a scale of 1-6. This test was found to be highly sensitive to a variety of plant and soil conditions (Herrick et al. 2001). Aggregate stability tests are useful in addressing a soil's potential for erosion, in particular, when comparing the same soil type among management systems (Kemper and Koch 1966; Kemper and Rosenau 1986).

Soil organisms are also important indicators of soil health as they are responsible for organic matter breakdown and nutrient release and may rapidly respond to shifts in management practices (Pankhurst et al. 1997). The rate of organic matter turnover and mineralization potential is an important factor to consider when determining nutrient application rates in efficient systems (Guillard et al. 2015). The most common simple biological tests are counting earthworms and soil respiration in a given volume of soil; however, earthworms are not native to all soils and soil respiration can be highly affected by weather (Friedman et al. 2001). Litter bag tests are not commonly used for agricultural applications. However, they may provide farmers with an easier, cheaper and perhaps more reliable option for determining soil microorganism activity than completing a soil

respiration test. Litter bag tests can quantify decomposition rates over a longer period of time rather than being limited to current field conditions. (Keuskamp 2013).

Other tests to measure soil biological health include those for soil arthropods. Heteroptera (known as ‘true bugs’ have distinctive wings and piercing-sucking mouth parts) and Collembola (known as ‘springtails’ are wingless and lack metamorphosis) have been cited as important indicators of ecological health and or change (Fauvel 1999; Larink 1997; Meyer 2016a and 2016b; and Hopkin 1997). The Berlese funnel test is commonly used to measure abundance of soil arthropods in a laboratory (Macfadyen 1953; Macfadyen 1961; Sabu and Shiju 2010). There are no published studies using in-field versions tailored for growers; however, foldable or collapsible Berlese funnels have been constructed for lightweight transportation (Saunders 1959; Northon and Kethley 1988). Hence, a Berlese funnel could possibly be further modified as a convenient, affordable test for growers.

Chemical tests such as NPK and pH, are available in most laboratories. However, the accuracy of on-site chemical test kits commonly available, such as Rapidtest kit, Lamotte test kit, and Mosser test kit is uncertain. Accurate on-site tests might increase adoption of soil testing by growers.

The goal of this study was to increase adoption of soil quality testing by growers through assessing the effectiveness and use of a number of simple on-site chemical, biological, and physical soil quality indicator tests. A number of potential soil tests were initially screened for ease and time of use in addition to availability of materials. Twelve simple tests for measuring soil physical, biological and chemical properties were correlated to comparable lab analysis for their ability to distinguish between soils of

known soil quality characteristics. Physical simple tests measured aggregate stability and included the NRCS slake test and other modified slaking tests. The biological simple tests included in this study were litterbag tests (Keuskamp et al. 2013), the Solvita® respiration test measuring CO₂ evolved in a given volume of soil over 24 hours, simplified Berlese funnel tests (Saunders 1959; Northon and Kethley 1988), earthworm abundance tests (Friedman et al. 2001), and soil biodiversity tests measuring arthropods, earthworms and organism diversity in soils respectively. The chemical tests included LaMotte, Mosser, and Rapid soil test kits measuring macronutrients and pH; and the Hana pH meter to measure only pH. Tests that compared favorably with corresponding lab analysis were taught to orchardists through demonstrations; survey results were collected on their perceptions of these tests. Surveys on soil quality were also administered to Utah orchardists to gain a better understanding of their current level of interest in and knowledge of soil quality.

Materials and methods

Comparison of simple soil testing strategies to similar lab tests

Simple soil tests were selected based on the accessibility of the test or test components in terms of cost, availability and reasonable time commitment. The most expensive test kit purchased was the NRCS test kit at ~\$800. Other test test kits were under \$100 each, including the Solvita® test kit at ~\$60 for a set of 6 tests. Emphasis was placed on tests that could easily be constructed from materials for under \$20 and be completed in less than an hour. Many different types of test kits were available online; the NRCS test kit was one of the most comprehensive. (Friedman et al. 2001). The slake

and earthworm abundance tests were included in the NRCS test kit; they were selected from the NRCS test kit based on their simplicity and low time commitment. The earthworm test was slightly modified (labelled as the soil biodiversity test) to include observation of more organisms. A slake test using a kitchen sieve was developed as a further simplification of the NRCS slake test. Additional biological tests chosen were a Berlese funnel modified for in-field use to measure soil biodiversity, and litterbags to measure of decomposition rates of organic matter. The chemical tests chosen (Rapidtest kit, Lamotte, Hanna pH meter, and Mosser test kit) were either available locally or readily available online.

Experimental field sites

Soil samples were collected from three experimental peach orchards—one conventional, one integrated, and one organic-- located on the Utah State Horticultural Research Farm in Kaysville, Utah. The integrated and the organic orchard consisted of 11 replicated orchard floor treatments with documented differences in soil quality. The integrated orchard consisted of five tree-row treatments, all with grass alleyways: 1) herbicides and conventional fertilizers (HN in 2014); 2) herbicides and conventional fertilizers, switched to organic compost after tree establishment (HNC); 3) herbicides and compost (HC); 4) paper mulch with reduced herbicide in addition to conventional fertilizers (PR); 5) paper mulch, compost and organic herbicide (PC). The conventional fertilizer used in the HN and PR plots was 16-16-16, which was applied at a rate of 28.8 g N per tree; and 46-0-0 which was applied at a rate of 130 g N per tree in 2014. HN, HC and HNC received 148 mL of Alion herbicide per acre. The organic fertilizers used in

HNC, NC, and PC were paunch compost applied at a rate of 20 g N per tree, and feathermeal (NatureSafe 13-0-0) at a rate of 137 g N per tree in 2014. Copper sulfate and oil were used to treat coryneum and were applied once in the spring and once in the fall in 2014. Flubendiamide and spinosad were used to treat peach twig borer. Flubendiamide was applied once in the spring and the summer, while spinosad was used once in the summer. Imidacloprid and potassium salt of fatty acids were applied in the spring to treat green peach aphids in 2014. Tebuconazole and trifloxystrobin was used in the spring of 2014 to treat mildew.

In 2015, a conventional orchard was used instead of the integrated orchard since it was removed in 2014. The conventional orchard had a grass alleyway with some clover. The conventional orchard received 30-8-8 at a rate of 45 g N per tree, in addition to 46-0-0 at a rate of 104 g N per tree. Alion herbicide was used per acre at a rate of 148 mL. Copper sulfate and oil were used to treat corneum and were applied once in the fall. Oil and Tebuconaozone and trifloxystrobin were used to treat coryneum and applied once in the spring. Trifloxystrobin and difenoconazole and cyprodinil were used to treat mildew. Spinosad was used to treat peach twig borer.

The organic orchard included six understory treatments: 1) straw mulch in the tree row with a grass alleyway (SG) 2) straw mulch in the tree row with a legume (birdsfoot trefoil, *Lotus corniculatus* L.) alleyway (ST); 3) living mulch (low-growing shallow rooted alyssum, *Lobularia maritima* L.) in the tree row with a grass alleyway (LG); 4) living mulch in the tree row with a legume alleyway (LT); 5) woven plastic mulch in the tree row with a grass alleyway (WG); and 6) tilled tree rows with a grass alleyway (TG). All treatments had paunch manure compost and feathermeal (NatureSafe 13-0-0) applied

at a rate of 13.6 g N per tree in 2014 and 2015, and 136 g N per tree in 2014 and 2015 respectively. In the tillage plot the compost was applied under the drip line, in the straw mulched plots the compost was applied to a 30 cm tillage strip separating the tree row from the alleyway. Spinosad was applied to treat peach twig borer twice in 2014, and twice in 2015. Copper oxychloride/hydrochloride and Paraffinic oil was used once in the spring of 2014 and Paraffinic oil was used once in the spring of 2015, and both organic treatments were used twice in the fall of 2014 and 2015 to treat coryneum. Potassium salt of fatty acids was used to treat green peach aphids once in the spring of 2014.

All treatment were used to correlate the simple chemical tests to the laboratory tests, however only four of the treatments were used for the biological and physical tests: SG, ST, TG and HN. Each treatment consisted of four replicates in a randomized incomplete block design (RIBD).

Simple biological tests

The earthworm and biodiversity tests were conducted two to three days after an irrigation event during August in 2014 and 2015. To determine earthworm/biodiversity counts a 30 x 30 x 30 cm hole was dug in each designated test plot. The soil from the hole was placed in a bucket and visually inspected one handful at a time for earthworms and other macroscopic soil organisms. The number of earthworms and number of different kinds of organisms were recorded.

The Berlese funnel tests were conducted in August two to three days after an irrigation event in 2014 and 2015. The methods for construction of on-site Berlese funnel tests were modified and simplified from known laboratory and field methods

(Macfaydyen 1953 and 1961; Saunders 1959; Northon and Kethley 1988). A shovel of topsoil, about 15 – 20 cm in depth, excluding the top inch of soil, from each designated plot was placed in a 20 liter bucket. A 20 x 20 cm piece of cheesecloth was folded in half and taped to the inside of a 12 x 40 cm funnel with masking tape, approximately 10 cm below the opening of the funnel to function as a sieve. The spout of the funnel was placed into a glass jar, and the space between the funnel and the jar was sealed with aluminum foil. One large handful of gently mixed soil from the original shovelful, was placed on top of the cheesecloth in the funnel. The funnels were left in the sun for 3 hours at an average temperature that afternoon of 28.9 °C. The funnels were removed from the jars. The contents of the jars were poured onto a piece of paper, and the the number and type of organisms were recorded.

The Solvita® respiration test was conducted in late June in both years, two to three days after an irrigation event. The Solvita® test kit included plastic jars, lids and CO₂ reactive probes. Each jar was marked with the required soil volume, which came to about 64 g of soil. The CO₂ probe was removed from its metallic pouch and placed into the soil within the jar with the color indicator side facing upward. The jars were sealed with lids, placed in a cool dark place for 24 hours after which the probe color was matched to the test kit indicator sheet. The corresponding soil respiration number was recorded.

Litter bags were filled with three different substrates to measure decomposition rates: dried peach leaves, dried straw, and dried alfalfa with eight replicates per plot. The dried straw and alfalfa materials were cut into 2.5 cm segments. Two and one half grams of one material was put into a labeled nylon bag, the bag was sealed by tying a knot of

nylon at the end. The nylon bags were buried 8 cm below the surface on June 21st, 2014 and the location was marked with a landscape flag labeled with the littertype. One nylon bag of each littertype from each plot was unburied at week 1, 2, 3, 4, 6, 8, 12, and 48 weeks after burial. These methods were a modification of those used in Keuskamp et al. (2013).

Laboratory biological tests

Samples for the laboratory analyses were taken in the end of June, 2014 and 2015, two days after an irrigation event and were analyzed in the first two weeks of July. In 2014, samples were taken at a depth of 0-10 cm, and in 2015 samples were taken at a depth of 0-30 cm. Mineralizable carbon (RMC), basal respiration (BR), and microbial biomass (C_{mic}) determined by substrate induced respiration (SIR) were measured with an infrared CO₂ analyzer (Model 6251, LICOR Biosciences) on day 12, 13, and 14 of an incubation at 25 °C and 22 % moisture as described by Anderson and Domsch (1978) and Davidson et al. (1987). Dehydrogenase enzyme activity (DHA), the reduction of triphenyl tetrazolium chloride of 2.5 g soil dried weight equivalent at 22% moisture was measured as described by Tabatabai (1994).

Simple physical tests

Physical simple tests were conducted on soil collected in August in both years, two to three days after an irrigation event. The NRCS slake test was completed as described in NRCS (2001). Sieves were removed from the NRCS tray and one air-dried soil aggregate measuring 1 cm placed in each. The empty compartments in the tray were

filled with distilled water. Sieves were lowered into the compartments and soaked in the distilled water for five minutes. After five minutes, the sieves were lowered and raised from the water 4 more times. Sieves were placed on a dry surface and aggregates were examined, and rated according to the slake test scale in NRCS (2001). The rating was from 0 to 6. Zero was recorded if all soil disintegrated from the sieve upon first contact with the water. Six was recorded if 75 % to 100 % of soil aggregates remained intact after 5 dipping cycles (NRCS 2001).

The first modified slake test, the surface structure test, was conducted by taking a 20 cm diameter kitchen sieve filled to the rim with un-sieved soil from the designated plot, with rocks and large pieces of organic material removed. A picture and notes were taken to document the general appearance of the structure of the soil. The sieve was soaked in a bucket of water for 5 minutes. The sieve was raised and submerged four times, allowing water to drain (about 5 seconds) in between. The sieve was removed and another picture and more notes were taken documenting the soil surface structure. An estimate was recorded of the percent of soil structure remaining intact in the sieve.

The second modified slake test, the hose test, was conducted on the same sieve of soil directly after completing the first modified slake test (the surface structure test). The hose was turned on, using one and three quarters turn to the knob, to maintain the same water pressure on all of the tests. The sieve was held about one half meter from the hose and then sprayed for 1 minute in a circular motion, while maintaining an equal distribution of water flow over all surface points of the soil in the sieve. The amount of soil remaining by the end of 1 minute was recorded.

Laboratory physical tests

The laboratory procedure correlated to the physical simple tests was the machine aggregate stability test as described by Kemper and Rosenau (1986). Four grams of sieved and air dried soil, was placed in sieves in a mechanical sieving device (Make: 8.13.01; Model: 33255301; Giesbeck, Netherlands) and pre-moistened with steam to 4.75 g soil wet weight (19.5% water content). The instrument submerged the sieves and soil into water and raised and lowered them at regular intervals for three minutes. The soil that was lost during the sieving process was oven dried at 40 °C and weighed. The process was repeated in a 0.2 % sodium hexametaphosphate solution (NaPO_3)₆. The soil removed from the sieves by the (NaPO_3)₆ solution represented the stable aggregates.

Simple chemical tests:

Soil samples were taken the last week of July each year for both laboratory and simple test kit chemical analyses. Instructions were followed according to the respective manuals for testing N, P, K, and pH by the Rapidtest kit, Lamotte test kit, and Mosser test kit. Instructions were also followed according to the manual for the testing of pH by the Hanna pH meter.

Laboratory chemical tests

For the laboratory chemical analysis, soils were sieved and stored at -15 °C and processed within 10 days for measuring available N. Laboratory measured N was

measured by nitrate and ammonium extraction using 1 M Potassium Chloride and analyzed by Lachat (Quickchem 8500, Hach Company, Loveland, CO) using the sulfanilamide and phenate methods respectively as described in the manufacturer's protocols. Olsen's (1954) sodium bicarbonate extraction method was used for measuring P and K and were measured after sieving soils at 4 mm and air-dried for two weeks.

Statistical analysis²

Each simple test was compared to a relevant laboratory based test using Pearson's correlation. Pearson's correlations were measured and not P values because the analyses did not meet P value assumptions; individual observations were not independent of treatment and or replicated blocks. Results from the litterbag tests were also run through SAS as a randomized block design with two factors, treatment and littertype, with time as a repeated measure (SAS Institute, Cary, NC).

The estimated percentage of stable soil aggregates were correlated with the percent stable soil aggregates from the mechanized slake test for the NRCS slake test. The estimated percentages of stable soil aggregates from the simple slake tests were also correlated with biological laboratory procedures (RMC, BR, Cmic, SIR, and DHA) as the physical qualities of the soil are often directly linked to biological activity in the soil.

Training sessions with growers, and collection of feedback

² See Appendix, A1-A3 for analysis conducted as a regression

Soil quality training opportunities were presented to local farmers. Seven orchardists volunteered to be trained in soil quality and on-site soil quality tests which included the modified slake tests, NRCS slake test, Solvita® soil respiration, and earthworm abundance/biodiversity test. At the end of each training, they provided feedback on a prepared questionnaire. At South Ridge Farms in Santaquin, UT, a demonstration of the same simple on-site soil quality tests taught to the volunteers was presented at a summer field tour organized by the Utah State Horticultural Association (USHA) on June 30, 2015. Questionnaires were filled out at this event. Finally, a questionnaire was distributed through a USU orchardist listserv, to obtain general feedback from Utah orchardists on their knowledge and interest in soil quality and testing methods. The results from the 7 growers and those who attended the field demo were combined, and the results from the online survey analysed separately.

Results and discussion

Biological test results

As shown in Table 1, results from the Solvita® soil respiration test kit had the highest correlations with laboratory tests in both years. The results coincide with Haney et al. (2008), where Solvita® soil respiration tests strongly correlated with the titration method of measuring CO₂ soil respiration ($R^2 = 0.82$) and infrared gas analysis measuring CO₂ analysis ($R^2 = 0.79$). In the first year (2014), Solvita® soil respiration was able to differentiate between the two plots documented with higher soil quality and the two plots documented to have more limited soil quality (differentiated SG and ST from HN and TG, Figure 1) (Culumber 2016). In the second year (2015), similar

treatments were differentiated with less precision (Figure 2).

It is possible that precision could be improved by lessening the amount of time that the soil probes were incubated, as many of the organically managed soils maxed out at the upper range of the test within a few hours of the 24 hr incubation time specified in the instructions. The drawback with this test is that soil respiration is highly affected by weather, making it sometimes a difficult parameter for projected biological activity in a given location (Friedman et al. 2001). In our study we controlled for potential differences in soil moistures between years and treatments by timing the test two to three days after an irrigation event.

The earthworm abundance test, although often recommended by the NRCS as well as others, proved to have little relationship with laboratory soil biological testing measures (Table 1). In 2014, the earthworm abundance test differentiated between treatments somewhat (ST often showing the best soil quality parameters, followed by SG, TG and then HN), when correlated to DHA (Figure 3). In 2015, no correlation with DHA was found (Figure A5). Conversely, previous work at this site has shown that dehydrogenase enzyme activity, soil respiration and microbial biomass as measured in the laboratory have consistently differentiated between all treatments (Culumber, 2016). The earthworm test weakly correlated the second year with laboratory measured soil respiration ($R = 0.33$). The correlation of the number of different organisms found in the 30 cm³ pit to soil microbial biomass was higher ($R = 0.68$, Figure 4), and could potentially be improved by more repetitions. Earthworms have beneficial effects on soil quality, but numbers may not necessarily reflect laboratory biological indicators. According to Pelosi et al. (2015) earthworm abundance is highly variable due to climatic

conditions and in order to obtain soil quality data from earthworm counts, multiple years of assessments are required. The results for the on-site Berlese funnel tests hardly compared to laboratory tests ($R = 0.48$ correlation with microbial biomass, Table 1). The best correlation between the Berlese funnel tests and laboratory tests is shown in Figure A6. It was assumed that the heat of the sun over the space of a few hours would cause the soil arthropods to descend into the jar from the sieve (Saunders 1959). The sieves used, may have been too deep, allowing the organisms to remain in a comfortable environment for the duration of the test. A longer test period may also have improved the results. It is important to choose a sunny day with temperatures over $25\text{ }^{\circ}\text{C}$ for this type of test.

Litter bag tests failed to provide distinctions between soil quality, as shown in Table A4. In order to improve the accuracy of the recordings for the litterbag test, more replicates would be needed for each litter type and excavation date. After almost a year of burial, higher correlations with laboratory results were observed; however, none were particularly meaningful. Disadvantages of this kind of test for grower use is the requirement of a precise weight scale, and the time needed to dry, remove adhered soil from the outside, and transfer the contents of the litterbags onto the scale. This process was susceptible to loss of litterbag contents that affected the overall results. Also, the nylon material used to construct the litterbags was susceptible to penetration by roots and rocks, resulting in weight gain from entering debris. Nylon was chosen to prevent decomposition; however, a stronger material such as a commercially available synthetic teabag, as used by Keuskamp et al. (2013) might have produced more consistent results. Keuskamp et al. (2013) found that the tea bags prevented root penetration, and did not decompose after 3 months in the field.

Physical tests

There were no correlations between the machine aggregate tests and any of the simple slake testing methods, although several of the simple tests correlated well with the biological tests (Table 2). The machine aggregate stability test categorized the tillage management system with the strongest aggregate stability (Figure A7), which is the opposite of what would be expected (Paul et al. 2013 and Beare and Russell Bruce 1993). This typically occurs after leaving soils to air dry for months to years (Kemper and Koch 1966; and Kemper and Rosenau 1984), however these soils were stored air dried for only one week prior to testing. Kemper and Koch (1966) reported a factor necessary for obtaining reproducible results was sieving out soil particles with a diameter of less than 1 mm. This step was not done in this study, which could have influenced the results. However, the challenge of comparing results from different stability tests has been a persistent one, as the degree of variability between and within methods is large which can lead to weak comparisons. (Pulido Moncada et al. 2015).

Physical soil properties were more visible on a larger scale, allowing for more informative results. For example in the surface soil test, upon wetting the soil, the soil aggregates would hold together tightly showing strong aggregate structure or would smooth out and gloss over showing weak soil structure. Using smaller on-site slake tests such as the NRCS test, these visual cues were absent. Keyrodin (2014) recognised visual cues as being important indicators of changing or threatened soil quality.

In both years the best physical test correlation was between the first modified slake test: surface soil test, and microbial biomass (Table 2). The results were consistent with results from the Solvita® test, and easily distinguished between orchard floor management practices that build soil quality (such as addition of organic matter) and the soil management practices that typically diminish soil quality (such as tillage, Figure 5 and 6). In 2014, the hose test clearly distinguished between most treatments, even moderately differentiating soil quality in the tree row with a trefoil alleyway, and the tree row with a grass alleyway, Figure 7. Precision on the hose test could possibly be improved by reducing the water pressure, especially on soils containing limited to no organic matter. Previous research has shown that treatments with a trefoil alleyway had the best soil quality (Culumber 2016). In 2015, though, the hose test results were much less clear ($R = 0.42$:Table 2).

