A report for:

Regenerative Agriculture: The Path to Healing Agroecosystems and Feeding the World in the 21st Century

By Brian Dougherty

2018 Nuffield Scholar

September 2019

Nuffield International Project No. 1801

Supported by:

National Pork Board

© 2019 Nuffield International.

All rights reserved.

This publication has been prepared in good faith on the basis of information available at the date of publication without any independent verification. Nuffield Australia does not guarantee or warrant the accuracy, reliability, completeness of currency of the information in this publication nor its usefulness in achieving any purpose.

Readers are responsible for assessing the relevance and accuracy of the content of this publication. Nuffield Australia will not be liable for any loss, damage, cost or expense incurred or arising by reason of any person using or relying on the information in this publication.

Products may be identified by proprietary or trade names to help readers identify particular types of products but this is not, and is not intended to be, an endorsement or recommendation of any product or manufacturer referred to. Other products may perform as well or better than those specifically referred to.

This publication is copyright. However, Nuffield International encourages wide dissemination of its research, providing the organisation is clearly acknowledged. For any enquiries concerning reproduction or acknowledgement contact (+61) (0) 3 54800755.

Scholar Contact Details

Brian Dougherty

11899 Rupp Hollow Rd.

Dubuque, Iowa USA 52001

Phone: +1 563 239 7070

Email: 1briandougherty@gmail.com

In submitting this report, the Scholar has agreed to Nuffield International publishing this material in its edited form.

NUFFIELD INTERNATIONAL Contact Details:

Nuffield International

Telephone: (+61) (0) 3 54800755

Facsimile: (+61) (0) 3 54800233

Mobile: (+61) (0) 412696076

Email: jimgeltch@nuffield.com.au

Contact: Jim Geltch

Title: Chief Executive Officer

Address: PO BOX 586, Moama, New South Wales, Australia 2731

Executive Summary

This report details the efforts of farmers and researchers around the world to regenerate healthy soil and improve profitability by practicing what is referred to as Regenerative Agriculture. Regenerative agriculture (RA) is an emerging concept for managing agricultural land. It seeks to combine the best conventional, organic, and biological farming practices into a system that improves productivity while enhancing ecosystem services. It primarily focuses on improving the health of soils by following basic soil health principles. These include maximizing soil cover, maintaining a system of continuous living roots, and encouraging genetic diversity, while minimizing soil disturbance.

Regenerative agriculture is more than a set of farming practices. It also requires a different mindset and different management strategies. It seeks to address the root cause of production problems rather than simply treating the symptoms. Furthermore, RA takes into consideration the environmental and societal implications of our food production systems. Conventional agricultural practices of the past half century have produced abundant food but have done it at tremendous environmental and socioeconomic cost. These practices often relied on ‘mining’ the soil rather than improving it and have led to degraded soil, lost future production potential, and shrinking rural communities. The RA movement seeks a better way forward.

The following report explores the thinking and efforts of farmers who are making the switch from conventional to regenerative farming systems. Challenges and opportunities associated with regenerative farming are discussed, and recommendations for implementing regenerative practices are given. These techniques and ideas may prove useful to farmers as they work to improve their operations.

In the coming years it will be much easier to sell a vision of an agricultural production system that regenerates ecosystems rather than degrading them. As consumer preferences change, consumers are demanding food that is produced in an environmentally responsible way. Farmers who can improve their soils over time and do it economically will be the farmers who thrive in the 21st century. The successful farmers of tomorrow will use RA to produce more with fewer resources and build both economic and environmental resiliency into their farming operations.

Table of Contents

Executive Summary ii

List of Figures v

List of Tables v

Foreword vi

Acknowledgments vii

Abbreviations viii

Objectives ix

Introduction 1

- What is healthy soil? 4
- What is regenerative agriculture? 5

Chapter 1: Regenerative agriculture concepts 7

- Keep the soil covered 7
- Maintain plant cover throughout the growing season 8
- Diversify cropping systems as much as possible 9
- Disturb the soil as little as possible 10
- Cultivate a regenerative mindset 10

Chapter 2: Regenerative agriculture in practice 12

- Cover crops and agroforestry 12
- Cover crop ‘money strip’ trials 14
- Cover crops with direct drilling, controlled traffic, and variable rate seeding 16
- Biological amendments 17
- Composting 18
- Assessing soil health 21
  - Visual soil assessment 21

        Soil chemical analysis 22
        Soil biology tests 24
        Microscopic analysis 25
Chapter 3: Making the change to a regenerative system 28
    Is there and economic advantage with RA? 28
    Advice from farmers that are embracing change 31
Conclusion 32
Recommendations 33
References 35
Appendix 1: Resources 40
    General soil health and regenerative agriculture information 40
    Soil health testing resources (U.S.) 40
    Soil health assessments 40
    Books 41
    Nuffield Scholar reports 41
Appendix 2: Example soil test reports 42
Appendix 3: Precipitation rates 44
Plain English Compendium Summary 45

List of Figures

Figure 1. Area planted to corn, soybeans, hay, and oats in Iowa in 1930, 1970, and 2010....... 1
Figure 2. Daily Erosion Project map showing hillslope erosion estimates in U.S. tons/acre.... 2
Figure 3. Visible soil loss from water and wind erosion is still evident in Iowa....................... 3
Figure 4. Advances in yield potential and barriers to yield increases. 3
Figure 5. Soil erosion and transport processes.. 8
Figure 6. Soil food web relationships between above and belowground life. 9
Figure 7. Julien Senez discussing the benefits of multispecies cover crop mixes.................. 12
Figure 8. Strips of trees in the experimental agroforestry plots on Julien Senez’s farm. 14
Figure 9. Aerial view of the ‘chequerboard trial’ plot on the Deverel Farm........................... 15
Figure 10. The author investigating soil structure with Mark Dewes and Richard Squire...... 16
Figure 11. Compost turner designed to rotate for easier towing on public roadways. 19
Figure 12. Michael Luebbers making compost extract for application near Waverly, IA. 20
Figure 13. The same soil type on neighboring fields with a noticeable difference in color.... 23
Figure 14. Identification of microscopic species by shape... 26
Figure 15. Fields with the same soil type and corn variety after six weeks with no rain. 30

List of Tables

Table 1. Trial layout with X and Y axes representing cover crop species and cost. 15
Table 2. The effect of Ca;Mg ratio on water stable soil aggregation. 23
Table 3. Soil biology test results provided by Lancrop Laboratories..................................... 24
Table 4. Precipitation depth of 25-year 24-hour rainfall events in various regions of Iowa. .. 44

Foreword

I was raised on the family dairy farm in Northeast Iowa and learned to love agriculture at a young age. After high school, I attended community college to study agriculture and then returned home to the family farm. I spent 17 years there farming in partnership with my brother. We gradually expanded the herd, modernized the dairy facilities, and took on more land. Over time I began to see many problems with agricultural practices in the United States. I witnessed first-hand how farmers were struggling to make a living under a conventional commodity production system and saw the environmental degradation that resulted from that system.

My path to a Nuffield Scholarship was a bit unusual. I decided to return to school to study agricultural engineering, so I could work on some of the problems that I had encountered as a farmer. It was during my master's degree studies at Iowa State University that I discovered the Nuffield program. It seemed like the perfect opportunity to see how farmers in other parts of the world deal with those same problems and develop solutions to them. My goal was to see if there was a better way forward for farmers in my home state of Iowa. I wrote this report with this goal in mind. My intent is not to criticize current agricultural practices. Rather, I want to provide some 'food for thought' that might help farmers prosper in a farming system that focuses on maximising production without sacrificing their ability to pass on productive and resilient farmland to the next generation. Several other Nuffield Farming Scholars have studied soil health and regenerative agricultural practices and have written excellent reports on the topic. Some of these are listed in Appendix 1 and I encourage readers to explore those reports as well.

Acknowledgments

I would like to thank the National Pork Board, Iowa Pork Producers Association, Iowa Farm Bureau, Iowa Corn Growers Association, and Iowa Soybean Association for their generous support that made this scholarship possible. Traveling on a Nuffield International Farming Scholarship was a life-changing experience and I am forever grateful. I would also like to thank the many farmers, researchers, and agricultural advisors from around the world who generously shared their time and resources. They are too numerous to mention individually but this report would not have been possible without their support.

Many thanks to all current and former Nuffield Scholars who shared their wisdom and their homes with my wife Kecia and I while we travelled the world. To the Chile Champs GFP group, thanks for the friendship and the memories. I will never forget the time we spent exploring the world together.

The Chile Champs Global Focus Program group pictured together at the end of the trip in Santiago, Chile. Kneeling in front (L to R); Jonathan Gill (Wales) and Brian Dougherty (author-USA). Standing (L to R); Dudley Mitchell (Australia), Andy Elliot (New Zealand), Klaus Laitenberger (Ireland), Scott Nicholson (Australia), Emma O'Flaherty (Australia), and Robin Tait (Australia).

Special thanks to Dr. Tim Hutchings for his time and contributions towards reviewing and improving this report. Special thanks also go out to Dr. Matt Helmers and others at Iowa State University who provided the opportunity, support, encouragement, and additional funding for me to undertake my Nuffield Scholarship travels while finishing my degree. Finally, and most importantly, thank you to my wife Kecia and the rest of my family for the love, encouragement, and support that made it possible for me to pursue this scholarship.

Abbreviations

AMF	Arbuscular Mycorrhizal Fungi
CO_2	Carbon dioxide
Ca:Mg	Calcium to Magnesium ratio
C:N	Carbon to Nitrogen ratio
CTF	Controlled Traffic Farming
N, P, K	Nitrogen, Phosphorus, Potassium
NRCS	Natural Resources Conservation Service
SARE	Sustainable Agriculture Research and Education
SOM	Soil Organic Matter
RA	Regenerative Agriculture
U.S.	United States
USDA	United States Department of Agriculture

Objectives

This report investigates how regenerative agriculture (RA) practices can be integrated into farming systems in Iowa. The objectives of this study are to:

- Provide background information about RA concepts.
- Define soil health in the context of Iowa agriculture.
- Investigate the mindset and approaches of RA practitioners in different parts or the world.
- Explore how Iowa farmers can use the RA approach to improve the health and resiliency of their soil.
- Explore how RA can improve economic, social, and environmental outcomes for farming communities.

Introduction

The goal of this report is to explore how Regenerative Agriculture (RA) can improve the economic, environmental, and social outcomes for agriculture. While some of the general concepts may apply elsewhere, the combination of soils and climate in Iowa are somewhat unique. Thus, some specifics of this report may not apply outside of Iowa and similar areas of Upper Midwestern U.S. corn belt region.

Agriculture is fundamentally important to the state if Iowa. It is the dominant feature on the landscape, with 72.1% of the total land surface of the state dedicated to cropland and 8.6% to pastureland (U.S. Department of Agriculture, 2018). Iowa has been described as the most altered landscape in the U.S. and one of the most highly manipulated places on earth (Mutel, 2008). Corn, grass crops, and pastureland were the primary uses for farmland up until the 1940's. Much land was devoted to producing feed for draft animals that provided the 'horsepower' to farm the land. After World War II, technological advances and mechanization changed the landscape. Tractors replaced draft animals, eliminating the need to have land dedicated to producing feed to 'power' the farm. The advent of synthetic fertilizers and chemicals fundamentally altered the way crops were grown. Gone were the days of needing to return livestock manure to the land and grow green manure crops to maintain soil fertility. These changes greatly reduced labour needs and changed the balance of crops produced across the state. Area planted to corn remained relatively steady, but cereal grainsand hay crops were mostly replaced by soybeans (Figure 1).