Chemical tests

Simple chemical N tests yielded the highest correlations among chemical tests in both years (Table 3). The exception was the Lamotte simple N test in the organic orchard. The Lamotte test kit was slightly more sensitive to nutrients and pH than the Rapidtest kit (Table 3, Figure 8). In Figure 9, value 1 on the Lamotte scale correlates to 0-8 ppm. Although not very precise, the results roughly corresponded to the laboratory measured soil N. The Lamotte simple K tests had the next highest correlations, with better results from the organic orchard (Figure 10) vs. the conventional orchard (Figure A8). It is possible that the diminished accuracy of the Lamotte K and N tests for the organic orchard samples was an effect of organic materials such as humic acids on the chemical

solutions due to higher soil organic matter in those samples. As shown in Figure 10, the highest concentration of K recorded in the laboratory, corresponded to the highest concentration of K recorded using the Lamotte simple test—in particular for the treatment ST and SG. It was less accurate in distinguishing K levels in the other four treatments, which could also be an effect of such a narrow test scale.

The Mosser N test correlated best out of all of the chemical simple tests (Table 3, and Figure 11). The K test was not correlated (Figure A9). The test correctly identified the ST treatment as having greatest levels of K, however the overall scale shows that the concentration of K was often undervalued and not very precise. The soils that were rated with the lowest concentrations of K on the Mosser scale, were measured by the laboratory above 150 ppm, which is typically considered a sufficient/high level. The range of the scale also did not measure excessive nutrients. For example the Mosser K test maxed out at 180 ppm.

The correlations with soil P and pH were poor, regardless of the test used. The test kits came in packages of N, P, K and pH. To purchase a kit only to use one or two particular tests, is not the most efficient use of a product.

The Rapidtest kit did not provide information on the chemical information of the extractions used. However, the N simple tests for the Lamotte and the Mosser test kits were based on colorimetric standardized tests (Griess 1879; Sparks 1996). The tests used zinc to reduce nitrate to nitrite, nitrite would then react with a color agent allowing for the determination of concentration of N through observation. The Mosser potassium simple test used Sodium Tetraphenylboron which reacts with nonexchangeable K to form a white precipitate. The cloudiness of the sample is then recorded (Sparks 1996; Scott et al.

1960). The Lamotte K simple test did not match any standardized K laboratory procedures for K (Sparks 1996). The Mosser and Lamotte simple P tests, used modified versions of a colorimetric procedure for measuring P (Sparks 1996). The Mosser test, used ammonium molybdate which reacts with P, producing a complex that reduces to a blue color in the presence of ascorbic acid. The Lamotte simple test, used sodium molybdate instead of ammonium molybdate. No information was found as to whether these colorimetric methods work better in acidic soils or alkaline soils, or are affected by humic acids, however these soil attributes could potentially have an effect.

Grower feedback

Out of the 400 surveys sent via email, 101 growers completed the survey. The survey asked growers whether they tested their soil, why or why not, what kind of tests they used, and what soil quality meant to them. The respondents were primarily men between the ages of 55-64. Although, women did represent 43% of the respondents. The greatest number of respondents owned acreage between 1-5 acres.

When growers were asked how they rated their knowledge on soil testing, (Figure 12) 46% of the individuals mentioned that they had some knowledge. While only 4% mentioned having no knowledge on soil testing. Most growers affiliated healthy soil with healthy plants and good yields (Table 4), followed by healthy populations of soil microorganisms, and good soil structure.

In other studies categorizing how growers view soil quality, growers had similar views on soil quality indicators even in different regions with varying crops. In Lima et al. (2010), earthworms and soil color were classified as soil quality indicators by the

largest percentage of rice growers in southern Brazil. Yet when it came to the soil quality indicator that affected management practices, the growers only mentioned soil color. The perceptions of soil quality in Southeast Pampa of Argentina, were based on crop yields and the estimated returns on fertilizer. Smallscale growers had little concern for maintaining long term soil quality as they largely rented their fields (Ferrazino et al. 2014). For smallscale growers in Kenya, the soil quality indicators were also crop yield and crop performance. The growers also recognized soil color, soil texture and weed species as indicators of soil quality. (Mairura et al. 2007). The growers also expressed concern that overall soil quality in their region had been decreasing due to poor management practices and that soil erosion negatively affects crop production (Mairura et al. 2007).

Sixty-nine percent of 101 respondents from the email survey said they test their soil. With the majority of those respondents indicating they complete chemical tests (69%) (Figure 13). There were some individuals who did simple on-site chemical and physical tests. No respondent mentioned specifically having done any biological tests onsite, and one respondent indicated they had completed laboratory biological tests. This is likely due to unavailability of such tests in most laboratories, costs and issues associated with sending soils to laboratories with tests available, and the lack of opportunities to learn about biological tests on-site.

Respondents most often indicated that the reason they tested their soil was to determine soil fertility so they could apply the proper amendments. The next most common response to track soil properties (Table 5). The most common reason for not testing was that growers had not seen any problems with their plants, followed by

expense (Table 6). One grower in particular mentioned that to test his soils at a lab it costed a minimum of \$150, because of the distance he lived from a soil testing laboratory, and the need to send his soil through the mail.

In order to understand the current perceptions on soil testing strategies and what growers thought about them, they were asked to what extent they agreed that usefulness, affordability and ease were common traits among current testing strategies (Figure 14). The largest percentage of respondents indicated that these were common traits among testing strategies, while the next largest percentage of respondents indicated that they weren't particularly common traits but also not missing as traits. Less than 15% of respondents for each trait indicated that they were not common traits.

When asked what could be improved on standard tests known to or available to the public (Table 7), most growers actually felt that the methods available to them were sufficient, and nothing needed improvement. The next most common response was for more information on organic systems, in particular recommendations for organic ammendments. Mention was also made on making tests more affordable, convenient, and comprehensible, as well as an emphasis on biological tests. The last question asked was if they were interested in learning more from researchers on soil quality testing, and the majority of respondents, 87 %, said yes (Figure 15).

The growers who had worked with a researcher one on one or attended the soil testing demo indicated the first modified slake test/the surface structure test as the most likely test they would use on their own farm, followed by the eathworm abundance test (Figure 16). The main concern cited (mentioned by two growers), was that the water flow rate used in the hose test might be challenging to keep consistent. The other concern

mentioned 2 times by different growers, was the cost of the Solvita® test, and how that would limit their ability to use that test. The main positive comment mentioned by more than 2 growers on the simple tests demonstrated, was how hands-on the tests were. One farmer in particular had assumed the tests would all involve vials and chemicals. Another grower said, it gave her a new way to think about testing the soil.

All growers (7) that worked one-on-one with a researcher said that they learned something from the demonstrations. And 18 out of 19 from the demo survey stated that they had learned something from the simple testing methods. Previous attempts have been made to support growers through soil quality testing, yet using laboratory data as opposed to in field tests (Andrews et al. 2003). The drawback of these tests, was that the grower's ability to understand the lab results were limited without thorough interpretation. And, even with thorough explanation, farmers expressed concern over the local relevance of the baseline data used to compare their soil quality, as well as an interest to know long-term soil quality trends of their farming practices (rather than mere values). Another study, done by McGrath et al. (2002) developed soil quality index cards to raise awareness on soil health by increasing a farmer's ability to assess their own soils visually. According to feedback, the cards were most useful as teaching and educational aids. Farmers found the cards simple yet time consuming and subjective, and had difficulty associating card use with improved soil quality, profit or management practices. The simple soil tests developed here, particularly the modified slake test surface structure test, show real potential in terms of involving growers more intensely in soil quality testing.

The next steps needed are more educational opportunities for growers on soil quality and further work on refining these simple soil tests. For example, discovering if precision of the tests can be improved with more repetitions. Further information on test performance in a wider range of soil types and environments is also needed. Complete compilations of before and after pictures from various soil types, management systems and environments are needed to provide a good reference to aid in interpretation for the modified slake tests.

Conclusions and summary

Results from the grower surveys showed that growers are interested in soil quality and are interested to learn more about soil quality. Most growers do test their soil, however the majority of them only complete macro-nutrient laboratory tests. Many growers understand that soils are affected by much more than the nutrients they add, but also the organisms within the soil. Growers for the most part are satisfied with current testing methods, yet essentially half of the growers surveyed acknowledged only some or limited knowledge on soil quality. Hence, they may not be fully aware of the potential benefits of assessing soil quality over the long-term. And since soil quality testing is not routine--often cost prohibitive or unavailable—it seems accurate to assume that growers could benefit from more services and education in soil quality testing, in order to facilitate their own abilities in assessing soil quality. Simple on-site tests provide a possible avenue for farmers to improve understanding of their soil quality without the difficulty or cost associated with laboratory testing. The simple tests that were tested did not all prove to be accurate indicators of soil quality. Yet, despite overall weak

correlations to laboratory tests, some of the simple test results accurately differentiated the majority of orchard floor treatments based on soil quality. The order of orchard understory treatments generating best soil quality to poorest was ST, SG, TG and HN (Culumber 2016). The highest correlations between biological simple tests and laboratory findings were found between Solvita® respiration and microbial biomass ($R = 0.88$) in 2014 and DHA in 2015 ($R = 0.74$). The highest correlation among physical tests was the first modified slake test: surface soil test, and although it did not correlate to the lab aggregate stability test it was closely correlated to microbial biomass ($R = 0.83$ in 2014, and $R = 0.64$ in 2015). The highest correlation among chemical simple tests (2014), was the Lamotte simple N test with laboratory measured N in the conventional orchard ($R = 0.78$). the highest correlation among chemical simple tests in 2015 was between the Mosser N and laboratory measured N ($R = 0.80$). The worst correlation among chemical simple tests was actually the same Lamotte simple N test conducted in the organic orchard ($R = -0.21$ in 2014). Due to the variable nature of on-site chemical tests, they were not included in the farmer demos or surveys, and recommendations were given instead to continue conducting chemical tests through laboratories. In terms of user friendliness and cost of simple on-site physical and biological tests, modified slake tests and soil biodiversity/earthworm abundance counts consistently ranked as most preferred among growers.

References

- Anderson, J.P.E., and K.H. Domsch. 1978. A physiological method for the quantitative measurement of microbial biomass in soils. *Soil Biology and Biochemistry*, 10: 215-221.

- Andrews, S.S., C.B. Flora, J.P. Mitchell, and D.L. Karlen. 2003. Growers' perceptions and acceptance of soil quality indices. *Geoderma*, 114, no. 3–4: 187–213. doi:10.1016/S0016-7061(03)00041-7.
- Beare, M. H., and R. Russell Bruce 1993. A comparison of methods for measuring water-stable aggregates: implications for determining environmental effects on soil structure. *Geoderma*, 56(1–4): 87–104. [http://doi.org/10.1016/0016-7061\(93\)90102-Q](http://doi.org/10.1016/0016-7061(93)90102-Q)
- Davidson, E.A., L.F. Galloway, and M.K. Strand. 1987. Assessing available carbon: Comparison of techniques across selected forest soils 1. *Communications in Soil Science and Plant Analysis*, 18: 45–64. DOI: 10.1080/00103628709367802.
- Doran, J.W., and A.J. Jones. 1996. Soil quality and health indicators of sustainability. In *Methods for Assessing Soil Quality*, eds. J.W. Doran and A.J. Jones, xi–xiii. Madison, Wisconsin: Soil Science of America Spec. Publ. 49.
- Fauvel, G. 1999. Diversity of Heteroptera in agroecosystems: role of sustainability and bioindication. *Agriculture, Ecosystems & Environment*, 74(1–3): 275–303. [http://doi.org/10.1016/S0167-8809\(99\)00039-0](http://doi.org/10.1016/S0167-8809(99)00039-0)
- Ferrazino, A., S.E. Ratto, V. Cervio, and L. Giuffrè. 2014. The perception of soil quality of the southeast Pampa of Argentina and social attitudes. *International Journal of Business and Social science*, 5(5).
- Friedman, D., M. Hubbs, A. Tugel, C. Seybold, and M. Sucik. 2001. Guidelines for soil quality assessment in conservation planning. NRCS. USDA, Jan. 2001. Web. Jan. 2014.
- Griess, P. 1879. Bemerkungen zu der Abhandlung der HH. Weselsky und Benedikt 'Über einige Azoverbindungen.' *Chemische Berichte* 12: 426–428.
- Gugino, B.K., O.J. Idowu, R.R. Schindelbeck, H.M. van Es, D.W. Wolfe, B.N. Moebius-Clune, J.E. Thies, and G.S. Abawi. 2009. Soil Health Testing. In *Cornell Soil Health Assessment Training Manual*. 16–40. Geneva, New York: Cornell University, College of Agriculture and Life Sciences.
- Guillard, K., P. McIntosh, and W. Brinton. 2015. Solvita® Soil Test Kits To Categorize Turfgrass Site Responsiveness to Nitrogen Fertilization. 2014 Annual Turfgrass Research Report, University of Connecticut.
- Guimarães, R.M.L, B.C. Ball, and C.A. Tormena. 2011. Improvements in the visual evaluation of soil structure. *Soil Use and Management*, 27:395–403

- Haney, R., and W. Brinton. 2008. Estimating Soil Carbon, Nitrogen and Phosphorous Mineralization from Short-Term Carbon Dioxide Respiration. USDA-ARS & Woods End, published in *Communications in Soil Science and Plant Analysis*. - See more at: <http://solvita.com/publications#sthash.f1JCzgDQ.dpuf>
- Herrick, J.E. 2000. Soil quality: an indicator of sustainable land management? *Applied Soil Ecology* 15 (1): 75–83.
- Hopkin, S.P. 1997. Biology of the springtails (Insecta: Collembola). Oxford University Press, Oxford.
- Kemper, W.D., and E.J. Koch. 1966. Aggregate stability of soils from the western portions of the United States and Canada. Washington, D.C.: USDA Tech. Bull. 1355. U.S. Government Printing Office.
- Kemper, W.D., and R.C. Rosenau. 1984. Soil cohesion as affected by time and water content. *Soil Science Society of America journal* 48: 1001-1006.
- Kemper, W.D., and R.C. Rosenau. 1986. Aggregate stability and size distribution. methods of soil analysis, part 1. Physical and Mineralogical Methods-Agronomy Monograph no. 9 (2nd Edition).
- Keuskamp, J. A., B.J.J. Dingemans, T. Lehtinen, J.M. Sarneel, and M.M. Hefting. 2013. Tea Bag Index: a novel approach to collect uniform decomposition data across ecosystems. *Methods in Ecology and Evolution*, 4(11): 1070–1075. <http://doi.org/10.1111/2041-210X.12097>
- Keyrodin, H. 2014. Importance of Soil Quality and Agricultural soil indicators. *Academia Journal of Agricultural Research* 2(11): 231-238. DOI: <http://dx.doi.org/10.15413/ajar.2014.0140>
- Lal, R., K. Mokma, and B. Lowery. 1999. Relation between soil quality and erosion. In *Soil Quality and Soil Erosion*, ed, R. Lal, 237-258. Danvers, Massachusetts: Soil and Water Conservation Society.
- Larink, O. 1997. Springtails and mites: important knots in the food web of soils. In *Fauna in Soil Ecosystems: Recycling Processes, Nutrient Fluxes, and Agricultural Production*, ed, G. Benckiser, 225-264. New York: Marcel Dekker.
- Lima, A.C.R., W.B. Hoogmoed, L. Brussaard, F. Sacco dos Anjos. 2011. Farmers' Assessment of soil quality in rice production systems. *NJAS – Wageningen Journal of Life Sciences*, 58(1-2), 31-38. doi:10.1016/j.njas.2010.08.002
- Macfadyen, A. 1953. Notes on methods for the extraction of small soil arthropods. *Journal of Animal Ecology*, 22(1), 65–77. <http://doi.org/10.2307/1691>

- Macfadyen, A. 1961. Improved funnel-type extractors for soil arthropods. *Journal of Animal Ecology*, 30(1), 171–184. <http://doi.org/10.2307/2120>
- Mairura, F., D. Mugendi, J.I. Mwanje, P.K. Mbugua. 2007. Assessment of farmers' perception of soil quality indicators within smallholder farms in the central highlands of Kenya. *In Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities*, eds, Bationo, A., B. Waswa, J. Kihara and J. Kimetu, 1035-1046. Dordrecht, NL: Springer.
- Map of Solvita® Labs. *Solvita®*. N.p., 2014. Web. 06 Jan. 2016.
- Meyer, J. General Entomology: Hemiptera Suborder Heteroptera. North Carolina State University. 2016a. Web. 01 Apr 2016. Retrieved from <https://www.cals.ncsu.edu/course/ent425/library/compendium/heteroptera.html>.
- Meyer, J. General Entomology: Collembola Springtails. North Carolina State University. 2016b. Web. 01 Apr 2016. Retrieved from <https://www.cals.ncsu.edu/course/ent425/library/compendium/collembola.html>.
- NRCS. 2001. Soil quality test kit guide. United States Department of Agriculture. Retrieved from http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_050956.pdf
- Pulido Moncada, M., D. Gabriels, W. Cornelis, and D. Lobo. 2015. Comparing Aggregate Stability Tests for Soil Physical Quality Indicators. *Land Degradation & Development*, 26(8), 843–852. <http://doi.org/10.1002/ldr.2225>
- Norton, R.A. and J.B. Kethley. 1988: A collapsible, full-sized Berlese-funnel system. *Entomological News*, 991: 41-47
- Paul, B. K., B. Vanlauwe, F. Ayuke, A. Gassner, M. Hoogmoed, T.T. Hurisso, and M.M. Pulleman. 2013. Medium-term impact of tillage and residue management on soil aggregate stability, soil carbon and crop productivity. *Agriculture, Ecosystems & Environment*, 164, 14–22. <http://doi.org/10.1016/j.agee.2012.10.003>
- Pulido Moncada, M., D. Gabriels, W. Cornelis, and D. Lobo. 2015. Comparing aggregate Stability tests for soil physical quality indicators. *Land Degradation & Development*, 26(8), 843–852. <http://doi.org/10.1002/ldr.2225>
- Olsen, S. R., C. V. Cole, F. S. Watanabe and L. A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U. S. Department of Agriculture Circular No. 939. Banderis, A. D., D. H. Barter and K. Anderson. Agricultural and Advisor.

- Pankhurst, C.E., B.M. Doube, and V.V.S.R. Gupta. 1997. Biological indicators of soil health: synthesis. p. 419-435. *In* Biological indicators of soil health, eds, C.E. Pankhurst, B.M. Doube, and V.V.S.R. Gupta, 419-435. New York, New York: CAB International.
- Pelosi, C., M. Bertrand, J. Thénard, and C. Mougin. 2015. Earthworms in a 15 years agricultural trial. *Applied Soil Ecology*, 88: 1–8.
<http://doi.org/10.1016/j.apsoil.2014.12.004>
- Sabu, T. K., and R.T. Shiju. 2010. Efficacy of pitfall trapping, Winkler and Berlese extraction methods for measuring ground-dwelling arthropods in moist-deciduous forests in the Western Ghats. *Journal of Insect Science*, 10.
<http://doi.org/10.1673/031.010.9801>
- Saunders, L.G. 1959. Methods for studying forcipomyia midges, with special reference to cacao-pollinating species (diptera, ceratopogonidae). *Canadian Journal of Zoology* 27: 33-51. Retrieved from
<http://www.nrcresearchpress.com/dist.lib.usu.edu/doi/pdf/10.1139/z59-005>
- Sparks, D. 1996. Methods of soil analysis: part 3—chemical analysis. Madison, Wisconsin: Soil Science Society of America.
- 2015 Soil Health Testing Services. Cornell Soil Health. Cornell University: College of Agriculture and Life Sciences. N.p., 20 Oct. 2015. Web. 6 Jan. 2016.
- Tabatabai, M.A. 1994. Soil enzymes. *In* Methods of soil analysis, part 2. Microbiological and Biochemical Properties- SSSA Book Series, no. 5, 775-833. Madison, Wisconsin: Soil Science Society of America.
- Wienhold, B.J., S.S. Andrews and D.L. Karlen. D.L., 2004. Soil quality: a review of the science and experiences in the USA. *Environmental Geochemistry and Health*, 26 (2): 89–95. doi:10.1023/B:EGAH.0000039571.59640.3c.

Tables and Figures

Table 1. Pearson's correlations between in field biological tests and laboratory biological tests in 2014 and 2015.

Simple tests	Lab tests					
	DHA 2014	DHA 2015	BR 2014	BR 2015	Cmic 2014	Cmic 2015
Solvita® Respiration	0.83	0.74	0.64	0.81	0.88	0.70
Earthworm Abundance test	0.38	-0.02	0.31	0.33	0.32	0.06
Berlese Funnel test	0.43	0.22	0.29	0.68	0.48	0.55

Note: DHA = dehydrogenase enzyme assay, BR = basal respiration, Cmic = microbial biomass measured by substrate induced respiration.

Table 2. Pearson's correlations between in field physical tests and laboratory biological and physical tests in 2014 and 2015.

Simple tests	Lab tests					
	DHA 2014	DHA 2015	SIR 2014	SIR 2015	Machine slake test 2014	Machine Slake test 2015
Surface test	0.76	0.38	0.83	0.83	-0.05	-0.25
Hose test	0.73	0.26	0.80	0.42	0.04	-0.15
NRCS test	0.68	0.13	0.58	0.38	0.31	0.03

Note: DHA = dehydrogenase enzyme assay, SIR = substrate induced respiration.

Table 3. Pearson's correlations between in field chemical tests and laboratory chemical tests on conventional and organic orchard soils in 2014 and 2015.

Simple tests	Lab tests							
	Integrated/conventional orchard				Organic orchard			
	N	P	K	pH	N	P	K	pH
Rapid test 2014	0.74	0.02	-0.14	0.00	0.69	0.28	0.29	0.00
Lamotte 2014	0.78	0.13	0.45	0.03	-0.21	0.32	0.72	0.37
Hana pH meter 2014	--	--	--	0.20	--	--	--	0.24
Mosser 2015	--	--	--	--	0.80	-0.09	0.60	0.09

Note: N = available soil nitrogen, P = phosphorus, K = potassium.

Table 4. Growers' perceptions of what healthy soil means.