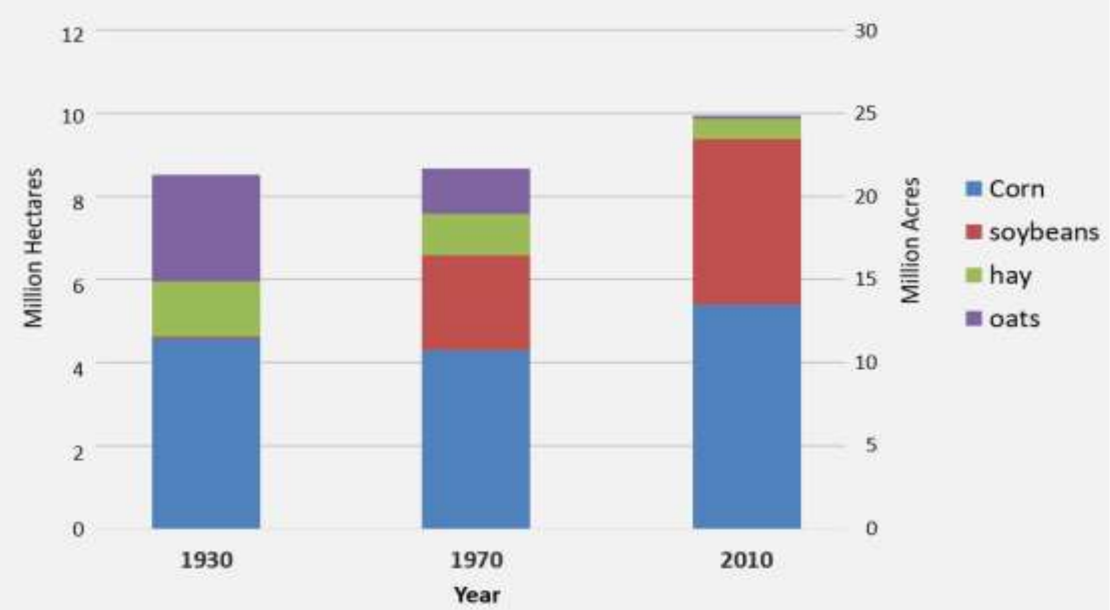


Figure 1. Area planted to corn, soybeans, hay, and oats in Iowa in 1930, 1970, and 2010.

Iowa has lost a significant amount of topsoil since modern agricultural practices have been implemented across the landscape. During the Dust Bowl era, it became clear that conservation practices were needed to prevent erosion (Egan, 2006). The loss of perennial vegetation over time has led to conditions where soil is more vulnerable to erosion, which has offset efforts to reduce erosion. Soil erosion rates in Iowa have declined somewhat, from an estimated 16.6 metric tons/ha (7.4 U.S. tons/ac) in 1982 to 11.4 metric tons/ha (5.1 U.S. tons/ac) in 2007 (Duffy, 2012). Despite efforts to reduce erosion, it is still a serious problem today. It will continue to be a challenge, given that Iowa is experiencing more intense precipitation events compared to historical averages (Tackle, 2011). Figure 2 gives an example of a daily erosion estimate for Iowa showing hillslope soil loss over a single 24-hour period on May 3, 2018 (Gelder et al., 2018). This shows that serious erosion can occur in a *single day*. There was nothing atypical about May 3, 2018. Erosion of this magnitude is a regular occurrence in Iowa.

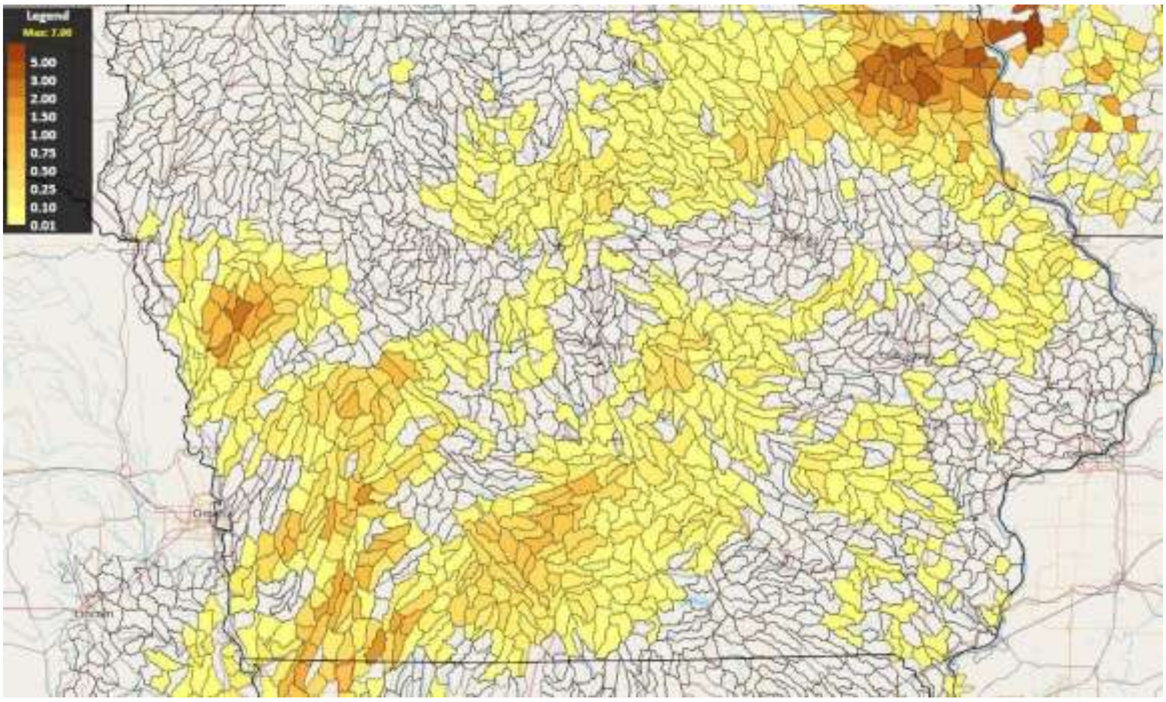


Figure 2. Daily Erosion Project map showing hillslope erosion estimates in U.S. tons/acre.

Iowa had an average topsoil depth of about 14 inches in 1850, which had declined to less than six inches by the year 2000. Visual evidence of both wind and water erosion is still commonplace (Figure 3). Farming methods in Iowa have clearly allowed unsustainable rates of soil erosion and land degradation to continue. It is even more clear that we cannot continue on this trajectory without serious consequences to human survival. Soil is the fundamental basis for most life on earth and we need farming practices that not only stop but reverse the trend of soil degradation.

Figure 3. Visible soil loss from water (left) and wind (right) erosion is still evident in Iowa.

Conversion of land from a diverse landscape to one dominated by corn and soybeans grown in monocultures and managed with synthetic chemicals has also had implications for the health of our soils (Montgomery, 2017). Soils with low soil organic matter (SOM) levels and poor biological nutrient cycling are more susceptible to erosion and nutrient loss. Our current system is still extremely productive, but serious challenges to long-term productivity need to be accounted for and remedied. These challenges are illustrated in Figure 4 (Image courtesy Dr. John Baker).

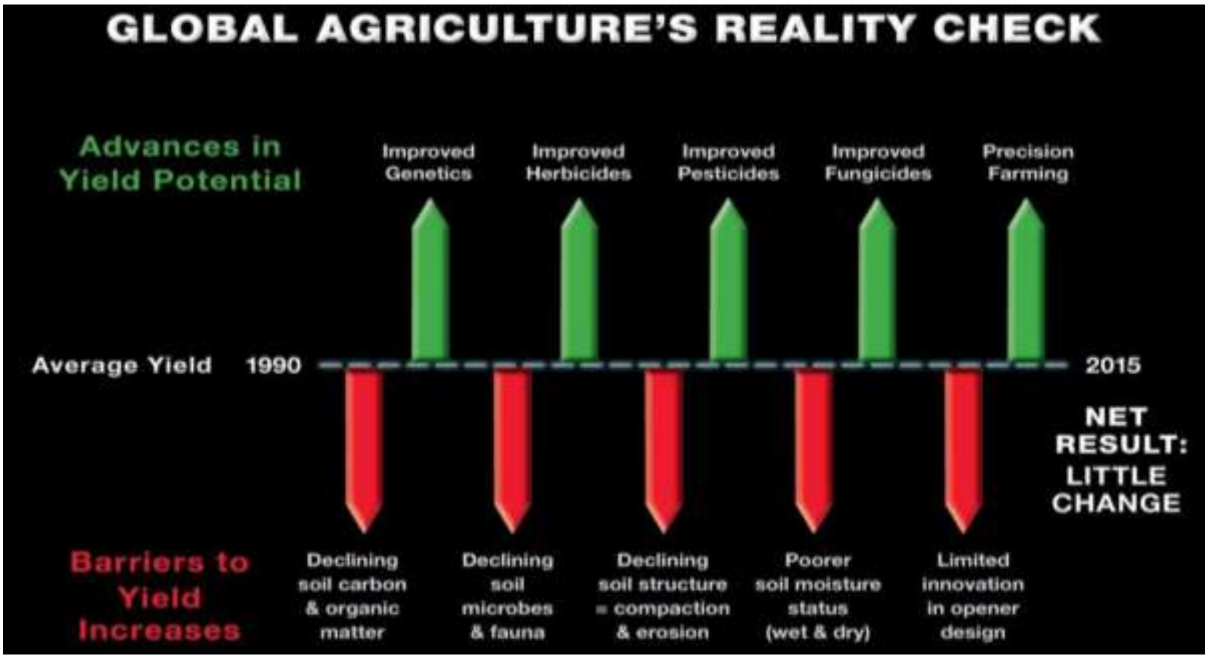


Figure 4. Advances in yield potential and barriers to yield increases.

Advancements in seed and technology have improved yields, but this has been offset by declining SOM levels and poor condition of soils. The result is that yield gains for many crops have slowed in recent years. We have tricked ourselves into thinking that we are passing the farm on to the next generation better than we found it because we have used technology (i.e. fertilizer and improved genetics) to improve yield and mask soil degradation. The good news is that soil is resilient and healthy soil can be regenerated to address many of these concerns.

What is healthy soil?

What is soil health and what makes one soil 'healthy' compared to another? This is a fundamental question. The answer depends upon the framework in which the term is being used. Soil health has been defined as the capacity of soil to function as a vital living system to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health (Doran and Zeiss, 2000). Al-Kaisi (2014) states that "*Soil health is a condition, or status, of the soil at a certain place and in a specific environment as compared to a certain reference or benchmark condition. However, the concept of soil health can vary in use based on the priorities placed on different soil functions. Therefore, the concept of soil health should be understood within the context and intention of the users of the soil health term, their goal, and the boundaries in which they are working.*" For the purposes of this report, as well as to prompt a wider discussion amongst the soil health community of the need for a more specific definition and methods for measuring soil health, I propose the following definition of what healthy soil is and how it should function.

A healthy soil:

- Provides an adequate supply of nutrients to aboveground biomass such that plants have no observable symptoms of nutrient deficiency or disease, with external nutrient applications at a rate not greater than that of nutrient removal via crop harvest.
- Has sufficient aggregation of soil particles such that water from a 25-yr 24-hr rainfall event infiltrates the surface rather than running off (see Appendix 3 for details).
- Has a rate of total soil loss via erosion that is not greater than the rate of soil formation.
- Does not leach nutrients into the environment at a rate greater than that of native (pre-row crop agriculture) habitat in a given area.

The relative health of a given soil would thus be measured by plant health indicators (visible and/or tissue sample analyses) and the rates of water infiltration, soil erosion, and nutrient loss to the environment beyond the crop field. Soil organic matter levels relative to pre-row crop agriculture should also be considered a primary measurement of soil health. This definition of soil health is admittedly exceedingly difficult to achieve with current farming practices, but it is important to define how an ideal soil would function so we have a goal to aim for. The definition considers not only the soil's ability to support healthy plant growth (and thus high yields), but also its ability to sequester and cycle nutrients and infiltrate water in a manner that does not lead to wider environmental degradation. The concept of infiltrating a given precipitation event is important and relevant to any discussion of soil health. It has direct implications for flood control and other ecosystem services that can be provided by soil and is an indicator of how well aggregated a soil is. Soil that supports healthy, productive crops while providing beneficial ecosystem services is ultimately the goal farmers and society should strive for.

The key to working towards these goals is to enhance plant diversity and beneficial biological activity in the soil. Research has shown that biological activity of soil can be successfully restored on land that has been farmed intensively by utilizing ecologically-based management practices (Kremer and Hezel, 2013). This idea is the basis of what is referred to as Regenerative Agriculture (RA).

What is regenerative agriculture?

Regenerative agriculture is an approach to farming that aims to regenerate topsoil, restore degraded soil biodiversity, enhance ecosystem services, improve water cycling, and increase the resilience of soils to extreme weather (Regeneration International, 2017; California State University, Chico, 2018). The 'regenerative' concept comes from the fact that a majority of our agricultural soils are currently degraded. The goal is to improve soil rather than just sustain it in a degraded state. Practices that minimize soil disturbance, incorporate diversified rotations and perennial corps, utilize livestock manure, and enhance biological activity in the soil could all fall under the category of RA. These practices have the potential to enhance yields by reversing soil degradation. There is much skepticism among farmers that they can implement these practices in a profitable manner. However, research has shown that diversifying crop rotations in Iowa can allow for substantial reductions in chemical usage without sacrificing profitability or yields (Liebman et al., 2013).

The details of how to implement these techniques are important, but more important is the change in mindset that comes with a regenerative approach to farming. The distinction between what makes a farmer 'regenerative' vs. 'conventional' is admittedly hard to define. One way to think of the difference is that conventional farming in Iowa has long focused on improving yield (maximizing gross income) as the primary goal or focus, with efforts to alleviate the negative consequences from the production system (e.g. downstream pollution) seen as less important or not something that farmers should be expected to do. The importance of soil carbon and biology to soil function receives little consideration in conventional farming systems. Regenerative farmers have instead started to focus on improving the soil (increasing SOM, infiltration rate, etc) as a primary goal, under the theory that net income will then increase over time and farming will be viewed as a benefit to the environment rather than a detriment. Managing soil carbon and biology is seen as the key to a successful farming operation. The need to prioritize soil ecosystem functions (e.g. water purification and biological nutrient recycling) is embraced. The increase in net income would come from maximizing nutrient use efficiency by utilizing soil biology to provide more crop inputs, thus reducing the need to purchase external inputs. They essentially strive to feed the soil and let the soil feed the crop, rather than trying to apply nutrients for direct crop uptake. It is a change in mindset and strategy compared to conventional farming.

It should be noted that the term ‘regenerative’ when applied to agriculture is a relatively new construct and is still poorly defined. Whether someone does or does not consider themselves a regenerative farmer is ultimately a personal decision. It is not dependent on the need to adhere to a specific set of practices or outcomes. The RA movement does not have a monopoly on good farming practices or holistic thinking, and many of the ideas discussed in this report may be utilized by farmers regardless of what, if any, label they use to describe themselves.

Chapter 1: Regenerative agriculture concepts

Regenerative agriculture primarily focuses on improving the health of soils and reducing external inputs. What a 'healthy' soil looks like will vary depending on climate, soil type, and other factors. Four basic principles for regenerating or maintaining healthy soil have been put forth by the United States Department of Agriculture Natural Resources Conservation Service (USDA NRCS) (NRCS, 2018a). These principles work by helping to restore biological activity to intensively farmed soils. Biological activity is a primary driver of soil aggregation (Wilpiszeski et al., 2019) and good aggregation is a key characteristic of healthy soil.

The soil health principles are:

1. Keep the soil covered as much as possible.
2. Maintain plant cover throughout the growing season to feed the soil.
3. Diversify cropping systems as much as possible.
4. Disturb the soil as little as possible.

Keep the soil covered

Keeping the soil covered with both living plants and crop residue helps to control both wind and water erosion. Residue prevents raindrops from impacting the surface directly, which can break up soil aggregates and dislodge particles from the surface. Figure 5 (Brady and Weil, 2010) shows this process in action. This can lead to soil compaction, surface sealing, and poor water infiltration. It also provides a mechanism for transfer of pathogens from soil to plants.

Soil cover also reduces evaporation from the soil surface. This can help maintain soil moisture during dry periods. Keeping the soil covered moderates soil temperature fluctuations, which is important because most plants and soil organisms are more sensitive to soil temperature than air temperature. Wide fluctuations in soil temperature cause stress in both plants and soil organisms (Brady and Weil, 2010). Soil cover can also supress weed growth and provide habitat for organisms at the soil surface. It is important to note that maintaining residue does come with challenges. Residue can serve as a disease carrier. It also tends to keep soils cooler and wetter, which can delay springtime field operations. Areas that normally have cool, wet soils in the spring may need to utilize strip-till or other minimum tillage to address this concern.

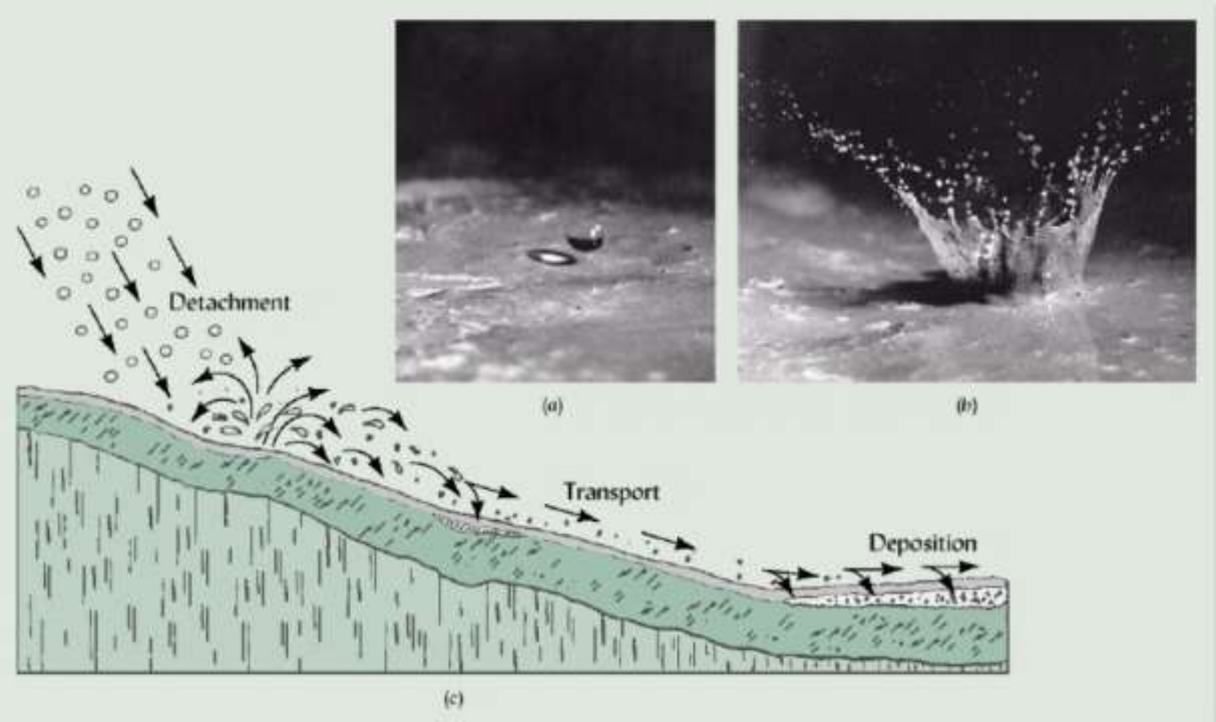


Figure 5. Soil erosion and transport processes.

Maintain plant cover throughout the growing season

Keeping plants growing for as long as possible during the year helps improve soil health by providing ‘food’ to soil organisms via plant root exudates. During photosynthesis, plants use sunlight, carbon dioxide (CO_2), and water to produce sugars and other carbohydrates. Plants leak a substantial portion of these sugars out of their root system in the form of root exudates, which provide a carbon source for microbes in the soil. In addition to crop residue and SOM, this carbon is one of the ‘food’ sources that help to sustain soil organisms. In exchange, these organisms provide nutrients to the plant that it cannot obtain on its own. Mycorrhizal fungi are particularly important in this respect. These fungi form symbiotic relationships with most terrestrial plants, including many agronomically important species. The fungi colonize the root system of a host plant, providing increased water and nutrient absorption capabilities, while the plant provides the fungi with carbohydrates formed during photosynthesis (Fulton, 2011). Mycorrhizae may also offer the host plant increased protection against certain pathogens (Harrier and Watson, 2004). It is this biological activity that is the driving force behind most nutrient cycling that takes place in the soil (Inderjit and Weston, 2003), and is the mechanism by which plants obtain most of the nutrients they need for growth and reproduction. This exchange forms the basis of what is known as the soil food web (Ingham, 2018). An example of the soil food web is included in Figure 6 (NRCS, 2018b). By maintaining living roots in the soil for as long as possible during the growing season, organisms that plants depend on are able to survive and the capacity of the soil to cycle nutrients is maintained. Living plants also provide habitat for the many aboveground organisms that complete the food web and recycle nutrients back into the soil.

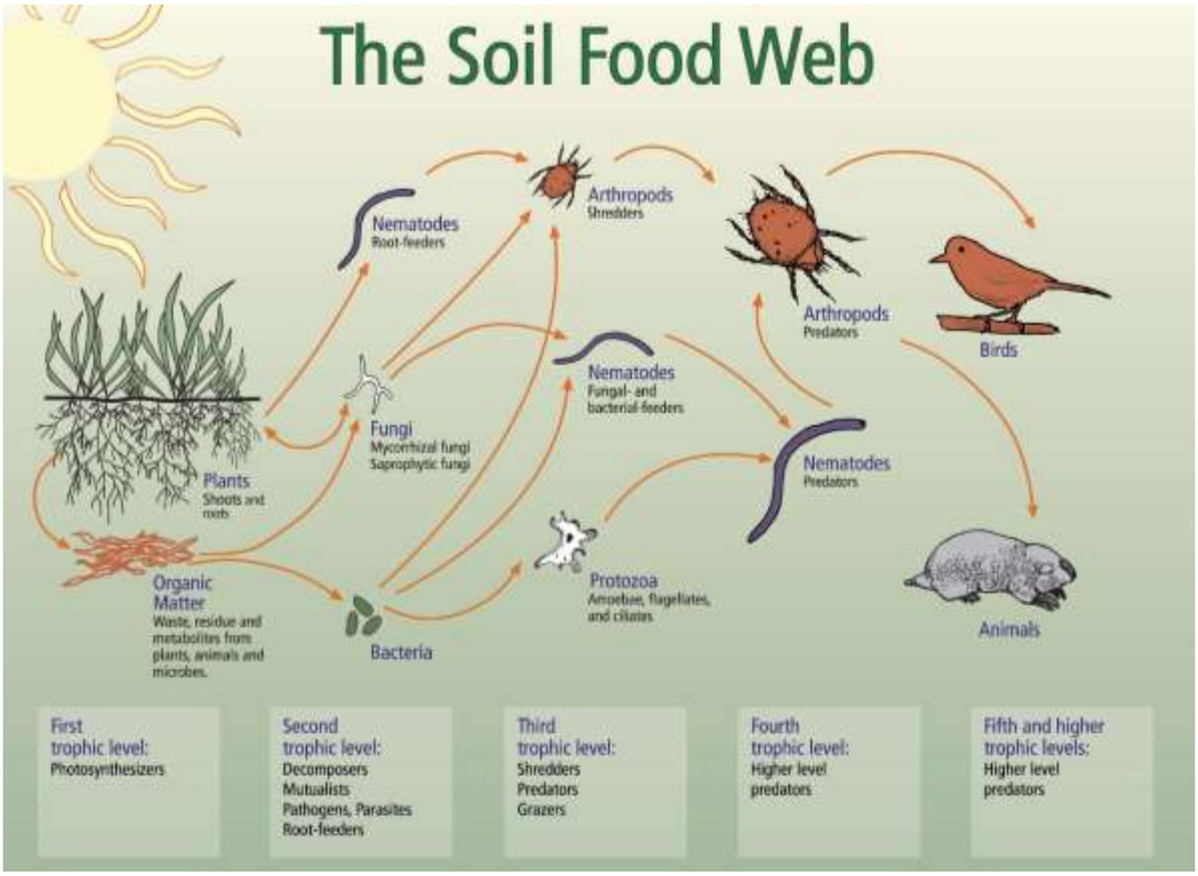


Figure 6. Soil food web relationships between above and belowground life.

Diversify cropping systems as much as possible

Maximizing the diversity of plants, as well as animals that feed on those plants, also helps to promote healthy soil. Providing a mixture of both warm and cool season grasses and broadleaf plants will ensure that a living root is present for as long as possible during the growing season. This can be accomplished in row crop corn-soybean systems via interseeding multispecies cover crop mixes. Each species of plant will interact with different organisms in the soil, thus maintaining belowground diversity as well. This diversity makes the system more resilient to extreme events because many of these diverse species can provide similar functions in the soil. Diversity can be maximized by growing multiple monocrops in rotation and changing the sequence of that rotation. Research by Gaudin et. Al (2015) found that increasing the diversity of crops grown in rotation in Canada helped to improve yield stability and mitigate weather variations. A meta-analysis of other research has shown that adding crops to a rotation increased soil carbon and nitrogen levels and increased microbial biomass (McDaniel et al., 2014). Another approach is to plant multiple species at the same time via cover crop mixtures or intercropping of two or more cash crops. These techniques can be combined in many different ways to maximize diversity within and across growing seasons. As Blake Vince, Canadian Nuffield Scholar stated, "*We need to think of soil organisms as our 'livestock' and we need to ensure that there is sufficient food to sustain and build the populations in the soil.*" Adding animals to the system can enhance this diversity and greatly speed up nutrient cycling. Livestock grazing can stimulate plant growth and root exudate production. Animals also digest plant residue and return manure to the soil, which can boost soil fertility and provide an additional source of microbes to the soil.