Responses	Number of responses
Soil that creates a healthy crop and or good yields	32
Soil that is full of healthy microorganisms and or fungi	21
Soil that has good soil structure/water holding capacity	20
Soil that has a balance of the appropriate nutrients	18
Soil rich in organic material	17
Soil that contributes to a healthy environment and is sustainability	8
Soil that is not contaminated with toxins	7
Soil that creates nutritious products for the consumer	5
Soil that has acceptable pH	5
Soil that contains no synthetic chemicals	5
Soil that recieves more inputs than are harvested	4
Soil that promotes biological diversity	3
Soil that is under crop rotation	3
Soil growing crops that are pest and disease resistant	3
Soil with acceptable saline levels	2
Soil with cover crops	2
Soil with containing minimal or manageable weeds	2
Soil that allows one to profit	2
Soil that has a balance of fertilizers and pesticides	1
Soil that is under no till management practices	1
Soil with crop diversity	1
Soil with a variety of minerals	1
Soil containing nutrients	1

Note: Survey responses (101) from survey emailed to USU grower listserv.

Table 5. Growers indicate why they test their soils.

Responses	Number of responses
To know the soil composition of nutrients in order to accurately apply amendments	20
To track the trends in soil properties	17
An attempt to understand why the plants had poor health	8
Requirement for organic certification for soil plan improvement projects	4
A curiosity to see what nutrients were present	3
To gauge the level of soil health	2
To maintain plant health and or peak production	2
Because of an NRCS pogram	1

Note: Survey responses (101) from survey emailed to USU grower listserv.

Table 6. Growers indicate why they don't test their soil.

Responses	Number of Responses
There is no reason to test as plants are healthy	9
Too expensive to test	8
Already knowledgeable about inputs the soils need, no use in testing	7
Lacking the necessary equipment/materials in order to test	4
Not interested to soil test, as it is too much effort	4
No available time to test the soil	3
No particular reason that the soil has not been tested	2
Currently renting property to farm, but if owned the land would test	1
Not knowledgeable on how to test	1
Not interested in recommendations from the soil test that are chemical solutions	1

Note: Survey responses (101) from survey emailed to USU grower listserv.

Table 7. Growers perceptions on what could be improved with modern testing methods.

Responses	Number of responses
Nothing could be improved with modern testing methods	14
Lab test results could include information on improving soil without using chemicals/comprehensive testing for organic standards	8
More accessible information on how to test and what to test	7
Create cheaper soil testing methods	8
Create biological tests more available and affordable and make more information accessible on how it may affect nutrients	6
Make soil testing easier and more convenient	5
Create data interpretation guides for soil tests with simple language	4
Not familiar enough with soil testing to make a comment on this/not sure	4
Soil testing facilities should be made closer to the farmers	3
Organic matter content should be included in routine soil lab tests	2
Make field tests more accurate	2
Soil tests should indicate if soils are improving or degrading with time	1
Adequate ranges of nutrients should be listed on the soil lab test results	1
More accessible information on when to test for certain contaminants	1
More accessible expertise on growing a wide variety of crops	1
There should be accessible soil tests to test for pathogens	1
More accessible information on micronutrients	1
More testing options to test for just lead -- needed in urban settings	1
Standard soil tests just don't seem like enough information	1

Note: Survey responses (101) from survey emailed to USU grower listserv.

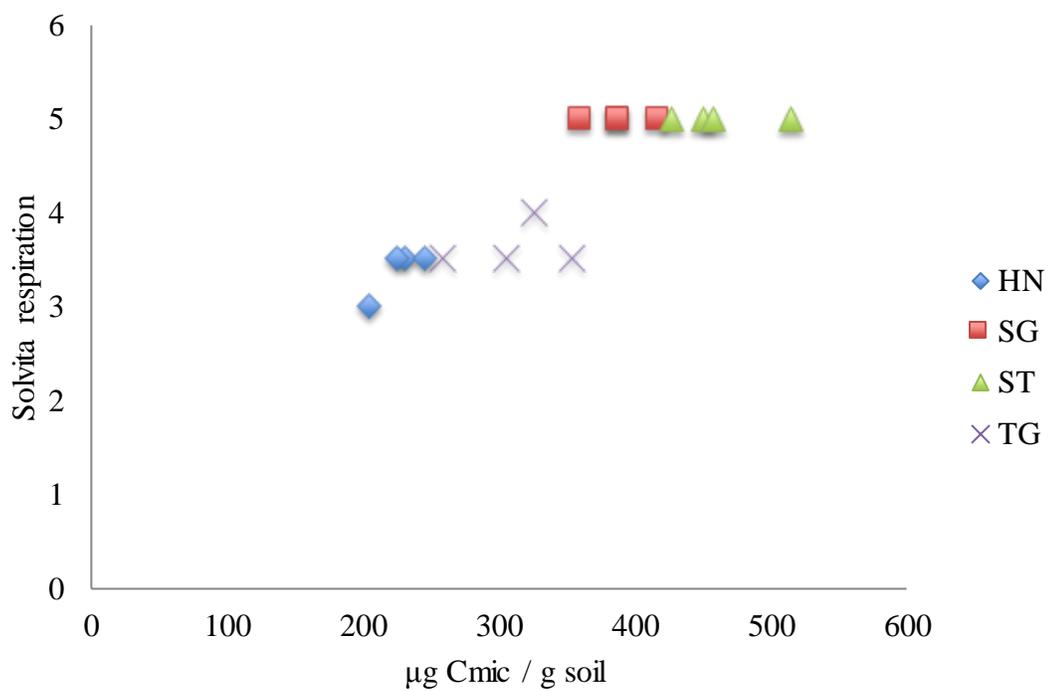


Figure 1. Solvita® respiration correlated with microbial biomass 2014. HN = NPK fertilizers and conventional herbicide with a grass alleyway, SG = straw mulch in the tree row with a grass alleyway, ST = straw mulch in the tree row with a legume (birdsfoot trefoil, *Lotus corniculatus*) alleyway, TG = tillage in the tree rows with a grass alleyway.

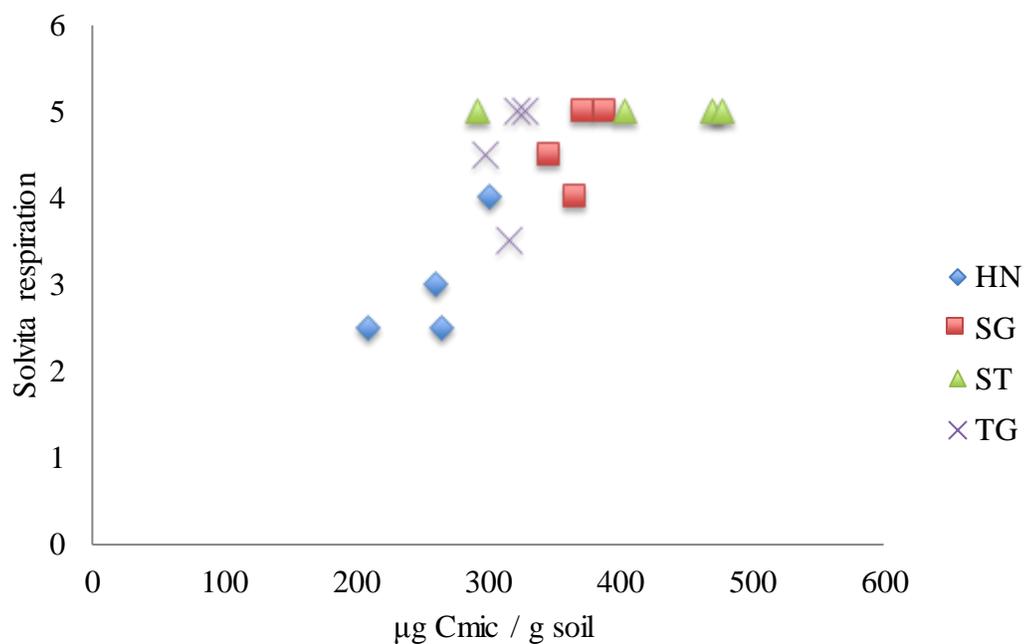


Figure 2. Solvita® respiration correlated with microbial biomass 2015. HN = NPK fertilizers and conventional herbicide with a grass alleyway, SG = straw mulch in the tree row with a grass alleyway, ST = straw mulch in the tree row with a legume (birdsfoot trefoil, *Lotus corniculatus*) alleyway, TG = tillage in the tree rows with a grass alleyway.

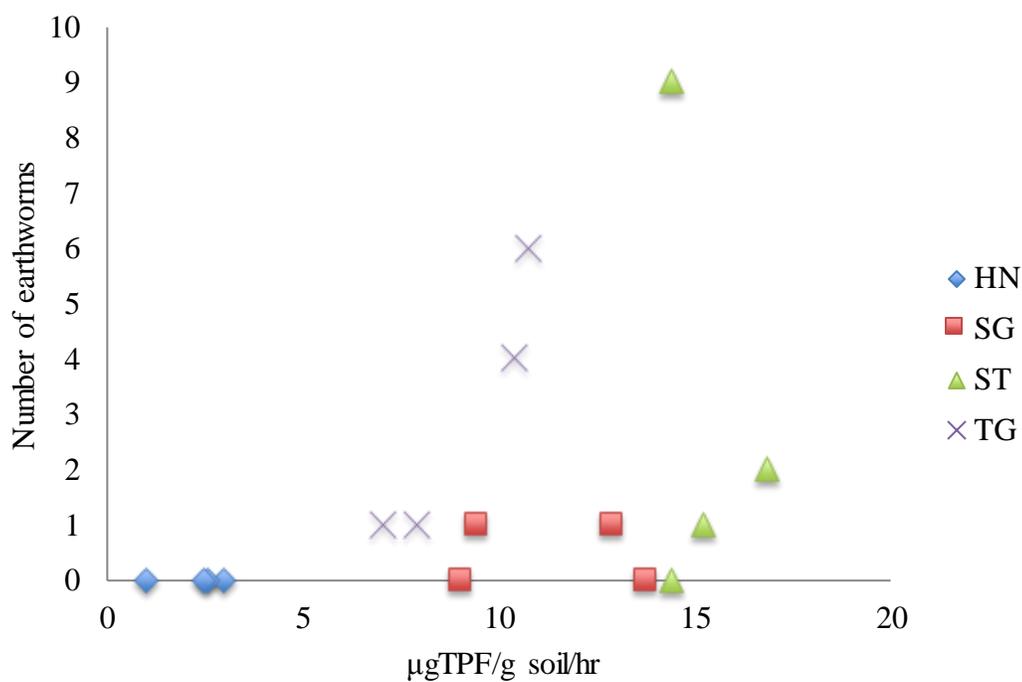


Figure 3. Earthworm abundance test correlated with dehydrogenase enzyme assay as measured by reduction of triphenylformazan per hour per gram of soil in 2014. HN = NPK fertilizers and conventional herbicide with a grass alleyway, SG = straw mulch in the tree row with a grass alleyway, ST = straw mulch in the tree row with a legume (birdsfoot trefoil, *Lotus corniculatus*) alleyway, TG = tillage in the tree rows with a grass alleyway.

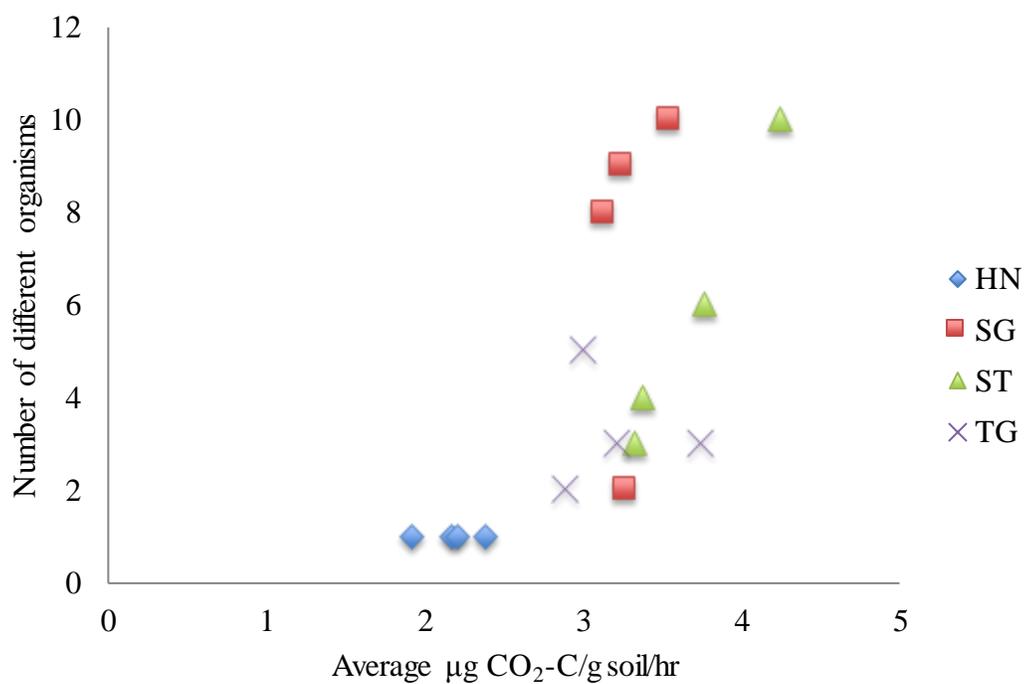


Figure 4. Biodiversity test correlated with laboratory measured soil basal respiration. HN = NPK fertilizers and conventional herbicide with a grass alleyway, SG = straw mulch in the tree row with a grass alleyway, ST = straw mulch in the tree row with a legume (birdsfoot trefoil, *Lotus corniculatus*) alleyway, TG = tillage in the tree rows with a grass alleyway.

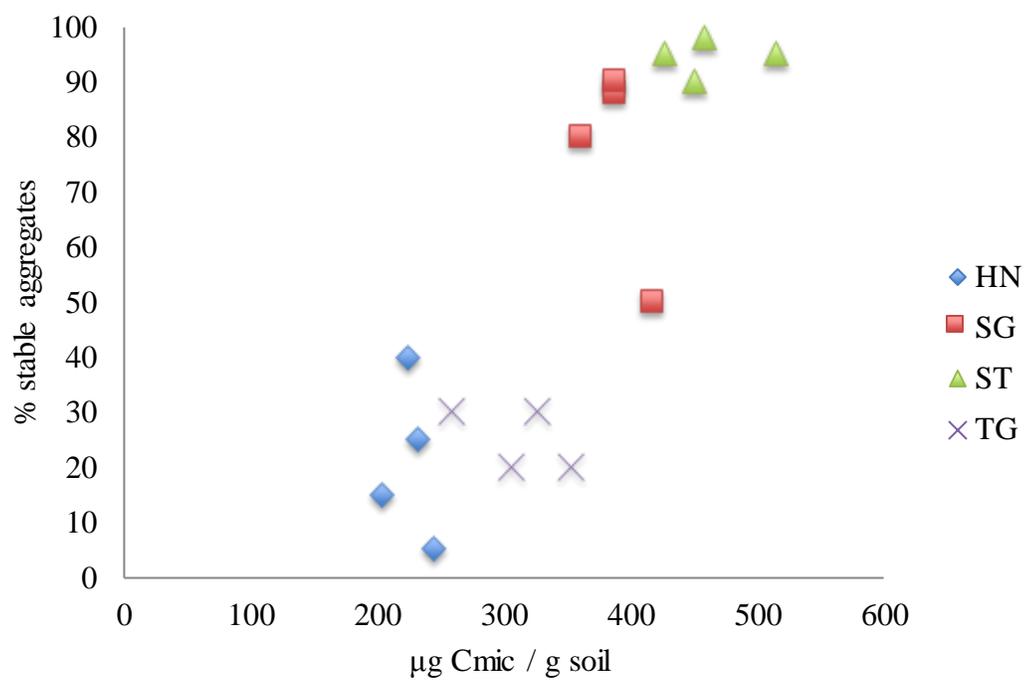


Figure 5. Soil surface test correlated with microbial biomass 2014.

HN = NPK fertilizers and conventional herbicide with a grass alleyway, SG = straw mulch in the tree row with a grass alleyway, ST = straw mulch in the tree row with a legume (birdsfoot trefoil, *Lotus corniculatus*) alleyway, TG = tillage in the tree rows with a grass alleyway.

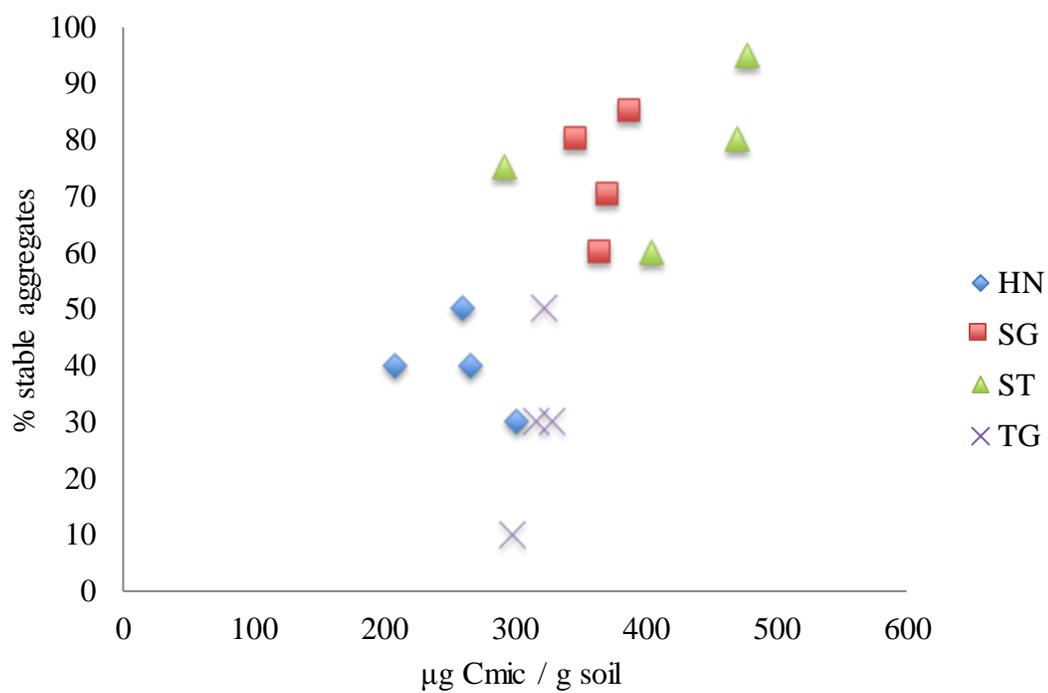


Figure 6. Soil surface test correlated with microbial biomass 2015.

HN = NPK fertilizers and conventional herbicide with a grass alleyway, SG = straw mulch in the tree row with a grass alleyway, ST = straw mulch in the tree row with a legume (birdsfoot trefoil, *Lotus corniculatus*) alleyway, TG = tillage in the tree rows with a grass alleyway.

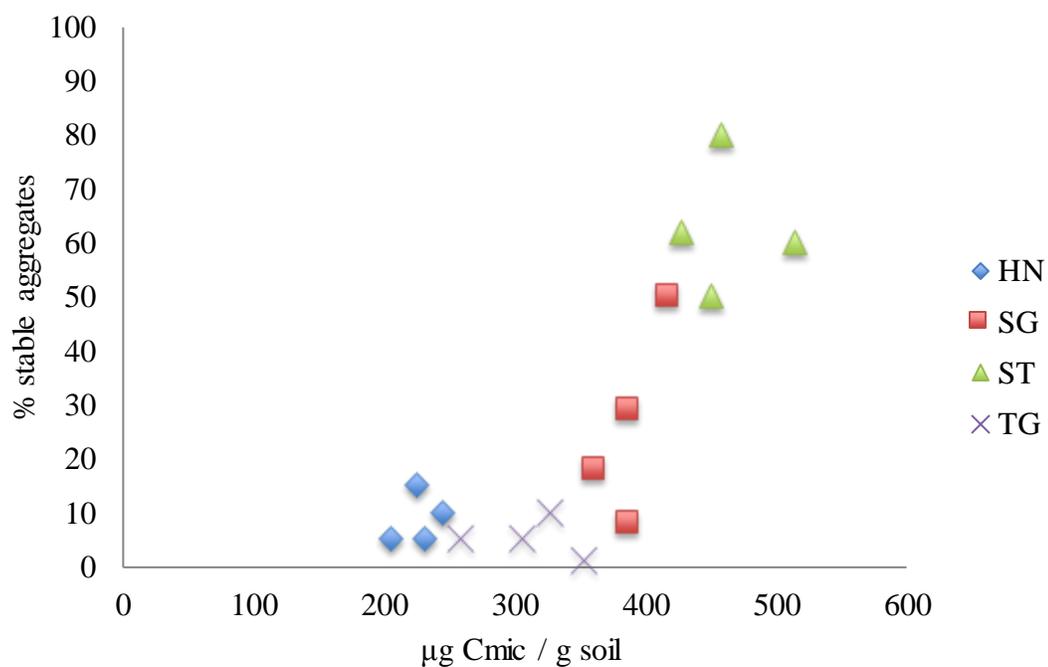


Figure 7. Hose test correlated with microbial biomass 2014.

HN = NPK fertilizers and conventional herbicide with a grass alleyway, SG = straw mulch in the tree row with a grass alleyway, ST = straw mulch in the tree row with a legume (birdsfoot trefoil, *Lotus corniculatus*) alleyway, TG = tillage in the tree rows with a grass alleyway.