Disturb the soil as little as possible

Finally, minimizing disturbance is critical to maintaining soil health. Tillage can cause compaction and disrupt soil aggregation, nutrient cycling, and soil microbial activity (Bronick and Lal, 2005). Mycorrhizal fungi are particularly susceptible to damage from tillage (Kabir et al., 1997). Tillage also makes the soil more susceptible to erosion by burying plant residue and leaving the surface exposed to the elements. Good aggregation in soil allows for rapid water infiltration and provides pore space for air and water storage. Aggregates also provide a 'home' for soil organisms. Breaking up soil aggregates via tillage leads to more surface runoff, more erosion, and less water storage capacity in the soil. When soil is disturbed by tillage, excess oxygen enters the soil and leads to oxidation (release as CO_2) of carbon in SOM. Tillage has been described as the equivalent of an earthquake, hurricane, tornado, and forest fire occurring all at once to soil organisms (NRCS, 2011). There are sound agronomic reasons to till the soil in certain situations and soils can recover biological function after tillage. However, keeping tillage to a minimum will promote soil health.

Cultivate a regenerative mindset

Regenerative agriculture is more a mindset than a set of practices. A concept of the RA approach is that it attempts to address the root cause of problems in the field. A real-world example is illustrated by the conventional vs. regenerative approach to weed control. By 'listening' to weeds you can learn a great deal about what is happening in the soil. With a weed infestation, the conventional mindset asks, "What chemical do I need to control this weed?" The regenerative mindset asks "Why is this weed growing in my field? What conditions does it thrive in?" The regenerative approach is to study the physiology of the weed rather than the mode of action of the chemical. Does it thrive in anaerobic soils? Then the soil is likely anaerobic. A chemical may still be used to control the weed to solve the short-term problem, but the regenerative approach is to develop a strategy to get more oxygen into the soil. If that is done, then weeds that thrive in anaerobic soils will become less of a problem. Spraying the weed every year and doing nothing to address the root problem with the soil just kicks the can down the road. Eventually, the weed will develop resistance to the chemical and you will still be left with a weed infestation and the fundamental problem that the soil needs more oxygen. David Walston, UK Nuffield Scholar, concluded in his report that "*The more we use artificial fertilizers and pesticides, the more we need to use them again next year*". This illustrates the trap that RA tries to break out of. Excessive use of tillage is another example. Tillage is often used to break up hardpans, introduce more oxygen into the soil profile, and incorporate nutrients. These all have short term benefits. However, tillage can also create hard pans. Tillage breaks up soil aggregates, which reduces aeration in the long run. Bio-tillage (soil disturbance via plant roots and soil organisms) can slowly cycle nutrients throughout the soil profile over time, but this process can be both disrupted, or accelerated, with tillage. If a soil has poor biological function, as defined by the rate of breakdown of organic matter, then there is likely very little aggregation and bio-tillage will be minimized. This is the situation in some heavily tilled soils but continuing to till the soil in a way that prevents biology from re-establishing will not address the problem in the long run.

Chapter 2: Regenerative agriculture in practice

Farmers, researchers, and agribusiness professionals from around the world are working to implement RA and are finding ways to do so that improve environmental outcomes and financial stability of the farm. The following are some examples of how these concepts have been put into practice around the world.

Cover crops and agroforestry

Cover crops can help with three of the four soil health principles by maximizing soil cover, living roots, and plant diversity. These effects are maximized in areas where plant growth is continuous in all seasons. Cover crops can provide a ‘living bridge’ that feeds soil biology during periods when a cash crop is not present and can take up excess available nutrients from the soil after cash crop harvest and release them at a later time. The timing if this nutrient release will depend upon moisture and temperature conditions as well as species composition and stage of growth when the cover crop was terminated. This requires careful management to ensure that nutrient tie-up does not affect yields in the following cash crop. Cover crops can be thought of as an insurance policy for your soil. They can make soil more resilient to weather extremes by helping hold topsoil in place and adding organic matter to the soil. There are many strategies for including cover crops in a cropping system. These strategies will differ depending upon climate, crop rotation, available machinery, and other factors.

Figure 7. Julien Senez discussing the benefits of multispecies cover crop mixes.

Julien Senez farms in the Vignemont region of France and has been using cover crops for many years. He recommends doing worm counts as a cheap and easy way to monitor soil health and determine which cover crop mixes work the best for a given farm. Senez believes that cover crops must be multifunctional to be worth the investment. He employs a strategy of planting cash crops within the cover crop mix (Figure 7). He can then make a decision at several points during the growing season depending upon plant growth and stand density. If the cash crop (i.e. rape) is doing well, he will harvest it in the spring after the other species in the mix have winterkilled. If the cash crop is not doing well, it just becomes another species in the cover crop mix and will be terminated to allow for establishment of a different cash crop. This provides significant flexibility along with the potential to capture income from the cover crop mix.

Senez believes that there are five keys to making cover crops work:

1. Plant several species together to add diversity and have different root structures present.
2. Fertilize the cover crop with nitrogen.
3. Monitor soil pH.
4. Drill the cover crop seed within one week of harvest.
5. Drill the seed 1.5 to 2.5 inches (38-64 mm) deep (except clovers) to ensure adequate moisture around the seed for germination.

He stated that a properly managed cover crop field is "*A big lake of nitrogen and water*" that will be there for the following cash crop to use (Senez, 2018). He is also experimenting with agroforestry, which is a strategy of growing rows of trees between crop fields (Figure 8). He has some 30 m (100 ft) and 60 m (200 ft) wide strips with trees along the edges. The plots have provided very good control of slugs and mice, which cause significant crop damage in the area. The tree rows provide habitat for ground beetles that eat the slugs. The beetles can only travel about 30 m (100 ft) so 60 m (200 ft) is the maximum strip width for effective control. The tree rows also attract field mice and help keep them out of the crop field. He places perches in the tree rows to attract birds that eat the mice. In addition to reducing pest pressure, there will be income from timber harvest longer term. This example of a synergistic approach to crop production has benefits both environmentally and economically. There is interest in implementing agroforestry techniques in Iowa. This practice is worth investigating further as a compliment to cover crops and diverse crop rotations to diversify revenue streams on the farm.

Figure 8. Strips of trees in the experimental agroforestry plots on Julien Senez's farm.

Cover crop 'money strip' trials

John Deverel farms with his family in the county of Dorset in southern England. The Deverels have been experimenting with cover crops for several years. They have also participated a rather innovative trial to test different cover crop mixes based on cost and species mix. Deverel stated that he likes to sow cover crops in 'money strips', i.e. strips of different mixes based on seed cost. Planting these different mixes in a criss-cross pattern allows the Deverels to study the interaction of many different cover crop species in different mixes based on cost. They can evaluate the performance of each mix and determine whether the cost of a given mix is worth the investment. This concept is illustrated in Table 1 (Table courtesy Wessex Water, Bath, UK). The individual species or mixes on the X axis are seeded across the top of those same species or mixes at a 90-degree angle, resulting in a checkerboard pattern as seen in Figure 9 (Figure courtesy Wessex Water, Bath, UK).

This is a relatively quick and easy way to compare multiple mixes using a rather small area of the field. Through this collaborative research with Wessex Water, the regional water and sewer company that services the Deverels farm, they have found that nitrate-N leaching increased with later seeding dates, with the latest sown cover crops leaching more than a bare stubble comparison (Wessex Water, 2018a). Sowing cover crops earlier in the season led to the greatest reductions in nitrate-N leaching from the fields. Oilseed radish was shown to have the greatest uptake of N when seeded in early August (Wessex Water, 2018b).

Table 1. Trial layout with X and Y axes representing cover crop species and cost.

Y \ X		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
		Oil Radish £10/ha	Phacelia £5/ha	Phacelia £10/ha	Linseed £5/ha	Linseed £10/ha	Buckwheat £5/ha	Buckwheat £10/ha	Vetch £5/ha	Vetch £10/ha	Spring Oats £10/ha	Spring Oats £15/ha	Spring Oats & Linseed £10/ha	Oil Radish & Phacelia £10/ha	Phacelia, Vetch, Lupin, Berseem Clover, Linseed £10/ha	Buckwheat, Linseed, Phacelia, Fodder Radish, Red Clover £10/ha	Buckwheat, Linseed, Phacelia, Fodder Radish, Red Clover £15/ha
1	Oil Radish £10/ha	1A	1B	1C	1D	1E	1F	1G	1H	1I	1J	1K	1L	1M	1N	1O	1P
2	Phacelia £5/ha	2A	2B	2C	2D	2E	2F	2G	2H	2I	2J	2K	2L	2M	2N	2O	2P
3	Phacelia £10/ha	3A	3B	3C	3D	3E	3F	3G	3H	3I	3J	3K	3L	3M	3N	3O	3P
4	Linseed £5/ha	4A	4B	4C	4D	4E	4F	4G	4H	4I	4J	4K	4L	4M	4N	4O	4P
5	Linseed £10/ha	5A	5B	5C	5D	5E	5F	5G	5H	5I	5J	5K	5L	5M	5N	5O	5P
6	Buckwheat £5/ha	6A	6B	6C	6D	6E	6F	6G	6H	6I	6J	6K	6L	6M	6N	6O	6P
7	Buckwheat £10/ha	7A	7B	7C	7D	7E	7F	7G	7H	7I	7J	7K	7L	7M	7N	7O	7P
8	Vetch £5/ha	8A	8B	8C	8D	8E	8F	8G	8H	8I	8J	8K	8L	8M	8N	8O	8P
9	Vetch £10/ha	9A	9B	9C	9D	9E	9F	9G	9H	9I	9J	9K	9L	9M	9N	9O	9P
10	Spring Oats £10/ha	10A	10B	10C	10D	10E	10F	10G	10H	10I	10J	10K	10L	10M	10N	10O	10P
11	Spring Oats £15/ha	11A	11B	11C	11D	11E	11F	11G	11H	11I	11J	11K	11L	11M	11N	11O	11P
12	Spring Oats & Linseed £10/ha	12A	12B	12C	12D	12E	12F	12G	12H	12I	12J	12K	12L	12M	12N	12O	12P
13	Oil Radish & Phacelia £10/ha	13A	13B	13C	13D	13E	13F	13G	13H	13I	13J	13K	13L	13M	13N	13O	13P
14	Phacelia, Vetch, Lupin, Berseem Clover, Linseed £10/ha	14A	14B	14C	14D	14E	14F	14G	14H	14I	14J	14K	14L	14M	14N	14O	14P
15	Buckwheat, Linseed, Phacelia, Fodder Radish, Red Clover £10/ha	15A	15B	15C	15D	15E	15F	15G	15H	15I	15J	15K	15L	15M	15N	15O	15P
16	Buckwheat, Linseed, Phacelia, Fodder Radish, Red Clover £15/ha	16A	16B	16C	16D	16E	16F	16G	16H	16I	16J	16K	16L	16M	16N	16O	16P

Figure 9. Aerial view of the 'chequerboard trial' plot on the Deverel Farm.

Deverel believes that it is better to seed a cover crop earlier in the season and go with a lower seeding rate, as this results in bigger plants with bigger root systems, which is a key benefit to planting cover crops. He will increase the seeding rate later in the cropping season to make up for a lower germination rate. Deverel's overall philosophy for planting cover crops is that "*The sunshine from August to March goes into the cover crop and feeds the soil, and the sunshine from April to July is the sunshine that we sell*" (Deverel, 2018). Other practices the Deverels follow include changing the tillage direction every year to minimize soil movement across the field and harvesting at an angle to even out residue distribution.

Cover crops with direct drilling, controlled traffic, and variable rate seeding

Richard Squire owns and operates Bassmead Manor Farm, a 688 ha (1,700 ac) estate near St. Neots, England. Squire is implementing cover crops to try to increase SOM levels because he does not have livestock or access to manure. He is transitioning away from tillage and plans to direct-drill his entire farm next year. He believes that this will help to improve soil health and to prevent new weed seeds from being brought to the surface (Squire, 2018).

Figure 10. The author (left) investigating soil structure with consultant Mark Dewes (center) and Richard Squire (right).

The inability to break up wheel compaction with tillage can be a serious concern with direct-drilling. Squire believes that controlled traffic farming (CTF) is vital to make direct drilling work. Controlled traffic farming utilizes tramlines where wheel traffic from all equipment always follows the same path. A recent review reported increased yields in wheat (8%), barley

(26%), oats (28%), corn (17%), and other crops when CTF was implemented (Gowdin et al., 2015). Farmers should evaluate the economic payback of equipment modifications to make CTF work on their own operation. An alternative to CTF is to use a low ground pressure system (low tire pressure) for wheel loads up to around 5 tons (Gowdin et al, 2015).

Squire also uses soil mapping to even out plant density in his cash crops and cover crops. He uses variable rate seeding equipment to apply up to twice the seeding rate in poorer soils compared to his best soils to compensate for poor germination. This has resulted in much more even stands and helps reduce in-field variability. Squire has also experimented with arbuscular mycorrhizal fungi (AMF) inoculants. These fungi form a symbiotic relationship with about 80% of plant species and provide water, nutrients, and pathogen protection to the plant in exchange for photosynthetic products (Berruti et al., 2016). Squire is using AMF inoculants after oilseed rape has been grown to try to boost AMF populations. Oilseed rape is a brassica, which is a family of related species that do not form mycorrhizal associations in the soil. In their review of AMF inoculation research, Berruti et al. found that AMF inoculation overall produced positive outcomes on plant production in open-field conditions. Farmers hoping to boost soil fungal populations should consider doing on-farm trials to see if AMF inoculants provide a benefit in their own operation.

Biological amendments

Biological amendments and an important component of RA on many farms. Biological amendments refer to any amendments containing biological materials. These can be applied directly to soil, as a seed treatment, or as a foliar spray. The general approach with biological amendments is to provide plants and/or soil with nutrients and biology that are lacking in the system. Biological nutrient cycling is the dominant mechanism by which plants obtain necessary nutrients. By using biological amendments, farmers are attempting to tap into the inherent potential of soils to provide nutrition to plants. They differ from chemical amendments in that they tend to be targeted more towards improving the biological functioning of the plant-soil system. In a chemical farming system, inorganic nutrients are typically soil-applied in the hope that the plant will access them. This can lead to problems if not properly managed. Applying excessive synthetic N disrupts natural nutrient cycling by providing N that is already in a plant-available form (Matson et al., 1997). This usually results in good plant growth, but problems with the timing of N availability vs. when plants need it can lead to excess losses to the environment. Biological amendments (i.e. compost, seaweed fertilizers, humic substances) tend to contain carbon along with other nutrients. Carbon is the primary ‘food’ source for most soil microorganisms, thus these products are promoted as being more compatible or beneficial to soil biology relative to inorganic fertilizers. The ratio of carbon to nitrogen (C:N) influences the immediate availability of nitrogen and determines the rate of organic matter breakdown in soils (Barbarick, 1996). Thus, adding a carbon source along with nitrogen fertilizer can help maintain a desired C:N balance.

John Barnes is the director of Fertilizer New Zealand Ltd., a company that produces biological amendments. He is often questioned about how he can achieve large yield improvements with a small amount of biological amendment. He responds with “*How can you use so much fertilizer and get so little in return*.” He stated that you cannot fix soil problems quickly, but you can fix plant problems quickly by using foliar fertilizers to get the correct plant nutritional balance. Foliar application works by applying liquid fertilizer directly to the plant, where it is absorbed through the stomata and epidermis of the leaf. This gets nutrition to the plant more quickly and efficiently than applying it to the soil and waiting for uptake through the root system. “*You don’t typically need more fertilizer, you need more life in the soil to make fertilizer work*” stated Barnes. The trade-off with foliar fertilization is that it may require multiple applications to meet plant needs, as foliar nutrient uptake is limited to smaller application amounts than is possible with direct soil fertilization. A review of foliar application research by Fageria et al. (2009) found that foliar application can be more economic and effective than soil application in certain circumstances for correcting plant nutrient deficiencies based on plant tissue tests or visual deficiency symptoms. They noted that soil application is most effective for nutrients required in high amounts (e.g. nitrogen) and that correct diagnosis of nutrient deficiency is important for successful foliar fertilization.

Moving away from a mindset based upon chemical farming methods that have been prevalent for decades can be a difficult adjustment. It requires a deep understanding of biological functioning in cropping systems to be successful. However, farmers should consider foliar application as a means to correct plant nutritional deficiencies. On-farm experimentation with biological amendments on a small scale is a good strategy to see which amendments work for the specific conditions on a given farm.

Composting

Composting is another strategy commonly used in RA. While composting may not be a viable option on some farms, it could be utilized more widely than is being done today. Camperdown

Compost Company in Victoria, Australia has shown that compost is a viable strategy for fertilizing large areas of land. The company began making compost from food processing and other waste in 1998. They also teach farmers how to make compost on-farm and have a side business providing compost turning services. Compost piles need to be stirred or 'turned' regularly to maintain the desired temperature and oxygen level in the pile for proper composting. A compost turner is pictured in Figure 11. They now convert about 110,000 tons (US) of waste into compost annually, enough to spread on almost 61,000 ha (150,000 acres) each year.

Figure 11. Compost turner designed to rotate for easier towing on public roadways.

The company's customers have reported fewer weeds in their pastures, more robust plant growth, higher income, and lower input costs when using compost. The company believes that compost helps protect soil and plants against pathogens, retains nutrients so they are less susceptible to leaching, and improves the uptake of soil or foliar nutrients. Compost provides N in an organic form (combined with carbon) which is more stable in the soil compared to inorganic N. Nick Routson from Camperdown Compost believes that compost is only part of the puzzle of a soil fertility program, and the successful farmers are those that are good at putting the puzzle pieces together. Routson stated that "*What we are trying to do is improve the soil. Everything else – carbon storage, water storage, etc. comes from that*". He believes that we need to transition away from large applications of water-soluble nutrients that are easily leached form the soil. Compost has the advantage of having nutrients that are plant available yet more stable in soil. However, Routson stated that "*Even free compost is not as good as growing soil carbon in-situ with plants.*" He believes that the land manager is the key to whether or not carbon is sequestered on the soil. He has observed that the best RA farmers were once the best conventional farmers. "*They made the switch because they pushed the conventional system as far as it could go and realized something was missing. It all comes back to the professionalism of the farm manager*" said Routson. "*Good farmers embrace complexity*". The missing ingredient has been the lack of recognition that soil carbon and biology are of fundamental importance to soil function.

Making compost extracts or compost teas is one way to cover much more area with much less compost than can be done with spreading compost directly. This method involves submerging the compost in approximately 15°C (60°F) water and using aeration to extract organisms from the compost (Figure 12). This mixture is called compost extract if it is sprayed on fields directly. It can also be mixed with a food source for the organisms (e.g. fish hydrolysate) in warmer water at about 21°C (70°F) for 24 to 48 hours. This is considered a compost tea. This process makes the organisms more active, but the mixture is less stable and must be applied immediately.

Figure 12. Michael Luebbers making compost extract with a GeoTea™ compost tea brewer for field application near Waverly, Iowa.

Michael Luebbers, NRCS Soil Conservation Technician from Waverly, Iowa is working with farmers in that area to help them make compost teas and extracts. Luebbers uses a microscope to assess the quality of the compost and compost extract products. He stated that starting with a good quality aerobic compost is critical. Compost teas have been shown to provide weed and disease suppression in some cases (Ozores-Hampton,1998; Recycled Organics Unit, 2006; Dearborn, 2011). Luebbers and area farmers will be assessing benefits of the technique.

Assessing soil health

Soil health testing is an important yet problematic component of RA. An ideal soil health test would reflect the physical, chemical, and biological condition of the soil. There are many different soil tests that attempt to measure some component of soil health, yet many lab procedures are too time consuming or expensive (e.g. soil aggregate stability) for widespread on-farm use. As proposed in the introduction, plant health, water infiltration rate, soil erosion rate, nutrient loss to the downstream environment, and soil organic matter levels relative to pre-row crop agriculture should be considered primary measurements of soil health. They are indicators of the status of multiple ecosystem services provided by soil. Plant health can be assessed via visual inspection and/or tissue testing. Infiltration rate can be easily assessed on-farm. A link to information on how to perform an infiltration test is included in Appendix A under *Soil health testing resources*. Erosion rate and downstream nutrient loss requires costly equipment to measure, but an estimate of soil erosion rates from a given field are available from USDA NRCS. Estimates of nutrient loss from different cropping systems and cropping practices are available from many U.S. land grant universities. Soil organic matter levels can be assessed and tracked over time with a standard chemical soil analysis.

Secondary methods of assessing soil health include tests for nutrient concentration, nutrient availability, and biological activity. The difficulty with tests of biological activity lies in the fact that the biological status of the soil is constantly changing, thus these tests tend to be more variable and subjective. A few of these secondary strategies for assessing soil condition are detailed below. There are numerous strategies for soil testing and many companies that offer soil health testing services, some of which are listed in Appendix 1.

Visual soil assessment

The most common tool for ‘measuring’ soil health for many RA farmers is simply visual inspection of the soil with a shovel. Many farmers that were interviewed as part of this study stressed the importance of carrying a shovel and looking at the soil regularly. During my farming career I spent thousands of hours looking at the soil on our farm. The problem was that I was looking out the back window of the tractor as I was pulling an implement through the field. I was never taught how to visually inspect the soil or why it was important. This is a common failure of many soil science classes taught around the world but is starting to change. Visual inspection costs nothing and can reveal many problems with soil health and related plant performance issues. Seeing and smelling the soil can provide a wealth of information for the experienced practitioner. Visual assessment can identify compacted layers, poor soil structure, root growth patterns, changes in soil color, and presence or absence of earthworms and other soil organisms. Biologically active soils tend to have an ‘earthy’ odor when wetted. This odor is partly caused by bacteria belonging to the genus Streptomyces (Meganathan, 2019). One of these bacteria produce spores that release a compound called geosmin, which translates to ‘earth smell’ in Greek. If the soil has an ammonia or rotten odor that is an indication there is poor drainage or lack of oxygen in the soil. Soil with no odor at all can indicate a lack of biological activity at that time. Anyone can learn to visually assess soil and there are several assessment tools available free of charge to help with this. A list of soil health testing and assessment resources is provided in Appendix 1. Visual soil assessment should be considered a necessary and important practice for all farmers.

Soil chemical analysis

Chemical analyses of soil rely on various analytical methods to determine the concentration of a given element in the soil. Soil chemical analyses are already performed on many farms and a standard test for macro and micronutrients should be performed at least every three to four years to track organic matter and nutrient concentrations.

Terry Hehir is an organic dairy farmer and walnut grower near Wyuna in Victoria, Australia. Hehir uses chemical analyses to track changes in his soil over time. Hehir described his approach to soil health as the Albrecht system, overlaid by biological agriculture. The Albrecht approach focuses on balancing the ratios of cations in the soil. The approach has been intensely debated in the scientific literature, with many scientists arguing that the approach is outdated and invalid. However, many farmers use the cation balancing approach and have had success with it. Detailed descriptions of the approach are beyond the scope of this report but can be found in such books as *The Biological Farmer* (Zimmer and Zimmer-Durand, 2017) and *Hands On Agronomy* (Kinsey and Walters, 2013). Hehir stressed the importance of properly balancing calcium (Ca) and magnesium (Mg) and has witnessed what he referred to as “*A staggering change*” in soils over 20 years using this approach. This is shown in Figure 13, where soil in a newly acquired field is pictured on the left and soil after 20 years of management by Hehir is shown on the right. Hehir has been able to increase his Ca:Mg ratio from around 1.25:1 to 4:1 and SOM levels have increased from around 1.2% to between 3.2% and 4.6% over the 20-year period. Cation exchange capacity (CEC) has also increased from around 14 to 25 or higher during that time.

Figure 13. The same soil type on neighboring fields with a noticeable difference in color.

Hehir explained that as Mg levels increase the amount of N needed by plants increases, which is one of many reasons why Ca:Mg ratio is important. Adding calcium to soil can help improve soil aggregation. Calcium is positively charged and thus helps negatively charged clay particles stick together. Liming the soil with calcium-derived products also increases the pH of acidic soils. Hehir relies on a soil consultant to provide test results and recommendations. Example soil test reports for a recently acquired farm as well as a farm under Hehir's management for 18 years are in Appendix 2.

Table 2. The effect of Ca:Mg ratio on water stable soil aggregation.

Ca Base Saturation %	Mg Base Saturation %	Ca:Mg ratio	Water stable soil aggregate %
70.0	11.5	6.1:1	40
61.5	14.7	4.2:1	40
53.0	16.0	3.3:1	36
41.0	36.0	1.1:1	33

The impact of Ca:Mg ratio on soil aggregation was demonstrated in a University of Missouri experiment shown in Table 2 (Reinbott, 2019). As the Ca:Mg ratio dropped below approximately 4:1, the percentage of water stable soil aggregates decreased. Tim Reinbott, Assistant Director at the Agricultural Experiment Station in Columbia, Missouri stated that *"We set out to prove Albrecht wrong, but it turns out he was on to something"*. It is important to note that the beneficial effects on aggregation may be due to the benefits of adding more Ca, rather than the Ca:Mg ratio specifically.