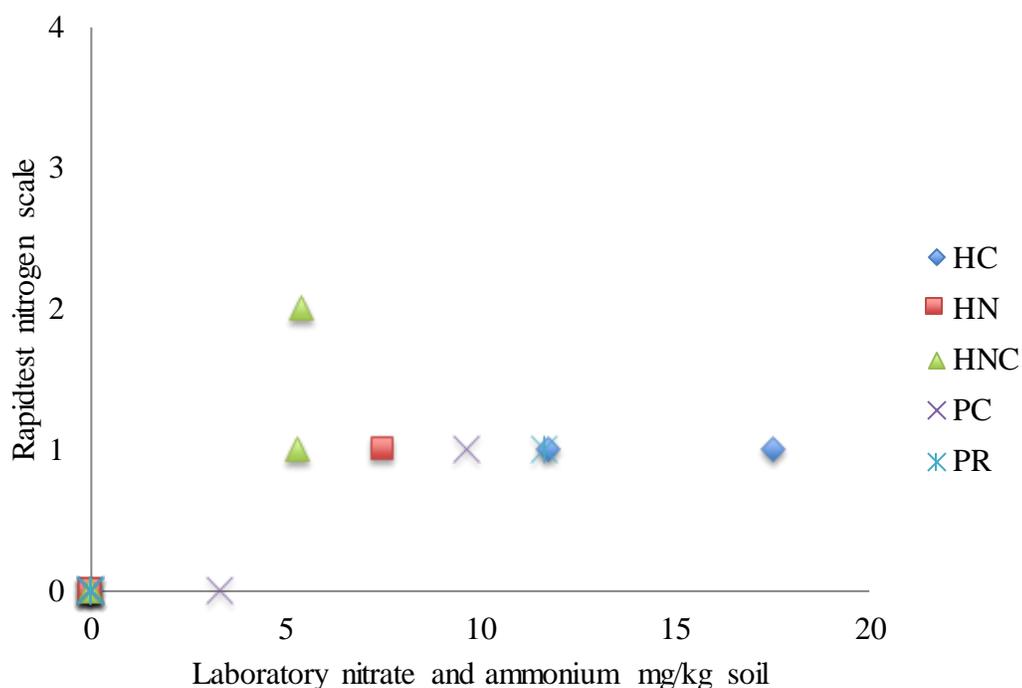


Figure 8. Rapidtest N correlated with laboratory N. The Rapid test scale is limited to four results. The manual only gives recommendations for N and no reference on how much N might be in the soil: 0= 415 - 430 (mL per 30 meters N recommended); 1= 230 – 237; 2 = 111 – 118 ; 3 = N/A. HC = herbicides plus compost for N, HN = NPK fertilizers and conventional herbicide with a grass alleyway, HNC = NPK fertilizers and herbicides, and converted to organic practices after tree establishment, PC = paper mulch, organic herbicide and compost for N, PR = paper mulch with reduced herbicide in addition to NPK fertilizers.

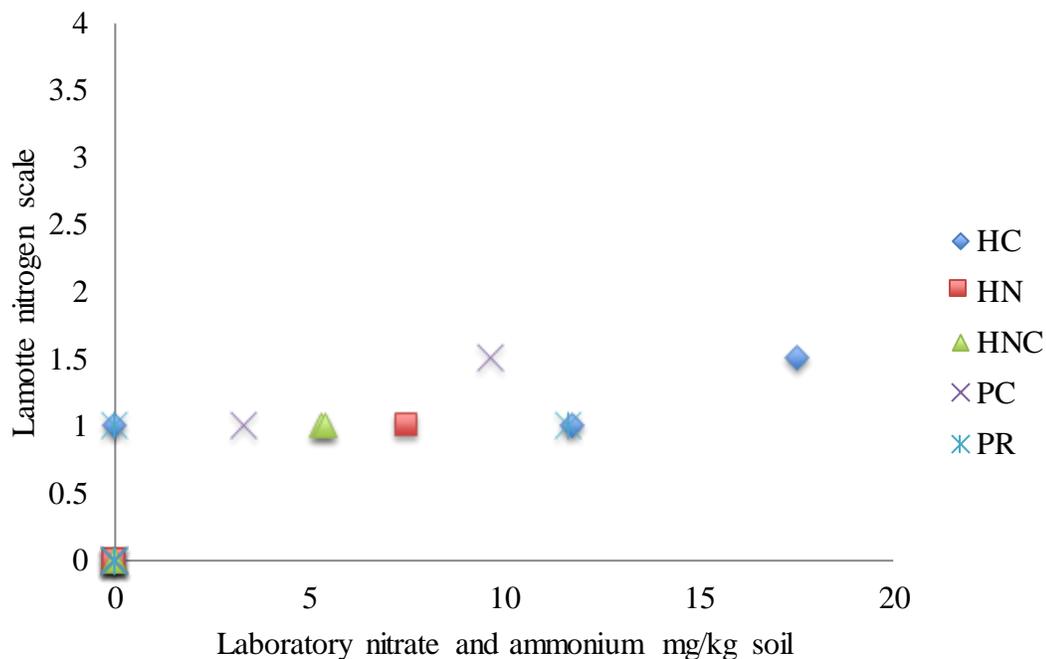


Figure 9. Lamotte N test correlated with laboratory N.

The Lamotte N scale is interpreted as: 1 = 0 – 35 kg / hectare, 2 = 35 – 70 kg / hectare, 3 = + 70 kg / hectare. HC = herbicides plus compost for N, HN = NPK fertilizers and conventional herbicide with a grass alleyway, HNC = NPK fertilizers and herbicides, and converted to organic practices after tree establishment, PC = paper mulch, organic herbicide and compost for N, PR = paper mulch with reduced herbicide in addition to NPK fertilizers.

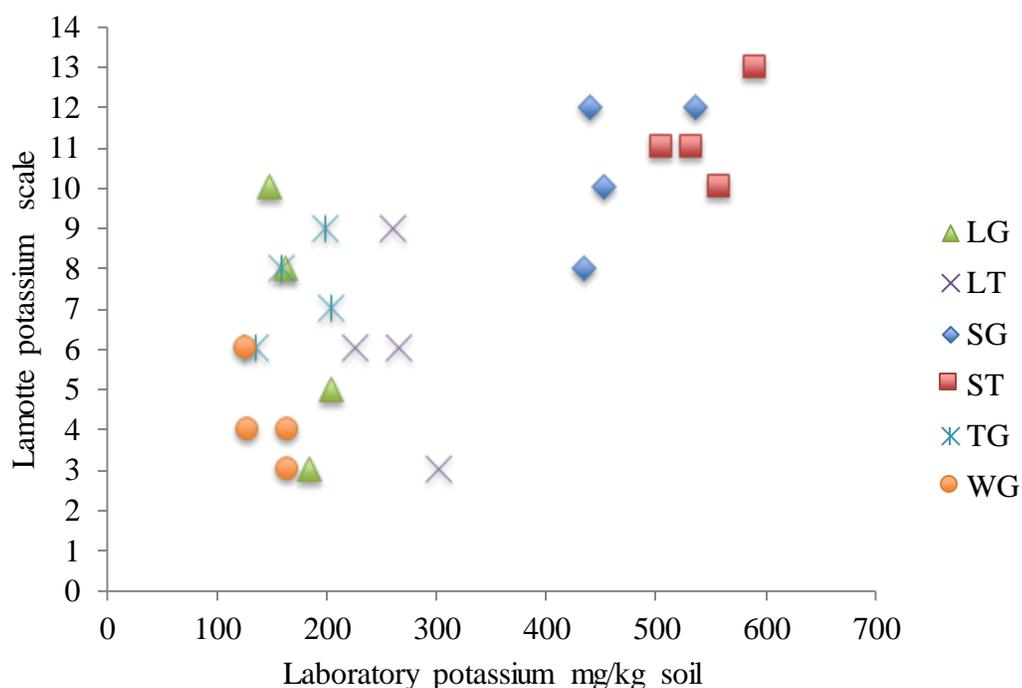


Figure 10. Lamotte K test correlated with laboratory K in the organic orchard. For the Lamotte K scale it is interpreted as: 0 – 136 kg per hectare for Low (1-2), 136 – 227 kg per hectare for medium (3-5), + 227 kg per hectare for high (6+). LG = living mulch (low-growing shallow rooted alyssum, *Lobularia maritima*) in the tree row with a grass alleyway, LT = living mulch in the tree row with a legume alleyway, SG = straw mulch in the tree row with a grass alleyway, ST = straw mulch in the tree row with a legume (birdsfoot trefoil, *Lotus corniculatus*) alleyway, TG = tilled tree rows with a grass alleyway, WG = woven plastic mulch in the tree row with a grass alleyway. All treatments were used to compare the simple chemical tests.

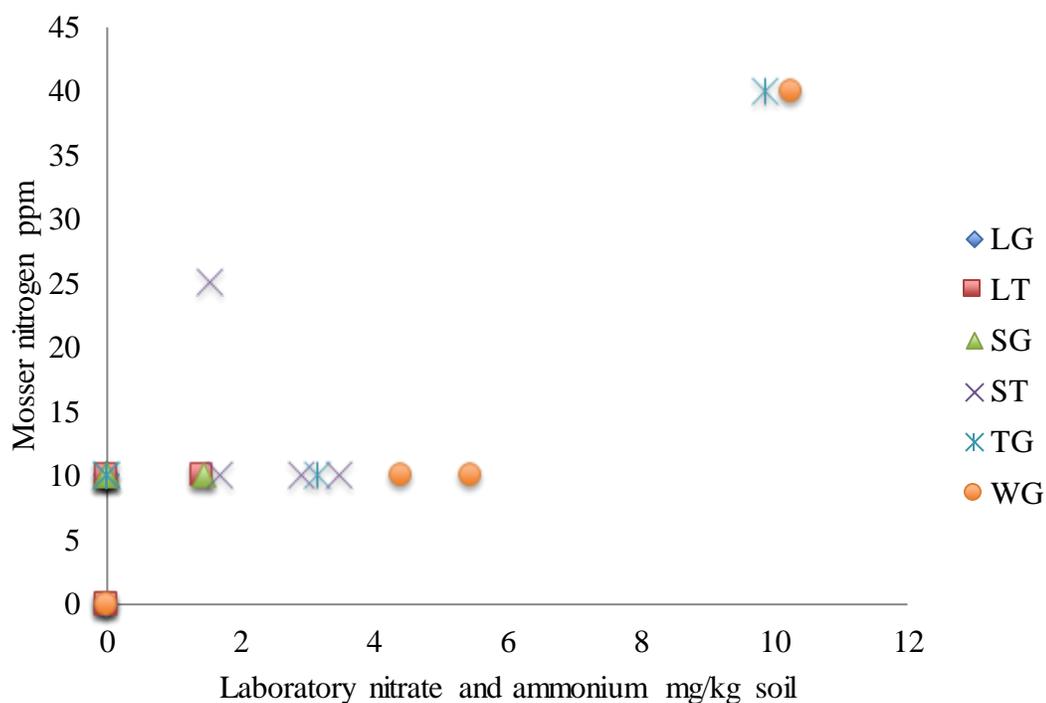


Figure 11. Mosser N test correlated with laboratory N. LG = living mulch (low-growing shallow rooted alyssum, *Lobularia maritima*) in the tree row with a grass alleyway, LT = living mulch in the tree row with a legume alleyway, SG = straw mulch in the tree row with a grass alleyway, ST = straw mulch in the tree row with a legume (birdsfoot trefoil, *Lotus corniculatus*) alleyway, TG = tilled tree rows with a grass alleyway, WG = woven plastic mulch in the tree row with a grass alleyway. All treatments were used to compare the simple chemical tests

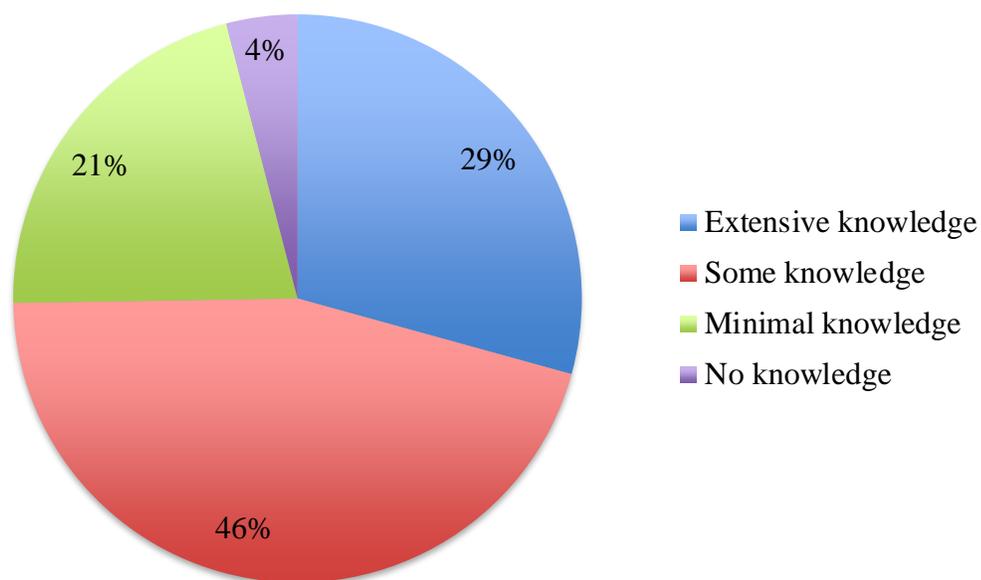


Figure 12. Growers perceptions of their soil testing knowledge. Response to the question: How do you rate your knowledge on soil testing? Responses (101) from survey emailed to USU grower listserv.

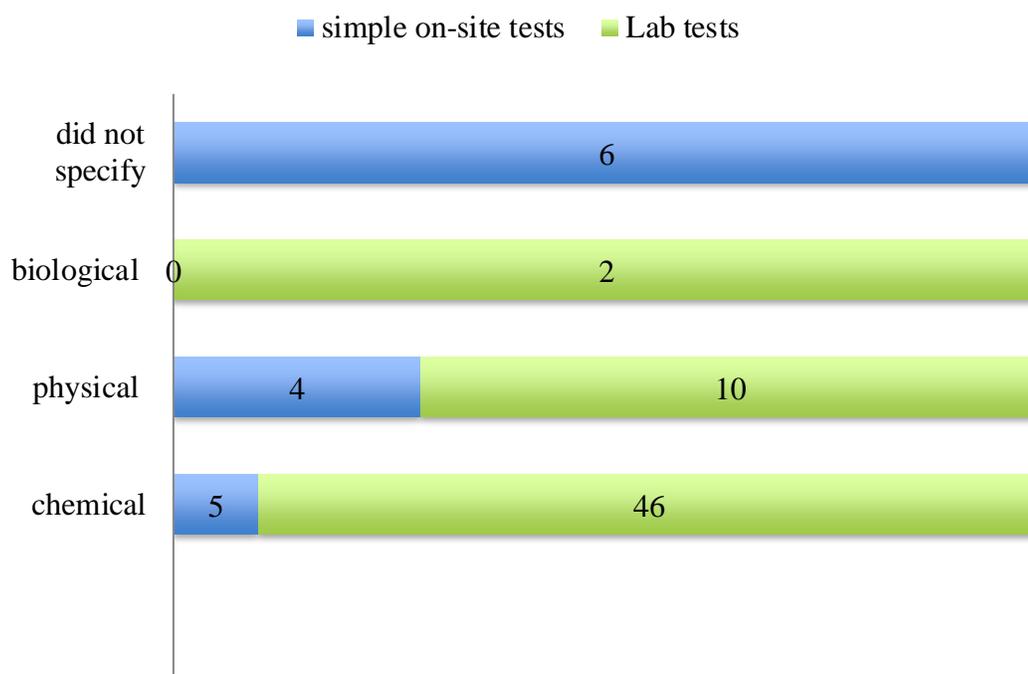


Figure 13. Soil tests growers use to test their soil. Responses (101) from survey emailed to USU grower listserv.

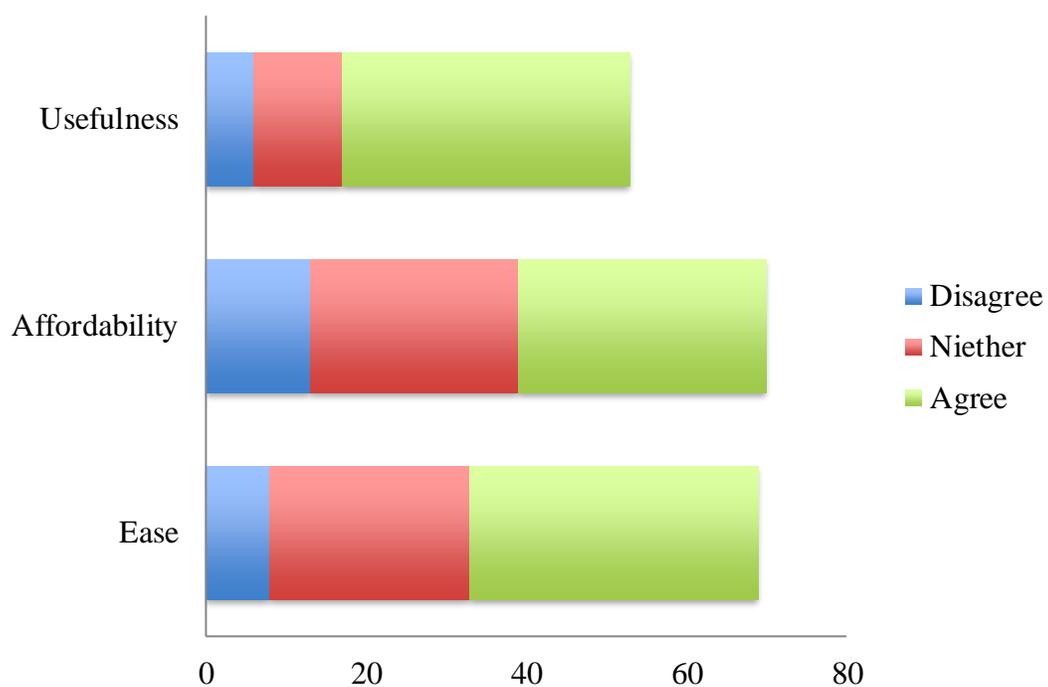


Figure 14. Growers indicate the usefulness, affordability and ease of current soil testing strategies. Response to the question: To what extent do you agree that the following qualities are common traits among current soil tests? Answers are indicated in percentages. Responses (101) from survey emailed to USU grower listserv.

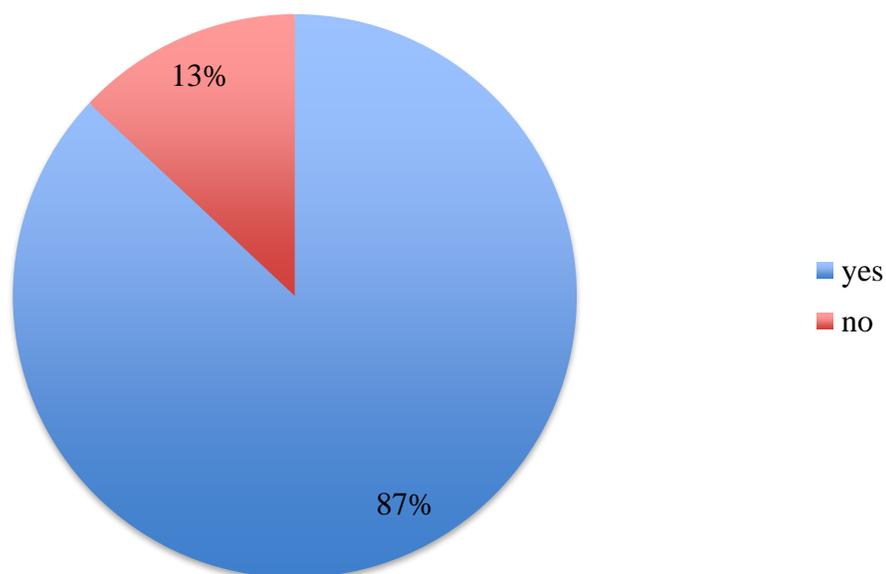


Figure 15. Percent of respondents interested to learn more from researchers on soil quality tests. Responses (101) from survey emailed to USU grower listserv

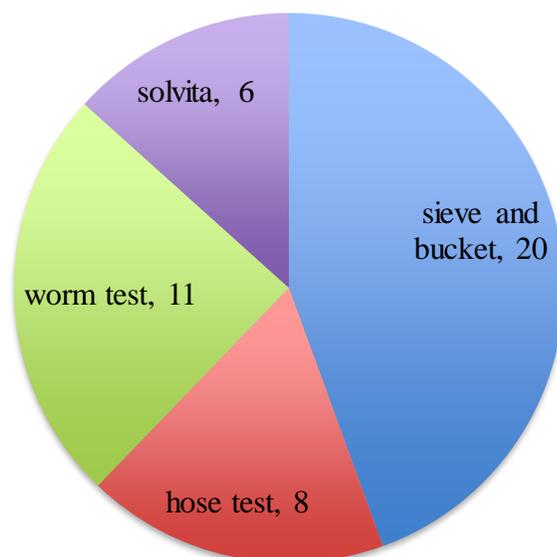


Figure 16. Growers indicate which simple soil tests they would most likely use. The results are from one on one meetings with farmers (7), and demo survey out of 21 feedback forms, some growers indicated more than one option.

CHAPTER III

SIMPLE SOIL TESTS FOR ON-SITE EVALUATION OF SOIL HEALTH IN ORCHARDS: FACTSHEET³

The Importance of Soil Health

Soil health or quality is the ability of a soil to function as a suitable environment for plant growth and to maintain water and environmental quality. Optimal soil health allows for water retention and infiltration, filtering of contaminants, buffering of pH, efficient recycling of nutrients, and maintaining a stable porous structure even under erosive pressures from water and wind. Healthy soil provides habitat for a diversity of soil life, and these diverse life forms can prevent soil borne diseases and help maintain soil properties over a long period of time.

The goal of simple on-site soil health tests is to enable a grower or landowner to track the effects of soil management practices on soil health. This can be achieved by comparing two different management approaches such as a tilled plot to an area covered in perennial vegetation in the same orchard, or testing the same orchard year after year to monitor long-term change in soil health. Keeping track of the physical and biological properties of soil as a complement to traditional measurements of soil fertility can be helpful to overall farm management decisions and may even save the grower money in the long-term through improved soil health. An example of an important soil physical

³ Coauthored by Thomsen E.O., J.R. Reeve, G. Cardon, R. Newhall, and D. Alston

property is aggregate stability, which is the ability of primary soil particles to remain attached under disruptive forces. Aggregate stability tests are specifically useful in addressing a soil's potential for erosion (Kemper and Koch 1966; Kemper and Rosenau 1986). Soil organisms are important biological indicators of soil health as they are rapidly responsive to shifts in management practices (Pankhurst et al. 1997). Soil organisms affect the rate of nutrients decomposition, and can inform to prevent over application of nutrients in efficient systems (Guillard et al. 2015).