Soil biology tests

Richard Squire has experimented with soil biology testing on Bassmead Manor Farm. He uses a soil health testing service provided by Lancrop Laboratories in York, England. It provides measurements of soil bacteria, fungi, and other organisms (Table 3) and gives guidelines for desired levels along with explanations for each category.

Table 3. Soil biology test results provided by Lancrop Laboratories.

Analysis	Result	Guideline	Interpretation	Comments
Total Bacteria (ug/g)	333	175	High	Total bacterial biomass is above the optimum range in this sample.
Total Fungi (ug/g)	82	50	Normal	Total fungal biomass is within the optimal range in this sample.
Active Bacteria (ug/g)	18.47	5.00	High	Only aerobically active bacteria aid plant growth by breaking down simple carbon compounds and providing nutrients to the plant. Aerobic bacterial activity is above the optimal range in this sample indicating that the bacterial biomass will continue to increase.
Active Fungi (ug/g)	1.7	1.0	Normal	Aerobically active fungi decompose complex carbon compounds, aid soil structure and retain nutrients in the soi making them available for plant uptake. Aerobic fungal activity is within the optimum range in this sample.
Hyphal Diameter (um)	2.60	2.60	Normal	Fungal hyphae extend from the plant root-fungal interface into the surrounding soil. Larger diameter hyphae can access greater amounts of water and nutrients.In this sample the hyphal diameter is above the optimal level.
Tot Fungi/Tot Bact	0.25	0.20	Normal	Plants earlier along the successional line, such as grasses and brassicas, require a more bacterial dominated soil. Plants further along the successional line, such as shrubs and trees, require more fungal dominated soils.In this sample the bacteria to fungi ratio is within the optimal range.
Active/Total Fungi	0.02	0.25	Very Low	Higher levels of fungal activity will increase beneficial fungal populatiions. A low ratio may mean the soil has a higher proportion of anaerobic, potentilly detremental, fungi.In this sample the ratio of active to total fungi is below the optimal range.
Active/Total Bact	0.06	0.25	Low	Higher levels of bacteriall activity will increase beneficial bacterial populatiions. A low ratio may mean the soil has a higher proportion of anaerobic, potentilly detremental, bacteria.In this sample the ratio of active to total bacteria is below the optimal range.
Act. Fungi/Act. Bact	< 0.1	0.75	Very Low	Bacterial activity predominates in this sample.
Ciliates (No/g)	< 1	50	Very Low	Protozoa play an important role in mineralising nutrients into plant available forms. They also regulate bacterial populations and help supress disease by competing with or feeding on pathogens. Ciliates are the largest protozoa and feed on other protozoa and bacteria.In this sample the population of cillate protozoa is below the optimal range.
Flagellates (No/g)	15975	10000	Normal	Protozoa play an important role in mineralising nutrients into plant available forms. They also regulate bacterial populations and help supress disease by competing with or feeding on pathogens. Flagellates are the smallest protozoa and feed primarily on bacteria.In this sample the population of flagellate protozoa is in the optimal range.
Amoebae (No/g)	9787	10000	Slightly Low	Protozoa play an important role in mineralising nutrients into plant available forms. They also regulate bacterial populations and help supress disease by competing with or feeding on pathogens. Amoebal protozoa live at the root surface and feed on bacterial populations.In this sample the population of amoebal protozoa is below the optimal range.

The proportion of bacteria to fungi in the soil is one indicator of soil health. Bacterially dominated soils are generally thought to indicate excessive tillage, because tillage can prevent establishment and growth of fungi. The proportions and types of bacteria and fungi will also depend on what crop(s) are grown. Greater above-ground diversity generally leads to greater below-ground diversity, which is thought to reduce plant disease pressure and increase the resiliency of the soil to extreme events (Montgomery and Biklé, 2016). Several companies offer tests that measure the biological activity or presence of certain species in the soil. A partial list is included in Appendix 1. Soil organisms vary geographically due to different topography, soil types, SOM levels, and other factors. They also cycle rapidly in response to weather, plant growth, and management practices. Frequent sampling is needed to identify shifts in soil microbiology. It is very important to be consistent when taking soil samples for biological analyses. Samples should be taken at the same location, depth, and time of year and submitted to the same lab. This is especially true if comparisons of change over time will be made. Soil biology assays can be a useful tool for determining species presence and abundance, but knowledge of which species are 'good' or 'bad' and at what level for a given soil is lacking. They should be used with caution.

Microscopic analysis

Microscopic analysis is becoming more common as interest in soil biological analysis increases. Using a microscope to analyse soil requires some training and experience. Several companies now offer microscopic analysis or provide classes to teach people how to use a microscope to evaluate soil and compost. Some farmers practicing RA have invested in their own microscope to learn more about what is happening in their soils or compost and to satisfy their general curiosity about soil life.

Dave Beecher is a soil consultant in Ireland who uses a microscope to evaluate soil. He explained that knowing what organisms are present in the soil can tell you a lot about how that soil is functioning biologically. Protozoa species, for example, play an important role in nutrient availability. Protozoa and nematodes have a lower concentration of nitrogen in their cells (higher C:N ratio) compared to bacteria that they feed on (Ingham, 2019). When protozoa consume bacteria, some of the excess N in the bacteria is released as ammonium (NH_4^+), which is a form of N that plants can easily take up. Ciliates are a group of protozoa that consume bacteria and release inorganic N. If certain species of ciliates (Metopids) are dominant in the soil, this can be an indication of anaerobic conditions (Foissner, 1999).

Whether soils are more bacterial or fungal dominated can also be assessed with a microscope. Testate amoebae and ciliates are common in fungal-dominated soils, whereas naked amoebae and flagellates predominate in soils that are bacterially-dominated (Ingham, 2019).

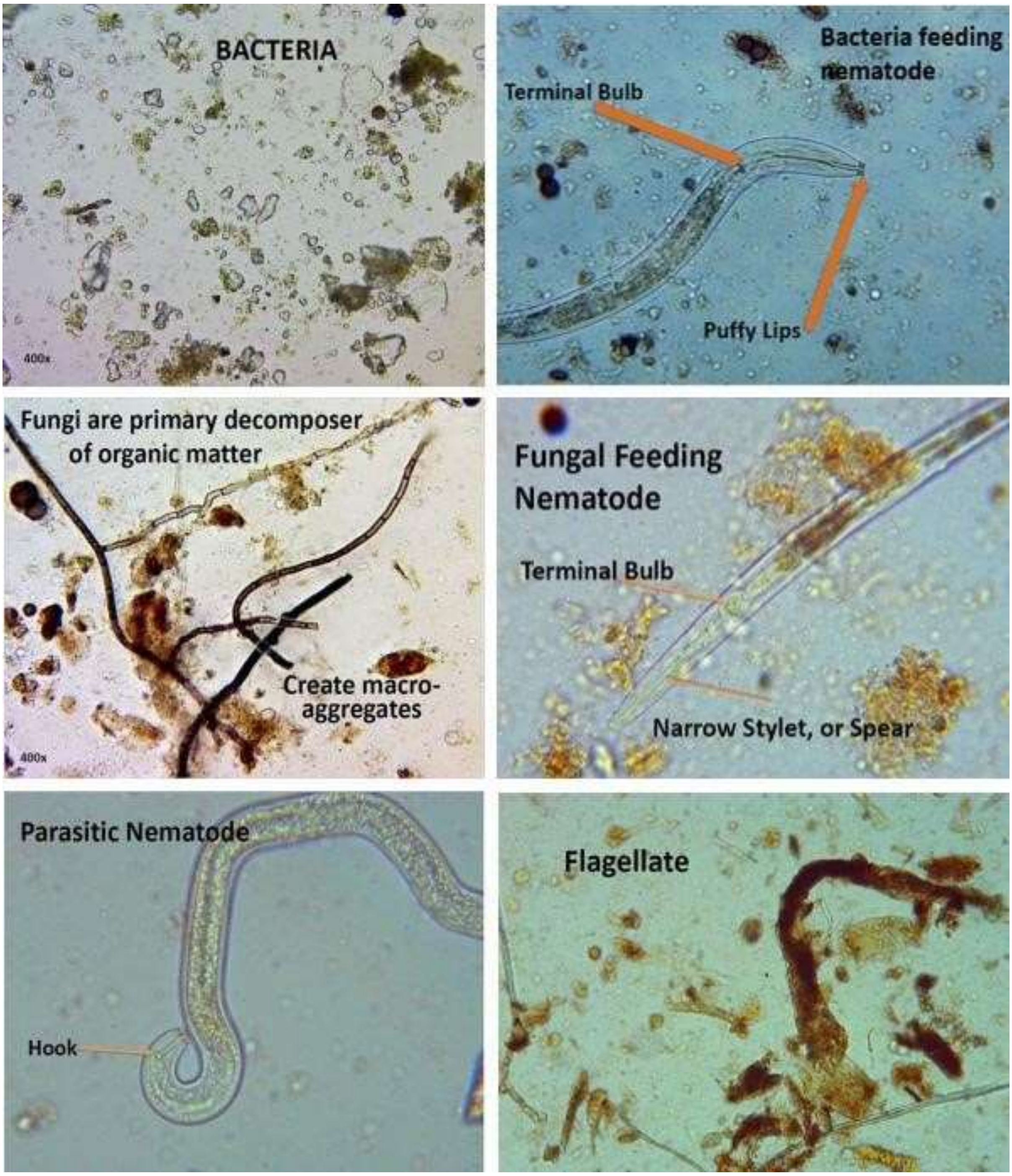


Figure 14. Identification of microscopic species by shape.

Knowing what is present or absent in the soil indicates how well the soil food web (Figure 6) is performing. Beecher explained that a healthy soil requires balance and good nutrient cycling requires that all the food web components are present in the desired proportions.

Soil organisms can be identified by their different shapes (Figure 14). Looking at the soil under different levels of magnification will reveal different information about the soil. Magnification at 10x to 50x will show soil structure and pieces of organic matter as well as larger soil organisms. Magnification of 400x or more will show fungal hyphae and bacteria. Beecher recommends that beginners start out by looking at compost rather than bulk soil. Compost typically contains more organisms per unit mass than soil, making it easier to find and identify different organisms. As with soil biology assays, a microscope can be a useful tool for determining species presence and abundance, but the importance of this for a given soil is uncertain and it requires skill and training to use. Caution should be used when making management decisions based upon microscopy.

Chapter 3: Making the change to a regenerative system

Regenerative agriculture involves taking the best ideas from conventional, organic, and biological systems and combining them. It is not necessarily about eliminating the use of synthetic fertilizers or chemicals. Rather, it recognizes the cost and inefficiency of purchasing something that nature can provide for free. Air, sunlight, and rainwater cost nothing. Everything else is an expense. Regenerative agriculture follows the logic of making the most out of these free resources. Massive amounts of free solar energy are wasted when the soil is left bare. Cover crops, multi-cropping, rotational grazing, and other RA practices are efficient because they allow more solar energy to be captured for a longer portion of the year and turned into plant and animal biomass. Capturing this solar energy is more challenging in dry climates, but farmers have shown that it can be done. Regenerating life in the soil further benefits the system. In a poorly functioning soil nutrient cycling is slow and organic matter degrades, so the missing inputs need to be replaced with more fertilizer. It is important to determine what is causing the poor functioning and address those issues when switching to a regenerative approach to soil management. Combining this with utilization of symbiotic relationships among different species can reduce the need for purchased fertilizers and pesticides.

Is there and economic advantage with RA?

There is much skepticism that regenerative farming practices will provide a return on investment, but there are many real-world examples of farmers practicing RA that have increased profitability while maintaining production from the cropping system (Montgomery, 2017; Brown, 2018; Bennett, 2019). It can be difficult for farmers to track and assign a specific economic value to the benefits of cover crops and other RA practices, but such value certainly exists (Environmental Defense Fund, 2019). Peer-reviewed research comparing RA practices to conventional management is lacking. More university research looking at the short and long-term profitability of different farming systems would be of great value. For now, we mostly rely on research done by farm organizations and the on-farm observations of RA managers. However, there is a small body of literature on the subject that suggests RA can be competitive from an economic standpoint. Liebman et al. (2013) stated that *"diversification of the dominant corn–soybean rotation with small grains and forage legumes can permit substantial reductions in agrichemical and fossil hydrocarbon use without compromising yields or profitability*'. LaCanne and Lundgren (2018) evaluated the effects of regenerative and conventional corn production systems in the northern corn belt in the United States. They concluded that "*Regenerative farming systems provided greater ecosystem services and profitability for farmers than an input-intensive model of corn production".* The Rodale Institute in Kutztown, Pennsylvania has been conducting the Farming Systems Trial® since 1981. This trial has shown that organic systems had equivalent corn and soybean yields after a five-year transition period (Rodale Institute, 2011). The organic system was more profitable given the premium paid for organic crops. Organic and regenerative systems may be managed differently, but the trial shows that conventional management is not a prerequisite to high yields or profitability.