Best Soil Testing Practices

For best results, choose soil test sites that represent the main soil textural type present in the orchard or field. It is important to test within the same soil textural type as it can have a greater effect on soil health than management practices. Soils rich in clay form aggregates much easier than soils rich in sand, and also tend to have greater biological activity as the primary particles are of a size that store water and carbon more easily than sandy soils (Franzleubers et al. 1996; Mulder et al. 2011). Sandy soils may show little to no structure at all, as larger primary particles are not as cohesive as smaller primary particles.

If possible choose a neighboring site on the same soil type that has a history of long-term management in perennial vegetation as a comparison. Repeat tests at the same time every year, and preferably at least 2 days after a rainfall or irrigation event to ensure similar soil moisture conditions. Supporting soil health promotes long-term plant and tree health. These tests will help you detect early signs of soil degradation so that remedial actions can be taken in order to help avoid or reduce costs associated with soil erosion

and compaction, increased irrigation and nutrient inputs. Reductions in pest management needs, and plant diseases may also be noticed as soil health improves over the long-term. The following tests include physical and biological parameters. Chemical evaluations of the soil, including N, P, K and pH are best completed by laboratories as simple chemical test kits available on the market are prone to inaccuracies. The following simple soil tests have been tested for their ability to discriminate between soils of different known soil health. They all ranked high when compared to similar lab based tests and were evaluated for ease of use by growers in the field.

Physical Soil Tests

Test #1: Soil Slaking

Fill a large sieve to the rim with un-sieved soil. Remove any rocks and large pieces of organic material. Soak sieve with soil in a bucket of water for 5 minutes, raise the sieve out of the water to let drain, and then slowly raise and lower the sieve 5 times into the water. Take note of the surface texture of the soil. Weaker soil structure will typically show a less varied surface texture, and qualities such as smoothness, shininess and glossiness will tend to be more apparent. Strong soil structure will show a variety of shapes and sizes of soil aggregates—clumps of soil. Rate the soil from 1-10 (see Table 1) based on how much of the surface soil texture appears to have remained the same after the repeated soaking, with one being the lowest health indicator and 10 being highest. Take pictures for a more complete recording of the test, and a way to directly compare soils from year to year. Soils with more stable soil aggregates will typically indicate a

better medium for root growth with more access to oxygen, a greater infiltration and water holding capacity, and a stronger resistance to erosion.

Table 1. Surface structure indicator table. List location of test, general visual features of soil before and after the test under the observations column, and checkmark the number that best fits the test, from 1-10 with 1 being less than 10% surface aggregates visible after repeated soaking of the soil, and 10 being 100% surface aggregates visible after repeated soaking of the soil.

Location	Observations	Soil rating from 1-10	Least desired 1	Mid-level 5	Most preferred 10
			<10% surface aggregates visible	50% surface aggregates visible	100% surface aggregates visible

Example pictures

Figure 1: Loam soil from a peach orchard under tillage for 30 years

Figure 2: Sandy loam from a peach orchard under conventional NPK and herbicide

Figure 3: Loam soil from a peach orchard under long-term undisturbed grass pasture



Figure 1. Least desired (rating=1)



Figure 2. Mid level (rating=5)



Figure 3. Most preferred (rating=10)

Test #2: Hose Test

Take the sieve filled with soil and bring it to a running water source, preferably a hose. Turn the hose on just above medium flow, but not the highest flow setting. It may be helpful to record the number of turns it took to reach the desired flow rate. Hold the sieve about two feet from the hose and spray down the soil in the sieve using circular motions, maintaining an equal distribution of water flow over all surface points of the soil in the sieve. Record the amount of time that 1) all soil is washed away, or 2) the percentage of soil left in the sieve after 1 minute of hosing. Record what is observed, see Table 2. The greater the percentage of soil remaining after hosing the stronger your soil aggregates and likely soil health.

Table 2. Hose test indicator table. List location of test, general visual features of soil before and after the test under the observations column, and checkmark the number that best fits the test, from 1-10 with 1 being less than 10 % of soil volume remaining after spraying of the soil, and 10 being 100 % of soil volume remaining after spraying of the soil.

Location	Observations	Soil rating from 1-10	Least desired 1	Mid-level 5	Most preferred 10
			<10% soil volume remains	50% soil volume remains	100% soil volume remains

Biological Soil Tests:

Test #1: Soil organism diversity test

For the diversity test, you will need a shovel, a large bucket, pen and paper. At your selected soil test site, dig a 1'x1'x1' cube of soil and place into a bucket. Examine a handful of soil out of the bucket at a time and count and record the number of different kinds of soil organisms (examples include, earthworm, centipede, ant, spider, ladybug, etc.) you find before returning the soil to the hole. Once you have sorted through all of the soil in the bucket, record the total number of organisms found for future reference, see Table 3. A soil with greater biological activity will often need fewer inputs, due to more efficient breakdown of organic residues and greater nutrient cycling. More biological activity also increases stable physical soil structure, as residues from organisms help bind soil particles together in aggregates, creating more pores for aeration, water passage and root access. *Note-According to the NRCS if you have more than 10 earthworms in this amount of soil, it is also good indicator.

Table 3. Soil organism diversity test indicator table. List location of test, general observations during the test, and checkmark the number that best fits the test, from 1-6 with 1 meaning 1 or less than one soil organism was found in the designated soil area and 6 being six or more different types of soil organisms were found in the designated soil area.

Location	Observations	Soil rating from 1-6	Least desired 1	Mid-level 3	Most preferred 6
			<1 visible soil organism	3 different soil organisms	>6 different soil organisms

Test #2: Solvita® test

Solvita® soil respiration test kits can be purchased from Woods End Laboratory at the link below. Fill the Solvita® test cup with soil to the indicated line. Put an unwrapped gel-probe narrow side down into the soil and close the lid. Let the closed cup sit for 24 hours at room temperature. After 24 hours open the container and match the color on the probe to the closest color on the indicator chart. Record the number corresponding to the color on the indicator chart, see Table 4.

If respiration is high, it's typically a good sign, meaning that your soil has a lot of organisms, and possibly also has good biodiversity which is beneficial to nutrient cycling and can help reduce crop pests and diseases. If respiration is high, yet the color of the soil is lighter, and organic material is not typically added, it could be an indication that your soil is depleted in organic matter, and may benefit from organic matter additions in the form of cover crops, composts or mulches.

If soil respiration is low, it is typically a sign your soil is low in organic matter. Soil structural properties and turnover rate of nutrients would be improved with small, regular additions of organic material to help restore a healthy population of soil organisms. Other practices that can be helpful are reducing tillage practices or incorporating cover crops into your system.

Table 4. Solvita® soil respiration indicator table. List location of test, general observations during the test, and checkmark the number that corresponds to the number associated with the best matched color to your probe after 24 hours. The scale is from 1-5 with 1 being the lowest available recording for soil respiration (CO₂) and 6 being the highest available recording for soil respiration (CO₂).

Location	Observations	Basal respiration ----- > most preferred		
		1	2.5	5

Further information for ordering the Solvita® test kit and interpreting your results can be found at the following website. : <http://solvita.com/soil/basal-co2-guide>

Summary

Less than optimal soil quality can promote erosion, poor water holding capacity and infiltration, and will likely need more inputs for optimal productivity. Soil quality tests, can help land managers compare the effects of land management practices and gauge over a period of time whether soil health is being maintained, improved or depleted. Timely recognition of soil health problems can be recognized and corrected before soil health worsens to the point that significant negative impacts on crops occur.

Practices that are helpful for maintaining and improving soil quality or health are additions of organic matter through mulch, compost or manure; reducing the frequency or extent of tillage; and incorporating cover crops and or more perennials into a system. Cover crops can be planted after the main crops have been harvested as a fall/winter cover crop, they can also be planted as buffer strips, companion plants and or understory plants. Maintaining or improving soil health will improve the bottom line for growers in

the long-term by reducing the need for inputs such as water and fertilizers and improving yields.

Related Factsheets:

Preparing Garden Soil:

https://extension.usu.edu/files/publications/factsheet/HG_H_01.pdf

Soil Testing Guide for Home Gardens:

https://extension.usu.edu/files/publications/factsheet/HG_H_05.pdf

Understanding your Soil Test Report:

http://extension.usu.edu/files/publications/publication/AG_Soils_2008-01pr.pdf

Preparing and Improving Garden Soil:

https://extension.usu.edu/files/publications/factsheet/pub_8066784.pdf

References

- Franzluebbers, A.J., R.L. Haney, F.M. Hons, and D.A. Zuberer. 1996. Active fractions of organic matter in soils with different texture. *Soil Biology and Biochemistry*, 28(10–11): 1367–1372. doi:10.1016/S0038-0717(96)00143-5
- Kemper, W.D., and E.J. Koch. 1966. Aggregate stability of soils from the western portions of the United States and Canada. Washington, D.C.: USDA Tech. Bull. 1355. U.S. Government Printing Office.
- Kemper, W.D., and R.C. Rosenau. 1986. Aggregate stability and size distribution. methods of soil analysis, part 1. Physical and Mineralogical Methods-Agronomy Monograph no. 9 (2nd Edition).
- Mulder, C., A. Boit, M. Bonkowski, P.C. De Ruyter, G. Mancinelli, M.G.A. Van der Heijden, M. Rutgers. 2011. A Belowground Perspective on Dutch Agroecosystems: How Soil Organisms Interact to Support Ecosystem Services. In Guy Woodward (Ed.), *Advances in Ecological Research*, 44: 277–357. Academic Press.
- Pankhurst, C.E., Doube, B.M., and Gupta, V.V.S.R. 1997. Biological indicators of soil health: synthesis. In *Biological Indicators of Soil Health*, eds, C.E. Pankhurst, B.M. Doube, and V.V.S.R. Gupta, 419-435. New York, New York: CAB International.

CHAPTER IV

STRATEGIES FOR MANAGING SOIL FERTILITY AND HEALTH IN ORGANIC ORCHARDS: A FACTSHEET⁴

Introduction

Soils in the Intermountain West are typically shallow, calcareous and are low in native organic matter. Low organic matter translates to less nutrient reserves for plants. Calcareous soils have a relatively high pH that can lead to trace element deficiencies. Some Utah soils have a high salt content that can be toxic to plants. These potential constraints require the organic fruit grower to pay particular attention to soil health and fertility. Utah State University faculty at the Utah State Horticultural Research Farm in Kaysville have been conducting research on methods in transitioning to organic management and in improving orchard soil health. A primary focus of this research is to provide growers with locally adapted advice and solutions for managing soil fertility in certified organic stone-fruits.

Transitioning to organic management

Organic certification requires a three-year period of organic-only management prior to organic labeling. A sufficient supply of soil nutrient reserves is necessary to a

⁴ Coauthored by Thomsen E.O., C.M. Culumber, J.R. Reeve, G. Cardon, D. Alston, B. Black

successful organic soil fertility management plan. In organic systems, nutrients are made available to the plant through the process of organic matter mineralization. Mineralization is the break down of organic residues into readily available nutrients (such as ammonium, nitrate, phosphate and potash) for plants. When transitioning to organic practices it is important to gradually build up organic levels in the soil. When soluble fertilizers such as urea or ammonium sulfate are withdrawn from a system, trees can rapidly become nutrient deficient and stop growing if there is insufficient mineralization of soil organic matter occurring to fill the gap. This is known as the transition effect. Ideally, a grower would start adding compost to the tree row a year or two before starting the transition process. The exact rate of this mineralization process can be difficult to predict because it depends on the type of residues used, soil moisture levels, and soil temperature.

Very young trees require fewer nutrients, so soil fertility can be built up over two or three seasons as they grow. A young orchard can be established in a former pasture or hayfield in order to eliminate the need to actively build soil fertility prior to the organic transition period. Soil organic matter and soil structure are always greatly improved after a period in pasture or hay. The growth and decay of perennial roots effectively builds organic matter deep in the soil profile and loosens dense layers.

Once soil organic matter is sufficient to sustain vigorous tree growth the orchard enters a maintenance phase. Organic nutrients need to be added in sufficient proportions to maintain growth and avoid deficiencies or excess nutrient buildup. This can prove challenging at times with limited budgets, product availability and time. Hence, the

importance of developing a long-term soil health management plan based on product availability, budgets and soil condition.

Building soil organic matter and providing appropriate nutrients

The six major nutrients derived from the soil are nitrogen, potassium, phosphorus, sulfur, calcium and magnesium. The nutrients needed in the largest quantities for crop growth are nitrogen, phosphorus and potassium. The most important of these is nitrogen especially on sandy or gravelly soils where deficiency is more prevalent.

Cover crops, mulches, and composts are important organic amendments. They can provide all of the major and minor nutrients necessary for tree growth, and buffer roots against extreme weather conditions such as drought and excessive rain. In order to support soil health, i.e. beneficial organisms that maintain nutrient mineralization and soil structural properties, it is helpful to reduce practices that harm soil structure, such as tilling. Tillage can reduce weed pressure and enhance the availability of nutrients. However, overtime it disturbs soil aggregates and compacts the soil, which reduces aeration, water holding capacity and compromises soil biodiversity.

Organic amendments should also not be overapplied. Conventional agriculture is often blamed for inefficiency of nutrient inputs and hence loss to the environment. However, organic agriculture can also result in water contamination or nutrient deficiencies/excess when organic composts and fertilizers are applied in excess. It takes time to build up the necessary nutrient reserves for competitive crop growth when switching to an organic operation from a conventional one. However, once these nutrients, in particular phosphorus, are sufficient, fertilizers should be applied only at a maintenance level to avoid excessive build up of nutrients in the soil. In dry climates such

as in Utah and the Intermountain West, excessive use of composts and manures can also rapidly contribute to salt buildup in the soil with negative effects on crop growth. Check the nutrient status and salinity of your soil with regular soil tests.

Nitrogen

Nitrogen is commonly the most limiting nutrient for trees. A deficiency in nitrogen will cause stunted growth and yellowing of older leaves. Manure, leguminous cover crops and compost are a few examples of nitrogen rich materials to incorporate into a management plan

In conventional agriculture, nitrogen is typically applied in its most soluble form--urea or ammonium nitrate, ranging from 30-40 % available nitrogen. In comparison, organic fertilizers are comprised of only 1-15 % total nitrogen with an even lower percentage of that nitrogen immediately available for crop growth.

Due to the limited amount of nitrogen readily available to plants in organic materials upon application, it can be a common mistake to apply these fertilizers in excess in order to meet the crops immediate needs. Over application of nitrogen fertilizers—such as compost and manure--in dry climates such as Utah and the Intermountain West, can leave soils with excess salts. This can contribute to impaired nutrient cycling, and overall reduced crop production (Stamatiadis et al. 1999). The ratio of nitrogen to phosphorus of many organic fertilizers is also often mismatched to plant needs. Plants typically require five parts of nitrogen for every part of phosphorus. However, many organic fertilizers such as manures and composts have a nitrogen to phosphorus ratio of two to one or less. Applying compost and manure to meet nitrogen

levels can quickly lead to excess phosphorus buildup in the soil which creates more nutrient problems to resolve for crops and trees, and will be discussed more in the phosphorus section below.

When choosing a nitrogen source, consider the percentage of nitrogen, the ratio of nitrogen to other nutrients, and the immediate, short and long term bioavailability of nitrogen. Bioavailability of nitrogen is dependent on multiple characteristics including soil type and weather, so this factor is relatively variable and challenging to predict. Typically the organic fertilizer with the highest percentage of soluble nitrogen is chicken manure. Alfalfa hay is also commonly found to contain relatively high amounts of total nitrogen (Sideman 2007). Growing alfalfa or other taprooted legumes such as Birdsfoot trefoil in the alleyways next to the tree rows is a great way to make use of this great nitrogen source; more about this will be discussed in later sections. Feather meal and blood meal have some of the highest proportions of readily available nitrogen per pound among organic amendments. These products are often more expensive, hence are likely best used as a supplement to other fertilizer sources. Table 1 shows the nitrogen, phosphorus and potassium ratios as well as typical cost both on a total nitrogen and per pound nitrogen basis.

Product	N	P2O5	K2O	Dollars per pound	Dollars per pound N
Alfalfa Meal	2.5	0.5	2.0	0.70	28.00
Blood Meal	12.5	1.5	0.6	1.19	9.52
Corn Gluten Meal	9.0	0.0	0.0	0.77	8.56
Cotton Seed Meal	6.0	0.4	1.5	0.70	11.67
Feather Meal	13	0.0	0.0	0.66	5.08
Composted Chicken Manure	3.5	2.0	2.0	0.07	1.71
Composted Steer Manure (Miller's)	2.0	0.8	0.8	0.07	2.80
Composted Yard Waste	1.2	0.2	0.2	0.05	3.33
Alfalfa Hay	2.5	0.5	2.0	0.05	2.00

Table 1. Common organic materials and their C:N ratios.

Note: ratios taken from WSU extension-
http://whatcom.wsu.edu/ag/compost/fundamentals/needs_carbon_nitrogen.htm

Essentially the choice of fertilizer depends on the immediate nutritional needs of the orchard, and what needs can be met in the course of a few weeks, months and years. The C:N ratio can help determine the best fertilizer choice. Typically the higher the C:N ratio, the longer it takes for the materials to break down and the nitrogen to be released. If the ratio exceeds 25-30:1, it does not provide adequate nitrogen in the short term. The nitrogen will actually be immobilized by soil organisms using it to decompose the carbon. Such materials are best composted or applied to the surface of the soil as mulch. Table 2 provides typical C:N ratios for common organic materials. For exact soil measurements send compost to a certified soil testing lab.

Table 2. Typical organic fertilizers with average nutrient contents and costs per unit and unit N.

Product	C:N
Food Scraps	15:1
Alfalfa Hay	18:1
Grass clippings	19:1
Oak leaves	26:1
Varied leaves	60:1
Corn stalks	60:1
Straw	80:1
Pine needles	85:1
Alder Sawdust	134:1
Newspaper	170:1

Note: Fertilizer nutrient estimates are sourced from the Oregon State University Fertilizer Calculator or from analyses conducted at Utah State University. Prices are quotes obtained from local suppliers in Logan Utah.

Phosphorus

Phosphorus is also needed for plant and tree growth in relatively large quantities. A deficiency in phosphorus will stunt growth, limit yields and fruit quality. Chicken manure and bone meal are both good sources of bioavailable phosphorus. Phosphorus is known to accumulate in soils over time with excess use of composts and manures. It is important to switch to a fertilizer with less phosphorus once soils have an adequate supply. Phosphorus in excess can cause nutrient deficiencies; essentially it can block the plant from absorbing key elements such as zinc and iron (Provin and Pitt 2005). Growing nitrogen fixing cover crops is an effective way to supplement soil nitrogen without building up phosphorus levels. If nitrogen needs are high the affordability of applying fertilizers with zero or limited phosphorus can be a challenge. Table I indicates that

composted manure has the highest ratio of phosphorus compared to nitrogen. Products with the lowest ratio of phosphorus to nitrogen include feather meal, and corn gluten meal. Both products are comparable in terms of their cost, with feather meal costing slightly less than corn gluten meal. Products with higher ratios of phosphorus to nitrogen can be used to largely meet phosphorus needs, while products with little to no phosphorus can be used to fulfill the plants remaining nitrogen needs.

Potassium

Potassium aids the plant's ability in regulating efficient water use, and CO₂ uptake. Potassium levels in unleached Intermountain desert soils tend to be high, yet can become depleted as plants use it and in heavily irrigated areas. Generally, providing sufficient nitrogen and phosphorus for crop growth through organic fertilizers will also provide sufficient potassium. Potassium can build up due to excess additions of organic matter, which can interfere with calcium uptake by trees, negatively affecting fruit quality. The amount of potassium needed is best determined by a soil test.

Secondary nutrients and trace elements

Sulfur, calcium, and magnesium are secondary nutrients and boron, iron, manganese, copper, molybdenum, chlorine, and zinc are needed in trace amounts. The most common micronutrient deficiencies on alkaline soils in the Intermountain west are zinc, iron and manganese (Swift 2009). Organic amendments typically will have sufficient levels of all of these nutrients needed for crops. However, it is still a good idea to obtain soil tests to expose any nutrient deficiencies as trace elements can be limiting in

high pH soils. Trace element deficiencies may be best ameliorated through foliar feeding. It is also important to recognize that excessive amounts of organic matter additions can lead to nutrient imbalances and trace element deficiencies.

Soil testing

Soil testing is the best way to find out exactly which nutrients are needed. Soil tests can provide the information needed to prevent nutrient deficiencies or surpluses from negatively impacting the crop. Regularly checking the nutrient status of cropland soils is the best way to save money from unnecessary amendments or diagnose potential deficiencies before they start to impact crops. For example, an excess of phosphorus can promote deficiencies of other nutrients, like iron and zinc. Adding iron and zinc to the soils, will not remedy the problem of deficiencies in the trees. If soil phosphorus becomes excessive it is advisable to replace manures and other phosphorus rich fertilizers with fertilizers low in phosphorus such as feathermeal and bloodmeal or nitrogen fixing cover crops, until soils return to equilibrium. In cases where trace elements are severely limiting zinc and iron foliar sprays will need to be applied. Another very important reason for soil testing is to ensure that excessive nutrient loads do not contaminate local water supplies.

Most nutrients can be easily determined from a soil test. Some nutrients, such as nitrogen are better tested through foliar tests or samples of root zone soil. Surface soil samples don't adequately identify the availability of nitrogen due to the fact that nitrogen is readily mobile in the soil. Since the mobility of phosphorus and potassium is

significantly less than nitrogen, effective monitoring of these elements can be done through soil tests alone.

Cover crops

Cover crops or living mulches can reduce dust and mud, increase soil stabilization, suppress weeds, add organic matter (Hartwig and Ammon 2002) and improve biological activity (Hoagland et al. 2008). Legume cover crops fix atmospheric nitrogen and can reduce the need for purchased nitrogen inputs considerably (Reeve et al. 2013). Applying organic fertilizers based on phosphorus needs and using nitrogen fixing cover crops to supply the additional nitrogen needed may be the most cost effective and ultimately sustainable approach to organic soil fertility management.

Also consider the timing of the nitrogen release from the legumes. The release of nitrogen from the legumes takes place all season. Delayed tree dormancy is a possible outcome of this late release of nitrogen. It could be less of a concern in Utah, especially on shallow sandy soils. In Utah, it's common for growers to actually apply some nitrogen at the end of the season to increase tree vigor.

Mulches

Non living mulches can be a great way to control weeds, contribute to long-term soil nutrient reserves, and potentially conserve soil moisture.

- Applying recycled paper to plots according to Hogue et al. (2010) decreased weed pressure, and had a positive effect on tree growth and yield. However, similar research in Utah found that paper mulch decreased tree growth under organic management due to nitrogen immobilization.

- Wood chips have been found to reduce water loss and increase tree growth, yet have also been found to result in reduced available nitrogen in the soil (Hoagland et al. 2008), in addition to being a potential source of imported weed seed (Rowley et al. 2011)
- Alfalfa Hay Mulch – Stefanelli et al. (2009) found an increase of foliar nitrogen and higher cumulative yield in apple (compared to flame burning and shallow strip tillage using the Swiss sandwich system).
- Weed fabric has proven to be a great weed suppressant for sweet cherry (Nunez-Elisea et al. 2005) although Nielsen and Hogue (1992) found that it created dramatic reductions in potassium in apple orchards. Research in Utah has shown excellent weed suppression and tree growth with weed fabric, although it must be removed from the bases of young trees in winter to prevent girdling by rodents.
- Straw mulch—may provide moisture retention as well as a slow release of nutrients to the tree. No benefits were observed using straw mulch in Utah over the course of a six-year study, so the cost may not be justified. If using straw, obtaining a weed free source is important and can be a challenge.

Possible organic management systems

At the Organic Systems research plots at the Utah State University Horticultural Research Farm in Kaysville, Utah, researchers are developing management strategies for the production of stone fruits in the Intermountain West. Cover crops were used initially for building the soil at the USU Horticultural Research plots prior to the peach orchard.

Broadleaf, grass and legume cover crops were grown in order to increase soil organic matter.

After the succession of cover crop plantings, the area was tilled, and trees were planted. Six different treatments were implemented: 1) straw mulch in the tree row with a grass alleyway 2) straw mulch in the tree row with a legume (birdsfoot trefoil, *Lotus corniculatus*) alleyway; 3) living mulch (low-growing shallow rooted alyssum, *Lobularia maritima* (which quickly transitioned to mowed weeds) in the tree row with a grass alleyway; 4) living mulch in the tree row with a legume alleyway; 5) woven plastic mulch in the tree row with grass alleyway; 6) tilled tree rows with a grass alleyway.

All treatments with mulches in the tree row used a swiss sandwich tilling system—a 12-inch tilled separating the tree row from the alleyway. Compost and feathermeal were applied directly to the tilled strips and incorporated, allowing the tree to readily access these nutrients without leaving too much bare soil exposed to the processes of erosion.

Legume cover crops grown in the alleyway in combination with mowed living mulches or weeds in the tree row have proved the most favorable management strategy at the USU Horticultural Research orchard plots in Kaysville. Especially as Birdsfoot tree foil (leguminous crop used) proved to be a successful alternative to aggressive weed control strategies (Reeve et al. 2013). Not only can cover crops provide weed suppression as well as keeping soil structure intact but they also provide nutrients to the trees. In fact, tree growth in the plots with legume alleyways (despite weed pressure in the tree row) were comparable to plots with good weed control (tillage and weed fabric) and exceeded tree growth in plots with grass alleyways and straw or living mulch treerows. Previous

research has shown legumes to be competitive with trees when planted in the tree rows with grass alleyways. Grass alleyways have been shown to restrict tree root growth to the tree row making weed control much more critical. Taprooted legumes such as alfalfa and birdsfoot trefoil may be much less competitive with tree roots. Also leguminous crops, especially alfalfa may use more water than grass. Birdsfoot trefoil can be difficult to establish due to very slow early growth, but is more shade tolerant than alfalfa and hence is likely to persist better in the orchard environment. Woven plastic mulch was another favorable strategy as tree growth in fabric plastic mulch plots was equivalent to tree growth in tilled plots. The disadvantage to fabric plastic mulch is it can be labor intensive. At the USU Horticultural Research orchard plots the fabric plastic mulch is rolled back every November to prevent rodent activity and put back into place in March after fertilizer has been applied. Organic herbicides were found to be ineffective against the perennial weeds typical at the USU Horticultural Research orchard. Organic herbicides are contact herbicides and generally much less effective than conventional herbicides as well as much more expensive

Chicken and or steer manure compost was used to meet nitrogen needs of the orchard in the early years. Due to rapidly rising phosphorus levels in the USU Horticultural Research orchards in Kaysville, the amount of compost was limited to 3-5 lb dry weight per tree after the third year. Supplemental nitrogen was supplied in the form of an organically approved feather meal product (Reeve et al. 2013). The feather meal used has an N:P ratio of 13:0, making it a very valuable resource for producers who may have adequate to high levels of phosphorus in their soils. Ongoing research will

determine whether nitrogen from Birdsfoot trefoil is sufficient to meet the needs of mature peach trees when planted in the orchard alleyways.

Table 3. Compost characteristics from 2008 to 2011
2008=chicken manure; 2009, 2010, 2011 = composted steer manure

Characteristic	2008	2009	2010	2011
Total N	1.89	1.46	2.25	2.18
C:N Ratio	7:1	13:1	12:1	12:1
P2O5	-	0.34	1.00	0.66
K2O	-	0.64	1.63	1.60

Table 3 shows the percentage of nitrogen, phosphorus and potassium in the compost applications for three years. It also gives the carbon and nitrogen ratio, in 2008 the ratio was the lowest, meaning the nitrogen would be quicker to decompose into the soil. Table 4 shows the sources and amounts of nitrogen inputs per tree in each orchard floor treatment.

Table 4. Nitrogen Inputs 2011 average nitrogen inputs for compost, feather meal, and alleyway biomass amendments for six different orchard floor treatments: living mulch tree row with grass (LG) or legume (LL) alleyway, non-living mulch tree-row with grass (NG) or legume (NL) alleyway, and tillage (TG) or weed fabric (WG) with grass alleyways.

Orchard floor treatment	Compost N per tree (lb.)	Feather meal N per tree (lb.)	Biomass N per tree (lb.)	Total average N inputs (lb.)
LG	0.11	0.170a	0	0.282b
LL	0.11	0.146b	0.229	0.487a
NG	0.11	0.152ab	0	0.265b
NL	0.11	0.141b	0.238	0.492a
TG	0.11	0.099c	0	0.212c
WG	0.11	0.110c	0	0.223c

Note: Different letters indicate significant differences at $p \leq 0.05$.

Conclusion

There are many possible ways to successfully manage orchards organically in the Intermountain West. The dry climate reduces pest pressure and the warm days and cool nights provide perfect conditions for growing high quality fruit. Careful consideration should be given to crop nutrient management and tailored for each specific site in question.

Covering the tree rows with non-living mulch such as straw or woodchips provides a good alternative to weed management and may increase moisture retention in this arid environment. The downside is that mulches can be expensive and not always effective at preventing weeds in the late season. They can also be a source of new weed seed imported into the orchard. Planting legumes in the orchard alleys, perhaps, is the most affordable and least labor-intensive method of increasing soil nitrogen and tree growth. Incorporating compost into small tilled strips (the Swiss Sandwich system) next to the trees to supply the additional nutrients needed, will limit disturbance to the soil structure. To further save on costs, find locally abundant inputs during seasons that they are at their best price. Regular soil testing will help prevent nutrient deficiencies and excesses that may negatively affect crops and/or pollution to the surrounding environment.

Organic agriculture in the Intermountain West is an enterprising development.

Best approaches are being researched and markets are expanding. There are many new avenues for growth and niches to be made.

For more on Floor Management of Orchards, visit:

http://extension.usu.edu/files/publications/publication/Horticulture_Fruit_2012-01pr.pdf

References

- Cooperband, L. 2002. Building Soil Organic Matter with Organic Amendments. Center for Integrated Agricultural Systems, College of Agriculture and Life Sciences, University of Wisconsin Madison.
- Hartwig, N.L., and H.U. Ammon. 2002. Cover crops in living mulches. 50th anniversary invited article. *Weed Science*, 50: 688-699
- Hoagland, L., L. Carpenter-Boggs, D. Granatstein, M. Mazzola, J. Smith, F. Peryea, and J.P. Reganold. 2008. Orchard floor management effects on nitrogen fertility and soil biological activity in a newly established organic apple orchard. *Biology and Fertility of Soils*, 45: 11-18.
- Hogue, E.J., J.A. Cline, G. Neilsen, and D. Neilsen. 2010. Growth and yield responses to mulches and cover crops under low potassium conditions in drip irrigated apple orchards on coarse soils. *HortScience*, 45: 1866-1871
- Kuhn, B.F. and H.L., Pedersen. 2009. Cover crop and mulching effects on yield and fruit quality in un-sprayed organic apple Production. *European Journal of Horticultural Science*, 74: 247-253.
- Neilsen, G.H. and E.J. Hogue. 1992. Long-term effects of orchard soil management on tree vigor and extractable soil nutrients. *Canada Journal of Soil Science*, 72: 617-621.
- Nunez-Elisea, R., H. Cahn, L. Caldeira, and C.F. and Seavert. 2005. Polypropylene row covers greatly enhance growth and production of fourth-leaf sweet cherry trees. *HortScience* 40: 1129. Abstract only.
- Provin, T.L., and J.L. Pitt. 2005. Phosphorus; Too Much and Plants Suffer. Texas Cooperative Factsheet. Agricultural Communications. The Texas A&M University System.
- Reeve, J., B. Black, C. Ransom, M. Culumber, T. Lindstrom, D. Alston, and A. Tebeau, 2013. Developing Organic Stone-Fruit Production Options for Utah and the Intermountain West United states.

- Sanchez, EE., A. Giayetto, L. Cichon, D. Fernandez, M.C. Aruani, and M. Cuetti. 2006. Linking soil properties and nematode community composition: Effects of soil management on soil food webs. *Nematol*,8: 703-715.
- Sideman, E. 2007. Providing Nitrogen to Crops. MOFG Fact Sheet #8
- Stefanelli, D., R.J. Zoppolo, R.L. Perry, and R. Weibel. 2009. Organic orchard floor management systems for apple effect on rootstock performance in the midwestern United States. *HortScience*, 44: 263-267.
- Swift, C.E. 2009. Fertilizing Fruit Trees. Colorado State University Extension Factsheet no. 7.612.

CHAPTER V

ZERO FERTILITY INPUTS METHODS FOR MANAGING MATURE PEACH
ORCHARDS IN CAPITOL REEF NATIONAL PARK: A CASE STUDY
FACTSHEET⁵**History**

The orchards in Fruita Utah, were first established in the early 1880's by Mormon pioneers. The valley became famous for its cultivation of fruit through the 1950's. Acquired by the National Park's Service during the 1960's, and named Capitol Reef National Park (CRNP), the district was listed on the National Register of historic Places in 1997. Today, Fruita's orchards are not primarily managed for fruit production, but rather for historical accuracy and tree longevity. Orchards in CRNP are preserved first and foremost to illustrate Fruita's cultural heritage.

Due to the emphasis on historical accuracy in managing the orchards, interesting challenges have presented themselves for park rangers and academics alike. For example, deer fencing is prohibited around orchards which historically had no fencing; and since early settlers used flood irrigation, that is the only type of irrigation allowed for use today. In addition since it is a National Park, animals are not allowed to be harmed or relocated, even when trees or fruit are being damaged.

⁵ Coauthored by Thomsen E.O., D. Alston, J.R. Reeve, G. Cardon, B. Black

A USDA organic research grant provided funding for Utah State University researchers to collaborate with CRNP orchard managers to explore options to improve tree health and fruit quality using organic management techniques while maintaining historical and cultural mandates of the National Park Service.

Project Goal

One of the ongoing dilemmas for the CRNP orchard manager was providing adequate nutrition to the trees organically with only a small-allotted budget for tree maintenance. Organic fertilizers are not always expensive, however shipment costs to remote locations can add up. The CRNP orchard manager and the USU research team decided to try nitrogen-fixing legumes on-site to affordably supply some of the nitrogen needs to trees. Alfalfa was chosen, as it is an historic feature of the landscape, hence an approved plant by the park services. In May 2012, the goals of the team at the Carrell Peach Orchard were: 1) Discover how orchard plantings of alfalfa affect soil nitrogen levels and soil quality in the tree rows. 2) Assess the interaction and competition between alfalfa, grass, weeds, and fruit trees. 3) Determine the influence of understory alfalfa plantings on insect and mite populations, both pest and beneficial species.

Implementation

In 2012, a 25 ft by 92 ft section of the orchard was tilled and planted with alfalfa. Soil and tree leaf tissue samples, vegetation biomass, density and percent cover were taken in early spring and late summer of 2013, 2014 and late spring of 2015. Insect counts were also taken during these times, brushed from peach leaves, swept with a net

from the orchard floor, and collected from soil samples via Berlese funnel tests. Test results were compared to samples taken from the control plot in an established perennial grass cover. Although, the influence of local wildlife on the alfalfa had not been considered. Yellow bellied marmots were so efficient at grazing the alfalfa, it was nearly all consumed from the test plot within a season. By late summer 2013 a new plot was established, where a perennial grass cover was inter-seeded with alfalfa using a no-till drill.

Results

Legumes

The legumes produced more foliage in the inter-seeded plots where their growth was hidden between tall blades of grass, otherwise it was decimated by the yellow bellied marmots (Figure 1, 2 and 3).

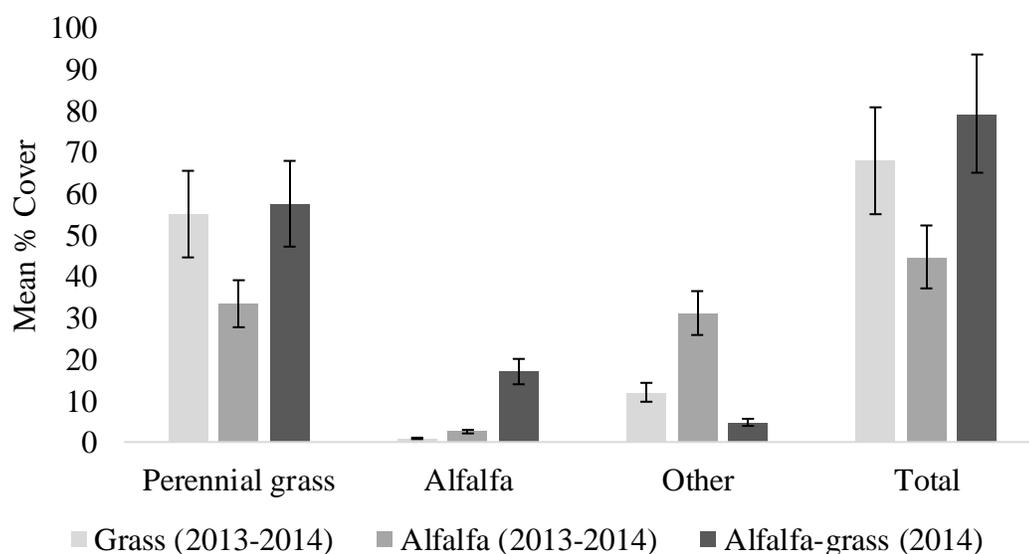


Figure 1. Average percent plant type (grass, alfalfa or other) coverage found in a 1.5 x 1.5 ft grid placed in four locations in each plot from summers 2013-2014.

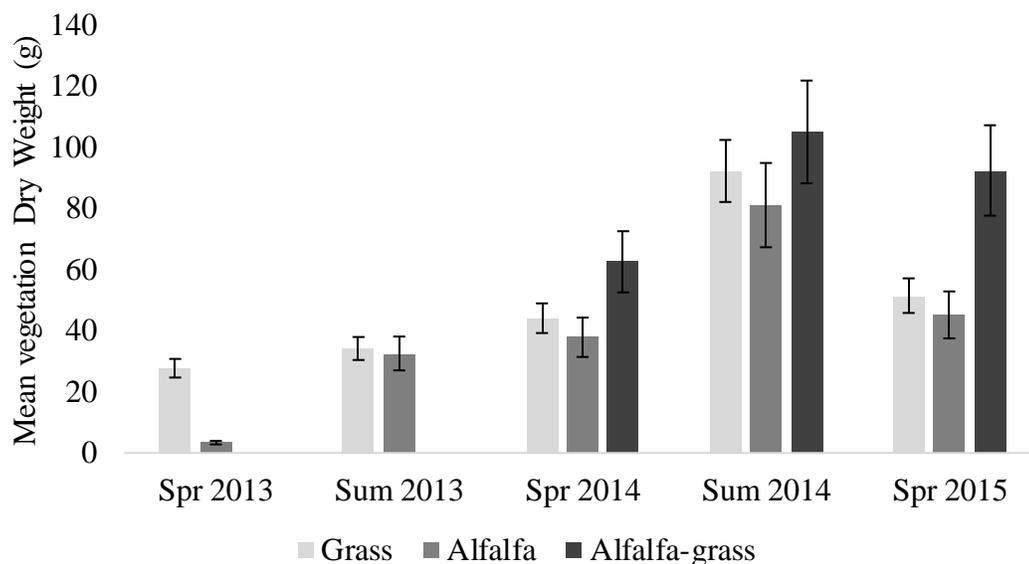


Figure 2. Average weight of total vegetation (dried) collected from a 1.5 x 1.5 ft grid placed in four locations in each plot from 2013-2015.

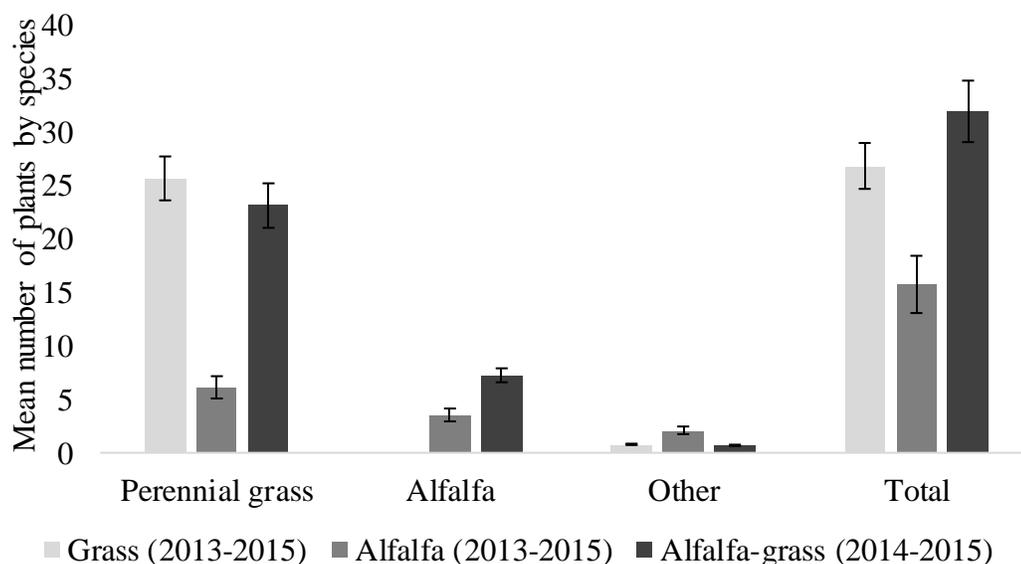


Figure 3. Plant density by each species was measured from a 1.5 x 1.5 ft grid placed in eight different locations in each plot from springs 2013-2015.

Nitrogen

Total available soil nitrogen is shown in Figure 4. Despite heavy grazing by marmots in the alfalfa plots, there was still a noticeable change in soil nitrogen compared to the grass-only plots. The increase of available soil nitrogen was likely caused by tillage, which released otherwise unavailable nitrogen in the soil through the breakdown of perennial grass roots, clippings and larger soil organisms. By 2014, available soil nitrogen was reduced in the plots on average, but was still greater in the alfalfa and the alfalfa-grass plots than in the perennial grass plots. In June 2015, available nitrogen was low throughout the treatments, but was greatest in the alfalfa-grass treatment. This suggests the potential for inter-seeded legumes to increase soil N even when present in relatively low proportions.

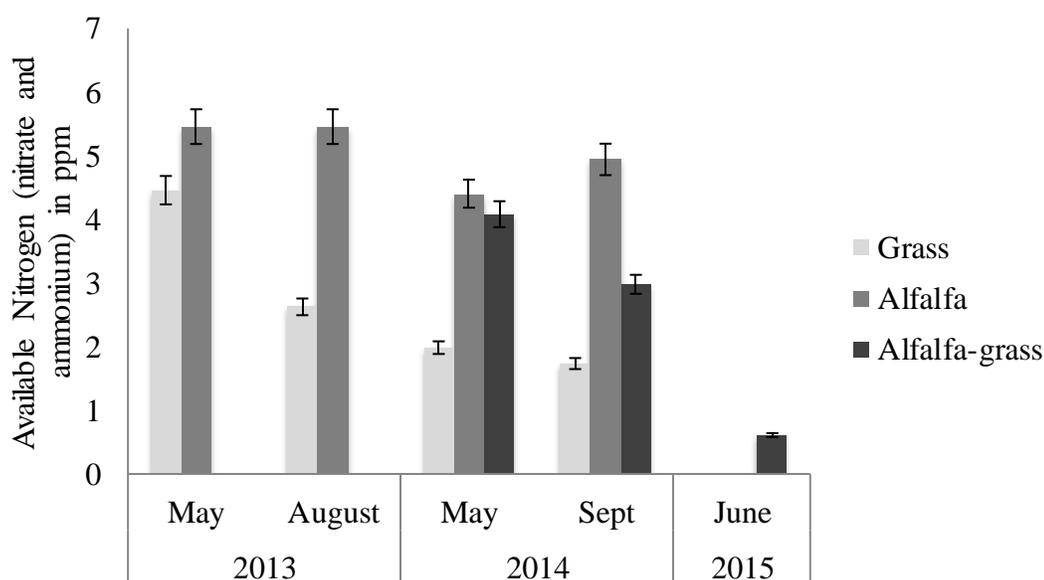


Figure 4. Available nitrogen (nitrate and ammonium) in ppm in grass, alfalfa and alfalfa-grass plots from 2013-2015.