An in-depth report by Sustainable Agriculture Research & Education (SARE) looked at the economics of using cover crops in row crop production (Meyers et al., 2019). The report includes survey data showing U.S. yields increased on average in both corn (1.3% to 9.6%) and soybeans (2.8% to 11.6%) following cover crops versus comparably managed fields with no cover crops between 2012 and 2016. The report estimated net economic losses the first year of using cover crops, but net gains after both three and five years of cover crop use in both corn and soybeans in a normal weather year. The report also evaluated cover crop use in situations where they may pay off faster, such as addressing compaction issues, suppressing herbicide-resistant weeds, providing grazing income, improving soil fertility, and enhancing drought stress. In these cases, economic gains in U.S. dollars ranged from $46/ha ($18.60/ac) after one year to $167.70/ha ($67.90/ac) after five years of cover crop use in corn. Gains were similar in soybeans.

A case study by the Iowa Soybean Association showed a potential annual value of between $52 and $148/ha ($21 to $60/ac) U.S. dollars by using cover crops to reduce erosion on sloping ground (Nelson, 2017). Similarly, a study by Iowa Learning Farms showed that for each ton of soil that is kept in place with cover crops or other conservation practices, $6.06 (U.S.) should be credited to that practice from nutrient savings and reduced erosion to help offset the cost (Iowa Learning Farms, 2015). The study placed a low value of $0.49 per U.S. ton on the soil itself. The true cost of soil loss is likely much higher as this number does not account for the cost of pollution, eutrophication of water bodies, and lost future production potential.

Many farmers in Iowa have reported saving money on herbicide costs due to weed suppression when cover crops are used. Jack Boyer of Reinbeck, IA estimated that he saved $99/ha ($40/ac) in herbicide costs in 2015 due to his cereal rye cover crop. The cover crop cost between $62 and $74/ha ($25 to $30/ac) to seed the previous fall, so he came out ahead by $25 to $37/ha ($10 to

$15/ac) (Gailans, 2018). Boyer has noted that his crop yields increased after three years of using cover crops, but his profit did not increase until the fourth year of cover crop use (Windsor, 2018). Similarly, Sam Bennett of Galva, IA has noted about a $12.50/ha ($5/ac) net advantage with cover crops due to weed suppression (Cullen, 2019).

Better soil structure and improved water infiltration are also benefits commonly noted by farmers when they adopt a cover cropping system, especially on no-till ground. Cover crops can be a benefit in both wet and dry conditions. Cover cropped ground typically has less surface runoff and better infiltration, which reduces erosion damage. Cover crops also help build soil organic matter, which increases the water holding capacity of the soil (SARE, 2017). Many farmers have reported that they are able to complete field operations in a timelier manner with less damage to fields since implementing cover crops (Gerlach, 2019; Iowa NRCS, 2019). Rick Bieber of Trail City, Nebraska has noted this on his farm. He farms in an area with about 400mm (16 inches) of annual precipitation. In 2012 the farm received no rain between July 3rd and mid-September. He noticed dramatic differences in soil moisture and crop viability between a newly rented farm under his family's management (Figure 15, left) and a neighbouring farm with the same soil type and corn variety also under his family's management (Figure 15, right). The farm on the left had no prior regenerative practices, whereas the farm on the right had a 20-yr history of regenerative practices including cover crops and a diverse crop rotation (Bieber, 2019). Bieber has also noted advantages during wet conditions. He has been able to drive on fields after heavy rains with no wheel track damage, whereas neighbouring farmers were unable to do any fieldwork.

Figure 15. Photos taken on the same day in September 2012 after approximately six weeks with no rain on fields with the same soil type and same corn variety.

Reducing fertilizer and chemical inputs is another way to capture economic value with an RA system. Rick Clark, of Warren County, Indiana has noted multiple economic benefits from moving to a RA system. Clark noted that *"We use no seed treatments, no insecticides, and no fungicides. We are to the point where we have nearly eliminated synthetic fertilizers."* (Roseboro, 2019). The Upper Midwestern U.S. is blessed with very fertile soil parent material in many places due to glacial activity. This makes it makes it possible to utilize biology to access this inherent fertility and maintain or increase yields without the need to add outside nutrient sources. It is important to note that we do not know how long this process could continue without depleting the parent material of its fertility. Replenishing the needed N with N-fixing legumes is also difficult in many cropping systems. Making these practices work on a given farm takes time and effort. The key is finding the right mix of practices and management adjustments needed to capture the benefits. These practices will necessarily differ from one farm to the next.

Advice from farmers that are embracing change

In conversations with farmers from around the world, several general recommendations were put forth for how to ease the difficulty of making a change to more regenerative farming practices. Many noted that the most difficult thing for them to change was their mindset. Once they got over the hurdle of convincing themselves that RA practices would benefit their farms, the transition became much easier. Below is a list of recommendations or 'ingredients' distilled from many conversations with farmers for making the change to RA work for themselves and others.

Ingredients for successful change:

1. Find a small group of like-minded farmers in your area that are willing to experiment with new practices and form a 'support group' to help and learn from each other. Use social media to network with farmers outside your geographical area if necessary.

2. Within or growing out of this group of farmers, work to make custom machinery services available. This could be a machinery-sharing agreement or one farmer purchasing equipment and doing custom work for others. This is critical expanding RA practices to other farmers who are interested but not ready or able to make the investment themselves. Many farmers need to see the change work on their own farm before they will fully adopt RA practices.

3. Provide a forum (social media, field days, meetings) for lots of one-on-one communication and information sharing between farmers. The open exchange of ideas makes change easier to

deal with. Having an expanding network of expertise and services available helps farmers capture the economic value from RA.

4. Set and track goals on your own farm to measure progress. Regenerative practices are site and management specific. Data from your own farm will be the most valuable as you experiment and find the best ways of doing things for your situation. Use on-farm replicated strip trials if possible. Support for this is available from several farm organizations and land-grant universities.

5. Be patient and persistent. Every farmer interviewed for this report noted that improving soil health takes time. Most stated that they saw some changes the first year, but it took three to five years before they started to notice major differences in soil structure and biological function. There will almost certainly be failures during this time, but they are learning opportunities that can be used to inform management changes.

Conclusion

Agriculture is fundamentally important to the state of Iowa and in many states/provinces/regions. Agricultural production practices are under constant scrutiny of their environmental performance. This is especially true regarding water quality, which is directly linked to how soil is managed. It is imperative that barriers to production and environmental enhancement are identified and solutions are developed. This report outlines a regenerative production model that could significantly enhance the ecosystem services provided by farmland, while improving the long-term economic viability of farmers. Farmers that can regenerate healthy soil in an economically advantageous way will thrive in the 21st century. The principles, practices, and ideas contained in this report may prove useful to farmers as they work to improve their farming operations, revitalize their local communities, and prepare for the future. I hope this report serves as a useful reference, and I wish everyone the best of luck on their journey towards a regenerative farming system.

Recommendations

1. **Cultivate a regenerative farming mindset.**
   A regenerative approach to agriculture is a paradigm shift that will take time to fully embrace. Changing one's mindset is the most difficult aspect of this. Many of us honor the tradition of how our parents and grandparents did things on the farm. They did these things because they were shown to work and made sense at the time. We were taught to focus on the chemical aspect of soils and few among us learned about how biologically active soils naturally function. However, we now have decades of evidence showing that we are still losing topsoil and contaminating water resources with our current farming practices. We must develop a new way of farming that reverses this for the sake of future generations.
2. **Mimic the complexity of natural systems on your farm whenever possible.**
   Just one crop growing in soil is an incredibly complex, dynamic, living system with thousands of interacting variables. Add in multiple species, diverse insect populations, or livestock and the level of complexity is multiplied exponentially. It is this complexity that we try to minimize with conventional agricultural practices so that we can exert more control over the system. But it is precisely this complexity that RA farmers embrace and use to their advantage. This is the key to future resiliency of your farming operation.
3. **Study the life in and on your soil. This is the key to understanding how to capitalize on regenerative practices.**
   It can be very rewarding and fun to observe how quickly soil can change when RA principles are implemented. Studying what, where, when, why, and how things grow can provide a wealth of information for making management decisions. Once you understand how energy flows and how nutrients cycle biologically in the soil, you can begin to use this knowledge to grow crops more efficiently with fewer inputs.
4. **Follow the soil health principles. Feed the soil and it will feed us.**
   Keeping the soil covered, maintaining living cover throughout the growing season, diversifying cropping systems, and minimizing soil disturbance are principles that have been shown to provide benefits in many different climates and cropping systems. These practices work by providing the air, water, food, and shelter that soil biology needs to survive. It is this biology that drives nutrient cycling and builds soil structure. It takes time to see changes in the soil with these principles, but once the biological function has returned you may find that your soils are more productive and resilient. Many farmers using these principles have observed this on their own farms and are willing to share their experiences and insights with others.

5. **Be an early adopter. Those who don’t embrace change will find it ever harder to compete in the future.**
   The future of agriculture will have less to do with what farmers produce or who they sell it to and will be more about how they tell the story of how it was produced. Consumer perception is a farmer’s reality. Consumers want food that is grown in a way that aligns with their values. There will always be a segment of society that does not care how food is produced, but that segment is steadily shrinking. In the future it will be much easier to sell a vision of an agricultural production system that regenerates ecosystems and provides better environmental outcomes. The successful farmers of tomorrow will embrace this change and use RA to build both economic and environmental resiliency into their operations. The key will be to be an early adopter of RA to capture and monetize the benefits of the system.
6. **Diversify the farming operation with new revenue streams.**
   The diversification of farms with RA often leads to new revenue streams, additional job opportunities, and new business creation to support RA. This brings much needed economic activity to rural communities. Growing, processing, and selling cover crop seed is one example. Capturing new revenue through direct marketing of products that bring a premium because of how they were grown is another. This is much more work than just selling the product as a commodity, but this can be a feature of the system rather than a bug if it provides opportunity for young people to return to the farm.
7. **Start small, start now, and try new things. Learn from your mistakes and network with other like-minded farmers for support.**
   Many farmers interviewed for this report stressed the importance of tapping into a network of other farmers for support. Take the time to attend meetings and field days to see what is working for other farmers in your area. Even if there are no options locally, the internet and social media provide a multitude of opportunities to engage with other farmers. It is critical to test out new ideas on a small scale on your own farm to see what works for you. Many companies use a fraction of their revenue on research and development. Consider implementing this strategy on your own farm by using a percentage (e.g. 5%) of your land as an on-farm testing ground for new growing methods. Leave a ‘control’ area and use replication, if possible, to compare the new strategy to what you are currently doing. Many farmers have used this approach as a low-risk way to try out new RA concepts without needing to make major changes to the operation.

References

Al-Kaisi, M. 2014. What is Soil Health and How Can We Improve It? Integr. Crop Manag. https://crops.extension.iastate.edu/cropnews/2014/02/what-soil-health-and-how-can-we-improve-it.

Barbarick, K.A. 1996. Organic Materials as Nitrogen Fertilizers. Colorado State University Extension Fact Sheet 0.546. https://erams.com/static/wqtool/PDFs/manure_nutrient/00546.pdf

Barnes, J. 2017. Fertilizer NZ. Nitrogen Sources Thereof. https://www.fertnz.co.nz/november-2017/.

Bennett, C. 2019. Soil Health Paves Road to Profit. Ag Prof. https://www.agprofessional.com/article/soil-health-paves-road-profit.

Berruti, A., E. Lumini, R. Balestrini, and V. Bianciotto. 2016. Arbuscular Mycorrhizal Fungi as Natural Biofertilizers: Let's Benefit from Past Successes. Front. Microbiol. 6. doi: 10.3389/fmicb.2015.01559.

Bieber, R. 2019. Around the World: 2019 soil health workshop. https://www.youtube.com/watch?v=X3D_kgHeR_0.

Brady, N.C., and R.R. Weil. 2010. Elements of the nature and properties of soils. 3rd ed. Pearson Prentice Hall, Upper Saddle River, N.J.

Bronick, C.J., and R. Lal. 2005. Soil structure and management: a review. Geoderma 124(1–2): 3–22. doi: 10.1016/j.geoderma.2004.03.005.

Brown, G. 2018. Dirt to soil: one family's journey into regenerative agriculture. Chelsea Green Publishing, White River Junction, Vermont.