Phosphorus

The effects of the treatments on soil phosphorus is shown in Figure 5. In the first two years there were marginal to no differences overall in soil phosphorus. By 2015, the alfalfa-grass treatment had significantly less phosphorus than the other two treatments. It could potentially be due to more biomass of alfalfa and grass in the plots, consuming more phosphorus (Figure 1, 2 and 3). Although, it could be due to natural variability since this difference was not apparent in other years

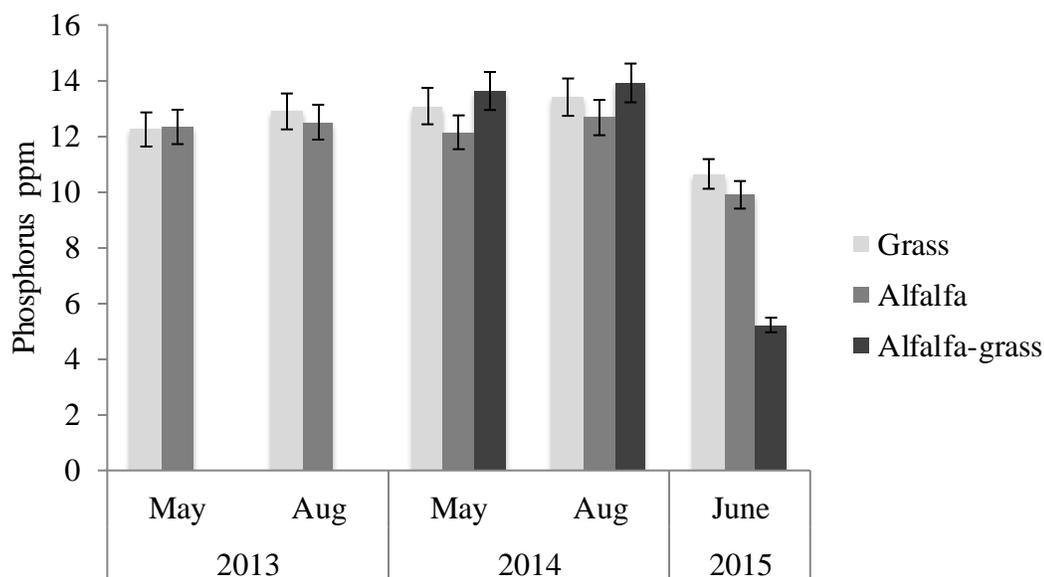


Figure 5. Phosphorus is shown in ppm in grass, alfalfa and alfalfa-grass plots from 2013-2015.

Leaf Tissue

The results from the leaf tissue tests are shown in Figure 6 and 7. The results show nitrogen, calcium, iron and manganese deficiencies in the trees at the Carrell orchard. The alfalfa plantings were insufficient, at least in the short term, to alleviate

nitrogen deficiency. To resolve the deficiencies in calcium, iron and manganese, foliar sprays would be the best nutritional amendment.

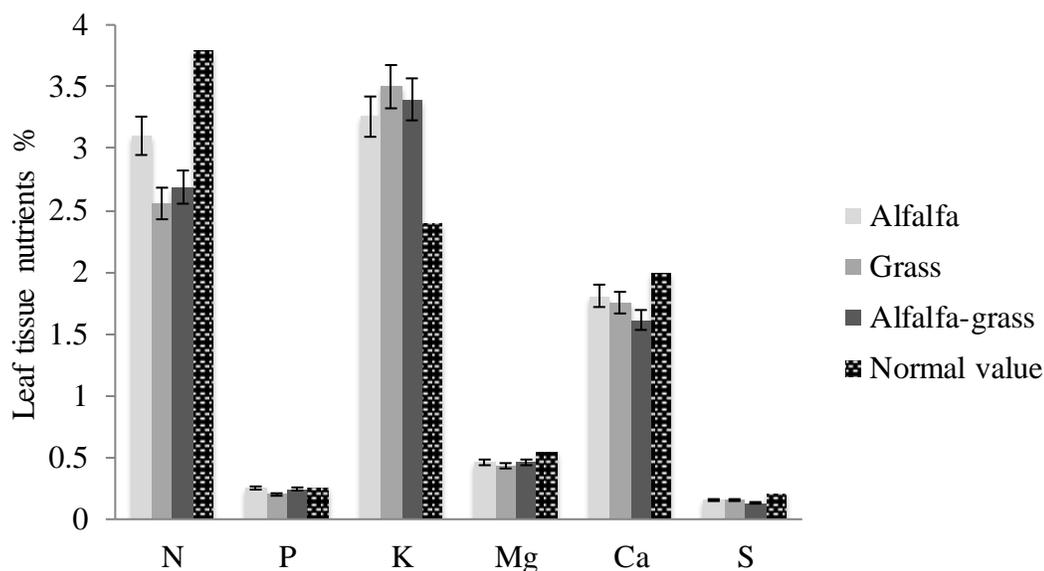


Figure 6. Macronutrient percent levels measured from peach leaves in the Carrell Orchard, from the alfalfa, grass and alfalfa-grass plots, in May 2014. Normal value is shown on the right.

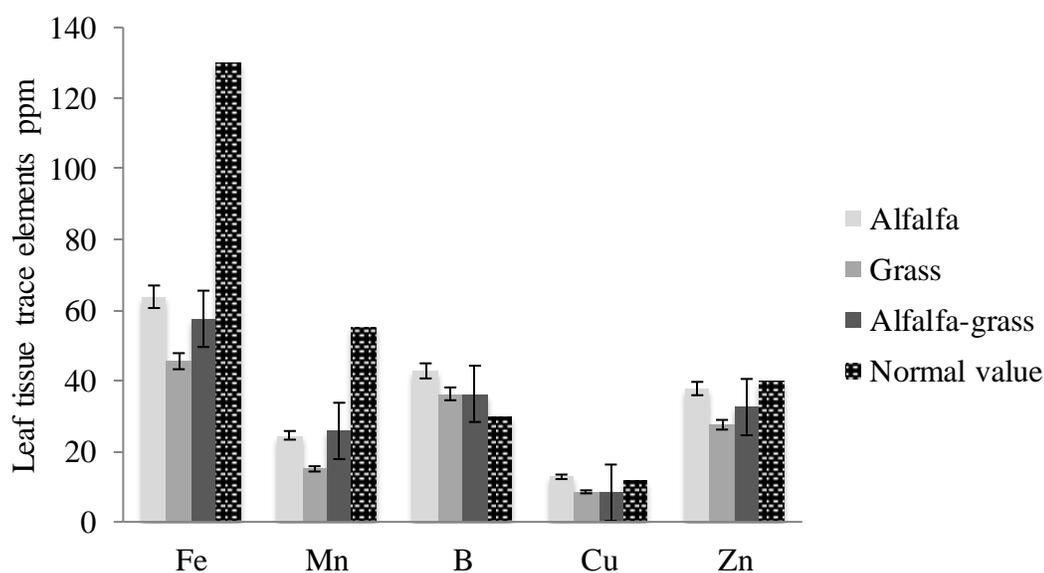


Figure 7. Micronutrient levels shown in ppm measured from peach leaves in the Carrell Orchard from the alfalfa, grass and alfalfa-grass plots, in May 2014. Normal value is shown on the right.

Soil Microbial Biomass

Figure 8 shows the results for soil microbial biomass. Microbial biomass provides an indication of nutrient retention and turnover in the soil. Initially the tilled alfalfa plots had greater microbial biomass than the grass plots, likely caused by the breakdown of soil aggregates and a release of otherwise unavailable organic matter, nitrate and ammonium. By May 2014, alfalfa grass plots had marginally higher respiration rates than the other plots. By September of the same year, alfalfa grass plots had higher respiration than any other plot so far recorded; alfalfa plots had the second highest respiration rates. By 2015, all recordings were very low, with alfalfa grass plots slightly in the lead. The fixation of nitrogen from the inter-planted legumes is the likely reason for the increased microbial activity, and may indicate the potential for soil health improvements over time.

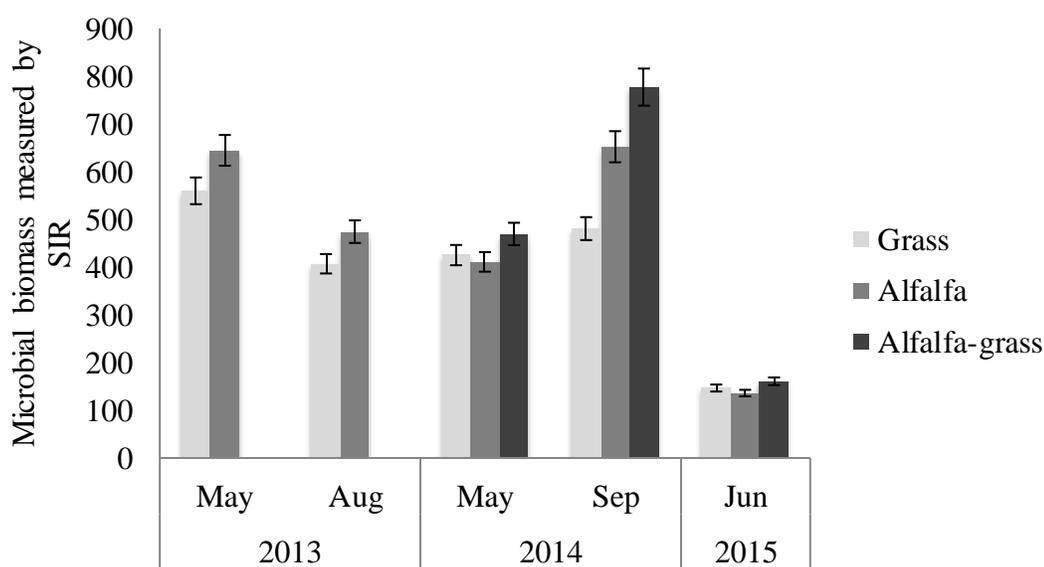


Figure 8. Microbial biomass measured by substrate induced respiration in grass, alfalfa and alfalfa grass plots, from 2013-2015.

Athropods

There were few differences in arthropod abundance or diversity among the different ground cover types (Figure 9 and 10); however the alfalfa plots did contain higher numbers of flat mites and beetle larvae (predominantly alfalfa weevil). The grass plots had the highest numbers of thrips, collembola, and oribatid mites, and the alfalfa-grass plots had the highest aphids and spider mites (Figure 9). The peach leaf brushing showed that the alfalfa plots had the highest number of herbivorous (plant-feeding) and detritivorous (decomposing) arthropods, followed by grass and then alfalfa-grass (Figure 10). Perhaps this was influenced by the greater density and diversity of weeds from tillage in the alfalfa plot, encouraging more plant-feeding thrips which made their way into the peach trees.

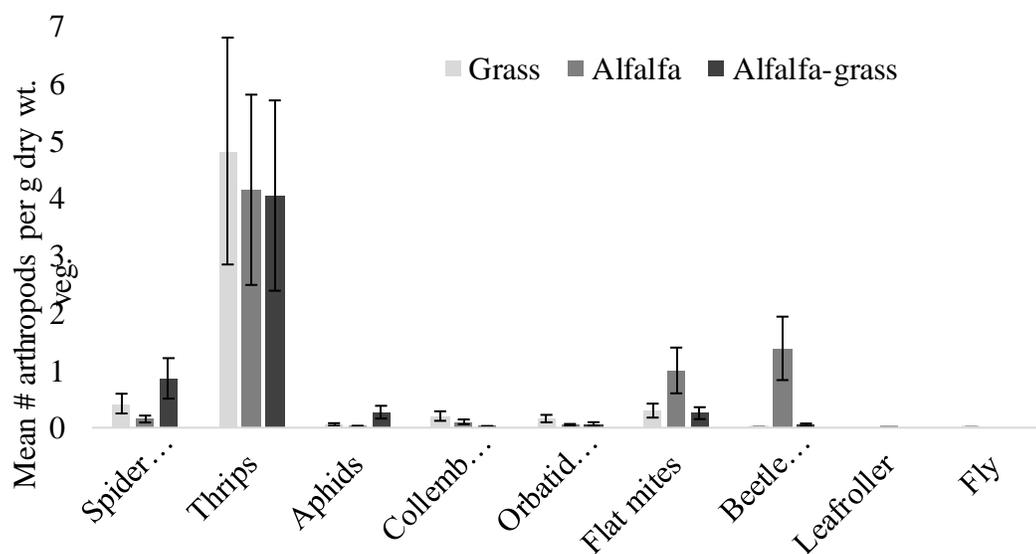


Figure 9. Arthropod density per gram dry weight on vegetation in the spring 2013-2015.

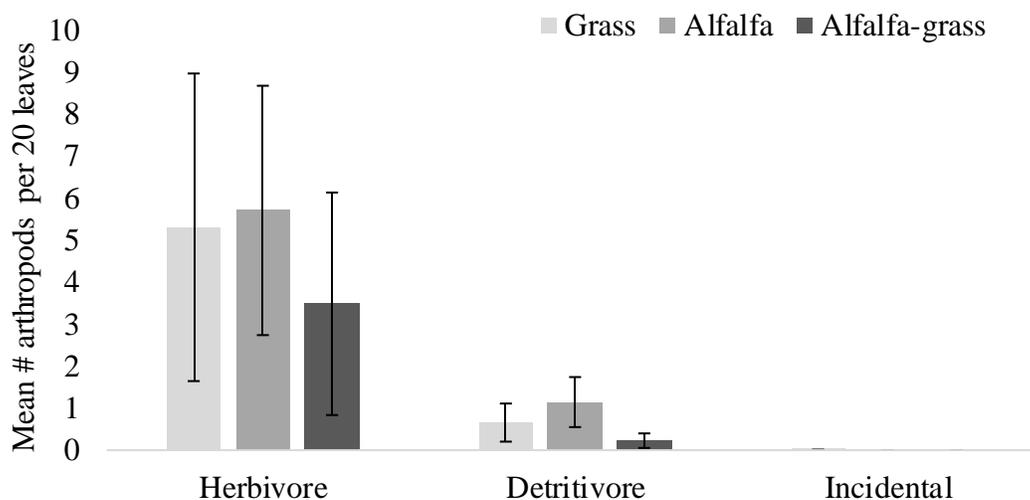


Figure 10. Arthropod density per 20 peach leaves in the Carrell orchard in the alfalfa, grass and alfalfa grass plots from springs 2013-2015.

Conclusion

Despite predation from marmots, and greatly reduced presence of alfalfa plants in the tilled plots, tillage and planting legumes still appeared to benefit available soil nitrogen in the short-term when compared to undisturbed grass plots. In regards to a longer-term solution, inter-seeding legumes into perennial grass may be a viable option to increase soil nitrogen available to fruit trees. Yet, legumes alone did not alleviate all of the deficiencies found in the peach trees in the Carrell orchard. The trees would benefit from receiving foliar sprays of calcium, iron, and manganese, in addition to nitrogen in the form of compost or other organic fertilizers. Plant cover only modestly influenced arthropod species and abundance: tillage seemed to increase the abundance and variety of

arthropods in the peach trees. This may have been caused by invasion of weeds into tilled plots and lack of competition from the alfalfa due to heavy grazing by marmots. CRNP has recently been given permission to start applying manure compost to increase soil nitrogen, phosphorus and tree health. Gradually, soil nitrogen availability and soil health should improve. Despite limited resources and constraints in wildlife management, this study demonstrated that soil health and quality can be improved with plantings of inter-seeded legumes while not perturbing the arthropod abundance and diversity in orchard trees, which could cause pest outbreaks. This strategy shows promise for alleviating soil N deficiencies in the long-term and reducing the need for purchased inputs.

CHAPTER VI

GENERAL CONCLUSIONS

There are many avenues to successfully build soil quality in the Intermountain West despite management challenges such as input costs, and environmental factors such as short growing seasons, drought or little rainfall. Growers are interested in learning more about soil quality and methods to improve their practices. Most growers recognize that soil health is not just about available nutrients, but is also influenced by complex interactions among soil organisms. Yet, in-lab chemical soil tests are the most common soil tests, and biological in-lab soil tests and or on-site trainings for biological tests are largely unavailable. It would be beneficial if biological tests could be made more available to the average grower, either by including them in local soil labs or providing more on-site biological testing information through agricultural extension agencies. Other information that would be beneficial to make more accessible for growers, especially organic growers, would be the consequences of overapplication of fertilizers, in particular manure composts.

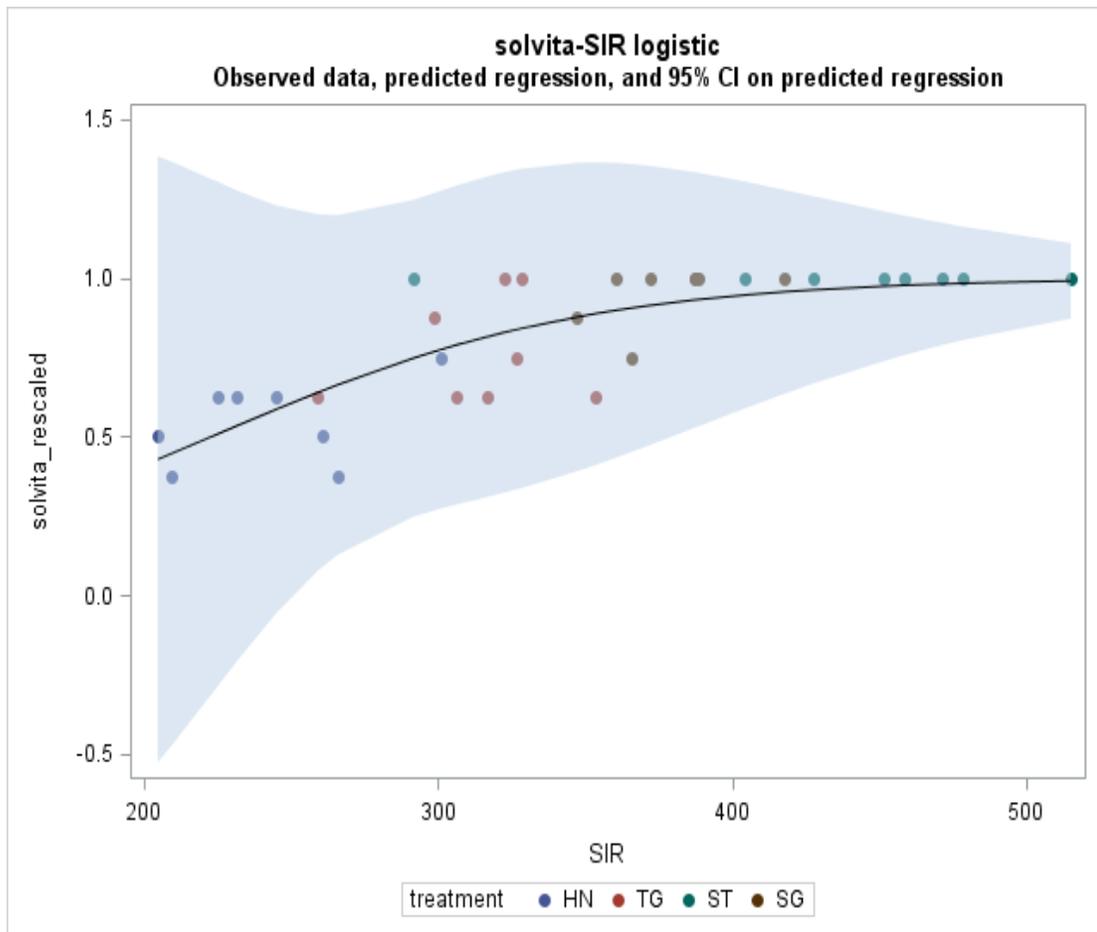
Correlations between simple chemical tests and laboratory analyses were generally poor, although some tests showed promise. In addition, simple chemical tests often had limited sensitivity so despite high correlations for some chemical tests, values may not be meaningful to growers. The tests which growers mentioned they would be the most likely to use on their farms, included the modified slake tests and earthworm abundance/biodiversity test. Earthworm abundance tests did not correlate strongly with

biological laboratory tests, however by including overall organisms counts the correlation was improved. Modified slake tests had generally high correlations to biological laboratory results. The Solvita® respiration test results were most highly correlated to laboratory results, but was less favored by growers due to cost.

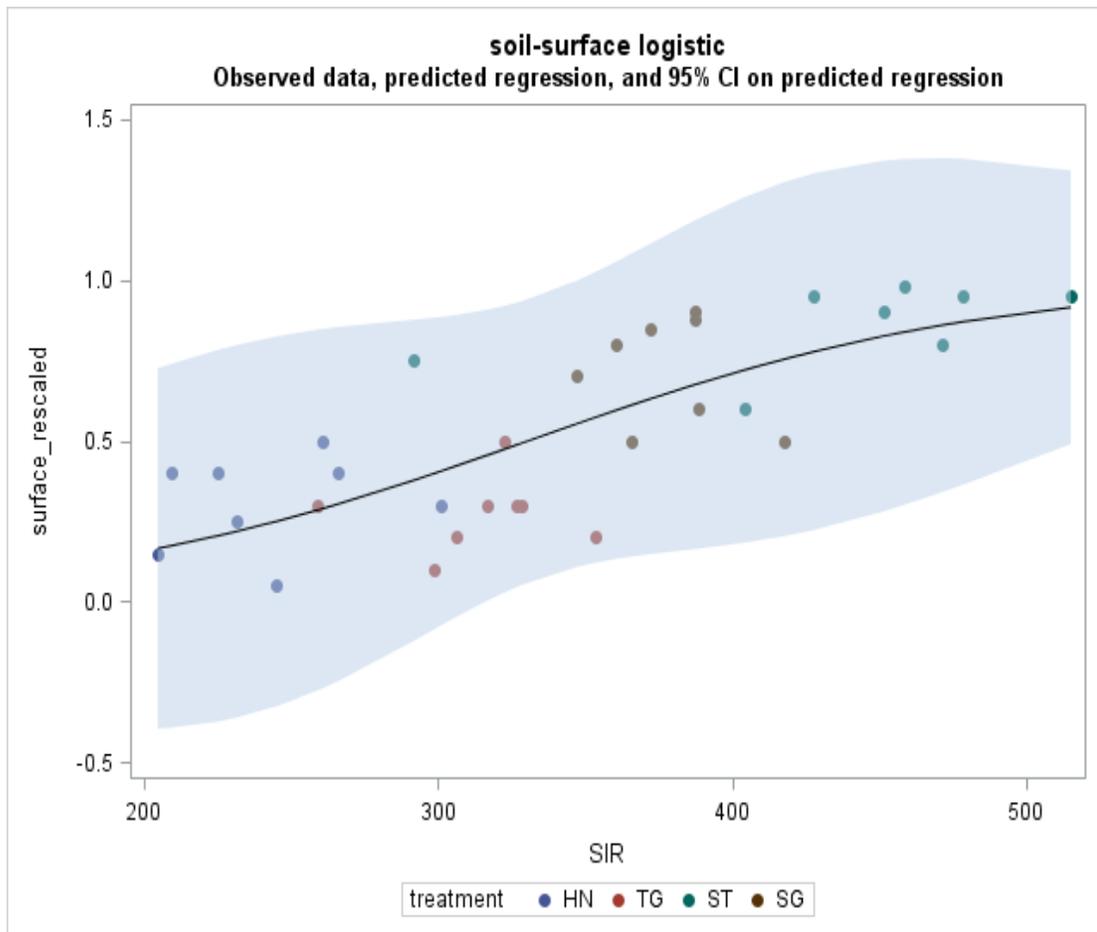
Soil testing in the same plot over time or in different plots with differing management practices and the same soil type, can help growers assess soil health patterns and may help growers mitigate potential soil health threats. There are many ways for growers to successfully build soil health, if needed. Legumes have been shown to have a beneficial impact on available soil nitrogen levels, however, may not always be a sufficient source of nitrogen for trees, especially in areas where wildlife may graze heavily. Other practices that are helpful in building soil fertility and quality are reduced tillage – such as tillage strips-- and or non-living mulches that can limit weeds and may potentially help retain moisture for this arid climate. Tillage and plant cover also influence arthropod number and species, and are important to consider when developing a management plan.

Soil health/quality is a topic gaining more attention both in the scientific community as well as among growers, soil health/quality tests and soil health building practices are likely to gain more momentum with time.

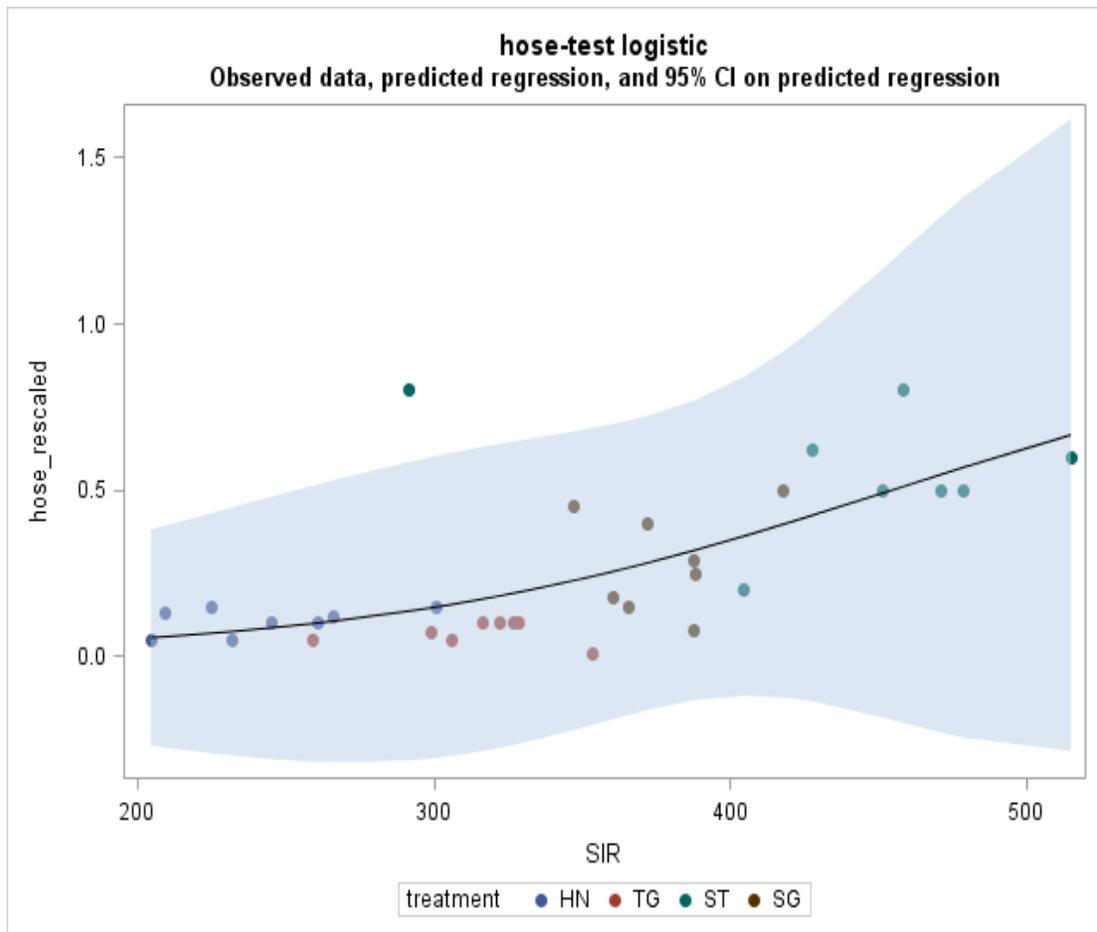
APPENDICES



A1. Solvita and SIR compared using a Hosmer and Lemeshon Applied Logistic Regression for 2014 and 2015 results. Results follow the trendline closely, $R^2 = 0.97$, however with a limited data set these measures can not be used accurately for predictive analysis. Note: Simple test scales were rescaled from 0-1 using a beta distribution. Only Pearson correlations obtaining a correlation of at least 0.80 in the first year and 0.40 in the second year were also ran through a regression analysis in order to possibly rank them further against each other.



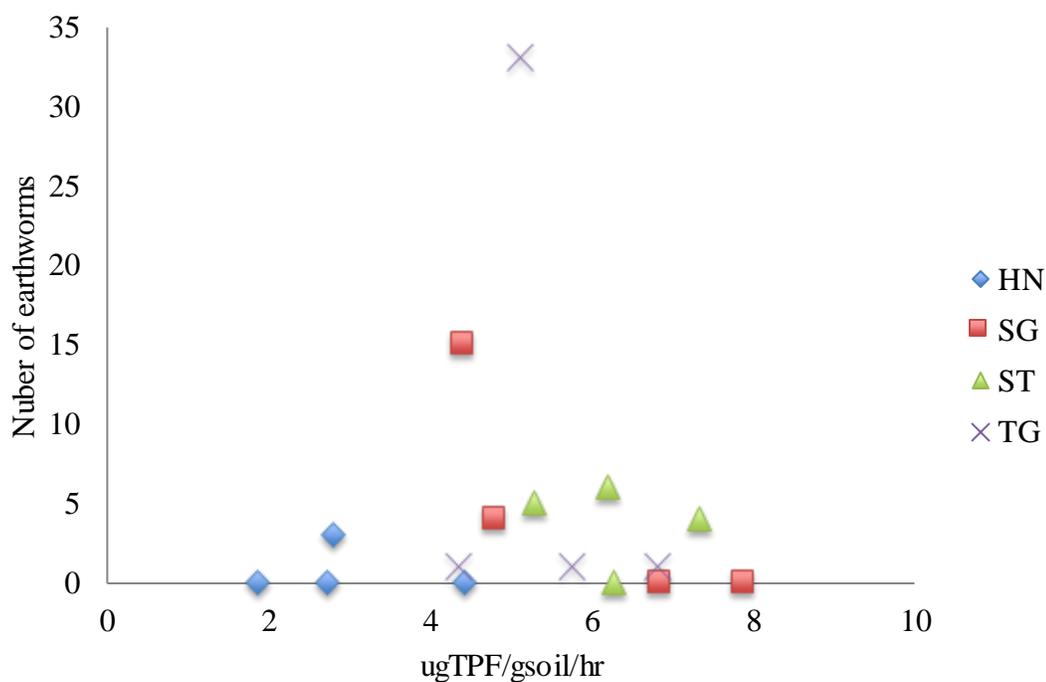
A2. Soil surface test and SIR compared using a Hosmer and Lemeshon Applied Logistic Regression for 2014 and 2015 results. Results follow the trendline closely, $R^2 = 0.99$, however with a limited data set these measures can not be used accurately for predictive analysis. Note: Simple test scales were rescaled from 0-1 using a beta distribution. Only Pearson correlations obtaining a correlation of at least 0.80 in the first year and 0.40 in the second year were also ran through a regression analysis in order to possibly rank them further against each other.



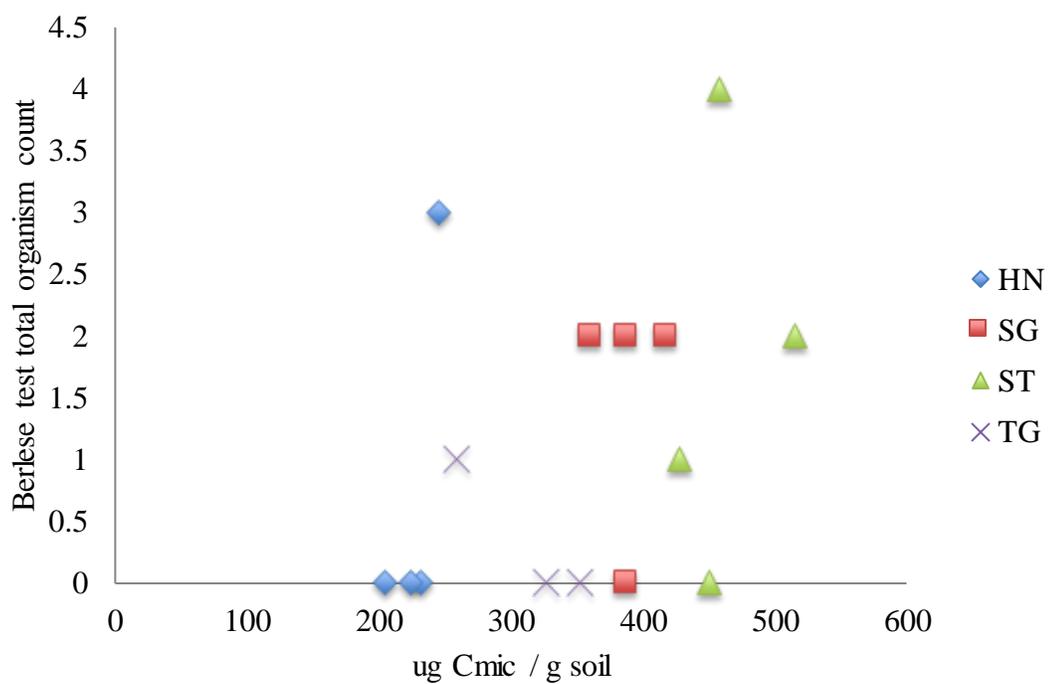
A3. The hose test and SIR compared using a Hosmer and Lemeshon Applied Logistic Regression for 2014 and 2015 results. Results follow the trendline closely, $R^2 = 0.99$, however with a limited data set these measures can not be used accurately for predictive analysis. Note: Simple test scales were rescaled from 0-1 using a beta distribution. Only pearson correlations obtaining a correlation of at least 0.80 in the first year and 0.40 in the second year were also ran through a regression analysis in order to possibly rank them further against each other.

% decomposed material from litterbag after number of weeks correlated to BR 2014						
Littertype	Weeks					
	2	3	6	8	12	48
Straw	-0.38	0.13	0.04	0.22	0.05	0.37
Alfalfa	0.35	0.05	0.03	0.03	0.31	0.57
Leaves	-0.16	-0.73	0.30	-0.18	0.08	0.47
% decomposed material from litterbag after number of weeks correlated to SIR 2014						
Straw	-0.34	0.03	-0.17	0.30	-0.08	0.51
Alfalfa	0.29	-0.01	-0.06	0.03	0.32	0.58
Leaves	0.01	-0.64	0.15	-0.30	-0.03	0.45
% decomposed material from litterbag after number of weeks correlated to DHA 2014						
Straw	-0.25	0.07	-0.29	0.19	-0.01	0.50
Alfalfa	0.20	-0.13	-0.09	-0.05	0.30	0.65
Leaves	-0.08	-0.65	0.20	-0.28	-0.05	0.38

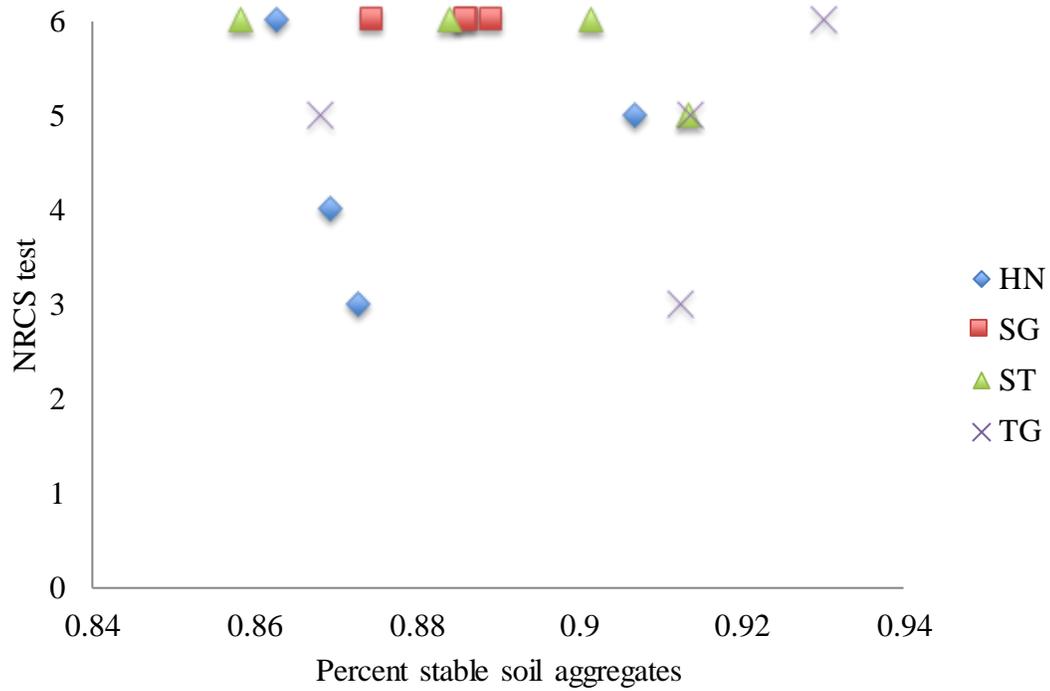
A4. Pearson correlations between litterbag tests at each unburial and laboratory biological tests. BR = basal respiration, SIR = substrate induced respiration, DHA = dehydrogenase enzyme assay.



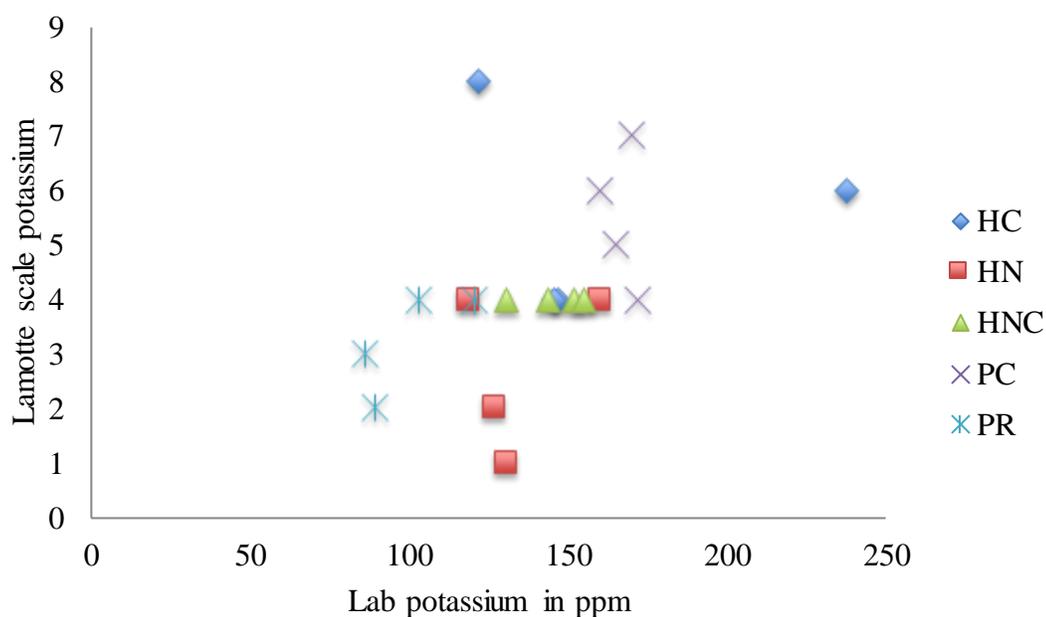
A5. Earthworm abundance test correlated with dehydrogenase enzyme assay as measured by reduction of triphenylformazan per hour per gram of soil in 2015. HN = NPK fertilizers and herbicides with a grass alleyway, SG = straw mulch in the tree row with a grass alleyway, ST = straw mulch in the tree row with a legume (birdsfoot trefoil, *Lotus corniculatus*) alleyway, TG = tillage in the tree rows with a grass alleyway.



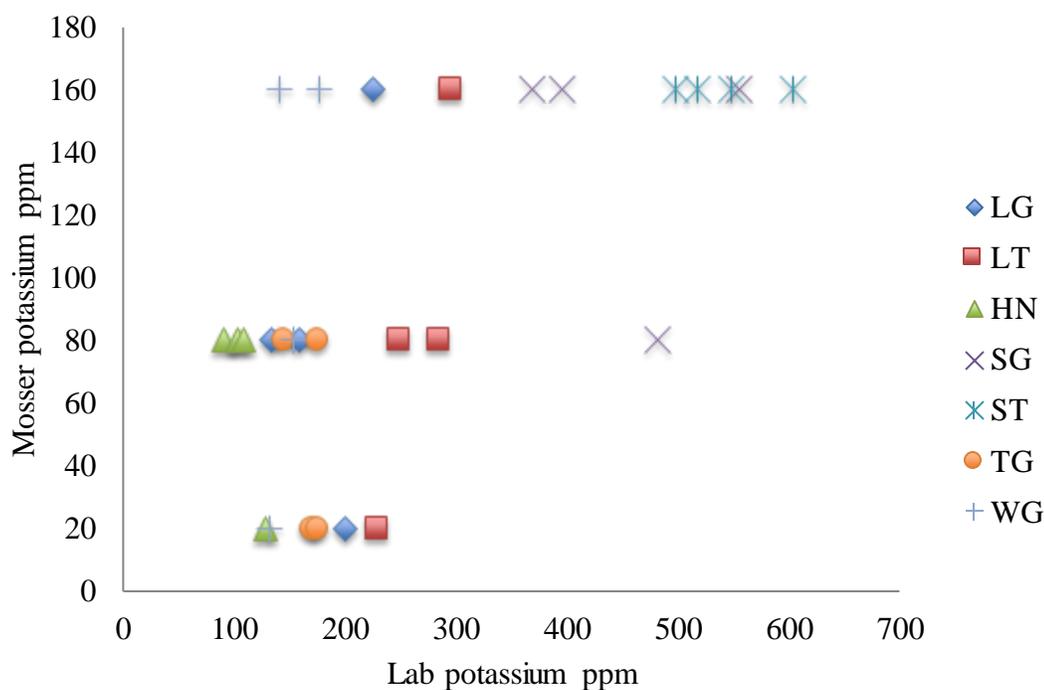
A6. Simple Berlese test correlated with microbial biomass 2014. HN = NPK fertilizers and herbicides with a grass alleyway, SG = straw mulch in the tree row with a grass alleyway, ST = straw mulch in the tree row with a legume (birdsfoot trefoil, *Lotus corniculatus*) alleyway, TG = tillage in the tree rows with a grass alleyway.



A7. NRCS slake test correlated with machine aggregate stability 2015. HN = NPK fertilizers and herbicides with a grass alleyway, SG = straw mulch in the tree row with a grass alleyway, ST = straw mulch in the tree row with a legume (birdsfoot trefoil, *Lotus corniculatus*) alleyway, TG = tillage in the tree rows with a grass alleyway.



A8. Lamotte potassium test correlated with laboratory potassium in the conventional orchard. The potassium tests in the conventional orchard were much less clearly defined than for the organic orchard. The Lamotte potassium scale is interpreted as: 0-120 lbs per acre for Low (1-2), 120-200 lbs per acre for medium (3-5), 200+ lbs per acre for high (6+). HC = herbicides plus compost for nitrogen, HN = NPK fertilizers and herbicides with a grass alleyway, HNC = NPK fertilizers and herbicides, and converted to organic practices after tree establishment, PC = paper mulch, organic herbicide and compost for nitrogen, PR = paper mulch with reduced herbicide in addition to NPK fertilizers.



A9. Mosser potassium test correlated with laboratory potassium. LG = living mulch (low-growing shallow rooted alyssum, *Lobularia maritima*) in the tree row with a grass alleyway, LT = living mulch in the tree row with a legume alleyway, HN = NPK fertilizers and herbicides with a grass alleyway, SG = straw mulch in the tree row with a grass alleyway, ST = straw mulch in the tree row with a legume (birdsfoot trefoil, *Lotus corniculatus*) alleyway, TG = tilled tree rows with a grass alleyway, WG = woven plastic mulch in the tree row with a grass alleyway.