California State University, Chico. 2018. Regenerative Agriculture Initiative. http://www.csuchico.edu/regenerativeagriculture/

Cullen, A. 2019. Cover crops pay off. Storm Lake Times. https://www.stormlake.com/articles/2019/07/17/cover-crops-pay.

Dearborn, Y. 2011. Compost tea literature review on production, application and plant disease management. EnviroSurvey, Inc, San Francisco, CA.

Deverel, J.Sr. 2018. Personal communication.

Doran, J.W., and M.R. Zeiss. 2000. Soil health and sustainability: managing the biotic component of soil quality. Appl. Soil Ecol. 15(1): 3–11. doi: 10.1016/S09291393(00)00067-6.

Duffy, M. 2012. Value of Soil Erosion to the Land Owner. Iowa State University Extension Service.

Egan, T. 2006. The worst hard time: the untold story of those who survived the great American dust bowl. Houghton Mifflin Co., Boston.

Environmental Defense Fund. 2018. Farm finance and conservation: How stewardship generates value for farmers, lenders, insurers and landowners. https://www.edf.org/ecosystems/how-farm-conservation-can-generate-financial-value

Fageria, N.K., M.P.B. Filho, A. Moreira, and C.M. Guimarães. 2009. Foliar Fertilization of Crop Plants. J. Plant Nutr. 32(6): 1044–1064. doi: 10.1080/01904160902872826.

Foissner, W. 1999. Soil protozoa as bioindicators: pros and cons, methods, diversity, representative examples. Agric. Ecosyst. Environ. (1–3): 95–112.

Fulton, S.M. 2011. Mycorrhizal Fungi: Soil, Agriculture, and Environmental Implications. Nova Science Publishers, Inc, New York.

Gailans, S. 2018. Finding cash in cover crops. Farm Prog. https://www.farmprogress.com/cover-crops/finding-cash-cover-crops.

Gaudin, A.C.M., T.N. Tolhurst, A.P. Ker, K. Janovicek, C. Tortora, et al. 2015. Increasing Crop Diversity Mitigates Weather Variations and Improves Yield Stability. PLOS ONE 10(2): e0113261. doi: 10.1371/journal.pone.0113261.

Gelder, B., T. Sklenar, D. James, D. Herzmann, R. Cruse, et al. 2018. The Daily Erosion Project - daily estimates of water runoff, soil detachment, and erosion: The Daily Erosion Project: Estimating Runoff and Soil Loss. Earth Surf. Process. Landf. 43(5): 1105–1117. doi: 10.1002/esp.4286.

Gerlach, J. 2019. No-Till, Cover Crops Pay Dividends on Dairy Farm. Cover Crop Innov. https://www.covercropstrategies.com/articles/209-no-till-cover-crops-pay-dividends-on-dairy-farm.

Godwin, R., P. Misiewicz, D. White, E. Smith, T. Chamen, et al. 2015. Results From Recent Traffic Systems Research And The Implications For Future Work. Acta Technol. Agric. 18(3): 57–63. doi: 10.1515/ata-2015-0013.

Harrier, L.A., and C.A. Watson. 2004. The potential role of arbuscular mycorrhizal (AM) fungi in the bioprotection of plants against soil-borne pathogens in organic and/or other sustainable farming systems. Pest Manag. Sci. 60(2): 149–157. doi: 10.1002/ps.820.

Inderjit, and L.A. Weston. 2003. Root Exudates: an Overview. In: de Kroon, H. and Visser, E.J.W., editors, Root Ecology. Springer Berlin Heidelberg, Berlin, Heidelberg. p. 235–255

Ingham, E. 2018. Soil Food Web | NRCS Soils. https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/health/biology/?cid=nrcs142p2_053868.

Ingham, E. 2019. Soil Protozoa | NRCS Soils. https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/health/biology/?cid=nrcs142p2_053867.

Iowa Learning Farms. 2015. The economic value of cover crops. Iowa Learning Farms. https://www.iowalearningfarms.org/files/page/files/Cover_Crops_economics_4pp_0.pdf

Iowa NRCS. 2019. Soil Health Producer Profiles. Nat. Resour. Conserv. Serv. Iowa. https://www.nrcs.usda.gov/wps/portal/nrcs/ia/newsroom/stories/STELPRDB1176927/.

Kinsey, N., and C. Walters. 2013. Neal Kinsey's Hands-on Agronomy: understanding soil fertility & fertilizer use. Acres, USA.

Kokornaczyk, M.O., F. Primavera, R. Luneia, S. Baumgartner, and L. Betti. 2017. Analysis of soils by means of Pfeiffer's circular chromatography test and comparison to chemical analysis results. Biol. Agric. Hortic. 33(3): 143–157. doi: 10.1080/01448765.2016.1214889.

Kremer, R., and L. Hezel. 2013. Soil quality improvement under an ecologically based farming system in northwest Missouri. Renew. Agric. Food Syst. 28(3): 245–254. doi: 10.1017/S174217051200018X.

LaCanne, C.E., and J.G. Lundgren. 2018. Regenerative agriculture: merging farming and natural resource conservation profitably. PeerJ 6: e4428. doi: 10.7717/peerj.4428.

Liebman, M.Z., M.J. Helmers, L.A. Schulte-Moore, and C.A. Chase. 2013. Using biodiversity to link agricultural productivity with environmental quality: Results from three field experiments in Iowa. https://www.semanticscholar.org/paper/Using-biodiversity-to-link-agricultural-with-from-Liebman-Helmers/5a660f90591bcdd595b4000031da2444ae9d4fe3.

Matson, P.A., W.J. Parton, A.G. Power, and M.J. Swift. 1997. Agricultural intensification and ecosystem properties. Science (5325): 504–509.

McDaniel, M.D., L.K. Tiemann, and A.S. Grandy. 2014. Does agricultural crop diversity enhance soil microbial biomass and organic matter dynamics? A meta-analysis. Ecol. Appl. 24(3): 560–570. doi: 10.1890/13-0616.1.

Meganathan, R. 2019. What causes the characteristic smell of soil? North. Ill. Univ. https://www.niu.edu/biology/about/faculty/meganathan/smell-of-soil.shtml.

Meyers, R., A. Weber, and S. Tellatin. 2019. Cover crop economics: Opportunities to improve your bottom line in row crops. Sustainable Agriculture Research & Education. https://www.sare.org/Learning-Center/Bulletins/Cover-Crop-Economics

Montgomery, D.R. 2017. Growing a revolution: bringing our soil back to life / David R. Montgomery. First edition. WWNorton & Company, New York.

Montgomery, D.R., and A. Biklé. 2016. The hidden half of nature: The microbial roots of life and health.

Mutel, C.F. 2008. The Emerald Horizon - The History of Nature in Iowa. University of Iowa Press.

Nelson, S. 2017. What is the return on investment for cover crops? | Iowa Soybean Association. https://www.iasoybeans.com/news/articles/what-is-the-return-on-investment-for-cover-crops/

NRCS. 2011. Farming in the 21st century: A practical approach to improve soil health. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_030943.pdf.

NRCS. 2018a. Core practices soil health checklist. https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/soils/health/

NRCS. 2018b. Soil biology primer photo gallery. https://www.nrcs.usda.gov/wps/portal/nrcs/photogallery/soils/health/biology/gallery/.

Ozores-Hampton, M. 1998. Compost as an Alternative Weed Control Method. HortScience 33(6): 938–940. doi: 10.21273/HORTSCI.33.6.938.

Recycled Organics Unit (2006). Overview of Compost Tea Use in New South Wales. Recycled Organics Unit, internet publication: www.recycledorganics.com

Regeneration International. 2017. What is Regenerative Agriculture? Regen. Int. https://regenerationinternational.org/2017/02/24/what-is-regenerative-agriculture/

Reinbott, T. 2019. How to Teach Soil Health Field Day. University of Missouri Soil Health Assessment Center. May 29, 2019.

Rodale Institute. 2011. Farming Systems Trial 30-year report. https://rodaleinstitute.org/wp-content/uploads/fst-30-year-report.pdf

Roseboro, K. 2019. Indiana farmer offers practical example of how soil health can transform agriculture. Org. Non-GMO Rep. https://non-gmoreport.com/articles/indiana-farmer-offers-practical-example-of-how-soil-health-can-transform-agriculture/.

SARE. 2017. Ecosystem services from cover crops. https://www.sare.org/Learning-Center/Topic-Rooms/Cover-Crops/Ecosystem-Services-from-Cover-Crops.

Senez, J. 2018. Personal communication.

Squire, R. 2018. Personal communication.

Tackle, E. 2011. Climate Changes in Iowa - Agricultural Marketing Resource Center.

U.S. Department of Agriculture. 2018. Summary Report: 2015 Natural Resources Inventory. Natural Resources Conservation Service, Washington DC, and Center for Survey Statistics and Methodology, Iowa State University, Ames, Iowa.

Wessex Water. 2018a. Wessex Water Cover Crop Trials, Winter 2016-17: Cover Crop Species & Drilling Date.

Wessex Water. 2018b. Wessex Water Cover Crop Trials, Winter 2017-18: Effect of varying cover crop species & drilling date on nitrogen uptake and leaching.

Wilpiszeski, R.L., J.A. Aufrecht, S.T. Retterer, M.B. Sullivan, D.E. Graham, et al. 2019. Soil Aggregate Microbial Communities: Towards Understanding Microbiome Interactions at Biologically Relevant Scales. Appl. Environ. Microbiol. 85(14): e00324-19. doi: 10.1128/AEM.00324-19.

Windsor, S. 2018. Trial and Error. Progress. Farmer. http://dtnpf-digital.com/article/Trial+And+Error/3009420/475046/article.html

Zimmer, G.F., and L. Zimmer-Durand. 2017. The biological farmer: a complete guide to the sustainable & profitable biological system of farming. Second edition. Acres U.S.A, Austin, Texas.

Appendix 1: Resources

Resources here are provided for informational purposes and are not intended as an endorsement.

General soil health and regenerative agriculture information

Cover crop economics tool: https://www.extension.iastate.edu/agdm/crops/html/a1-91.html

NRCS soil health: https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/soils/health/

Practical Farmers of Iowa: https://practicalfarmers.org/

Rodale Institute: https://rodaleinstitute.org/why-organic/organic-basics/regenerative-organic/agriculture/

Regenerative Agriculture Podcast: http://regenerativeagriculturepodcast.com/

Regrarians: http://www.regrarians.org/

Soil Carbon Coalition: https://soilcarboncoalition.org/

Soil Health Institute: https://soilhealthinstitute.org/resources/soil-health-educational/resources/

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

The Carbon Underground: https://thecarbonunderground.org/

Soil health testing resources (U.S.)

How to perform an infiltration test: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_052494.pdf

AgSource Laboratories: https://www.agsourcelaboratories.com/agronomy-agriculturalservices/agricultural-soil-testing/soil-health-testing-services

Midwest Laboratories: https://midwestlabs.com/our-industries/agriculture/soil-testing/

Ward Laboraties: https://www.wardlab.com/soil-health-services.php

Soil health assessments

Cornell University soil health assessment: https://soilhealth.cals.cornell.edu/

Iowa Soil Health Management Manual: https://store.extension.iastate.edu/product/Iowa-Soil-Health-Management-Manual

Books

A Soil Owner's Manual by John Stika

Call of the Reed Warbler by Charles Massy

Cows Save the Planet by Judith Schwartz

Dirt: The Erosion of Civilizations by David R. Montgomery

Dirt to Soil by Gabe Brown

For the Love of Soil by Nicole Masters

Grass, Soil, Hope: A Journey Through Carbon Country by Courtney White

Growing a Revolution by David R. Montgomery

Hands-on Agronomy by Neal Kinsey

Science in Agriculture: Advanced Methods for Sustainable Farming by Arden B. Andersen

The Biological Farmer by Gary F. Zimmer and Leilani Zimmer-Durand

The Hidden Half of Nature by David R. Montgomery and Anne Bikle

The Soil Will Save Us by Kristin Ohlson

The Worst Hard Time by Timothy Egan

Water in Plain Sight by Judith Schwartz

Nuffield Scholar reports

Reports can be accessed here: https://www.nuffieldinternational.org/live/Reports

Alex Nixon (Australia) *Farming for the Future. Optimising soil health for a sustainable future in Australian broadacre cropping.* March 2019.

Blake Vince (Canada) *Conserving Farm Land with Cover Crops and the Importance of Biodiversity*. December 2014.

David Walston (UK) *Above and below the ground: building resilient, productive and profitable soils*. June 2015.

Grant Pontifex (Australia) *Improving Soil Health with Manure and Cover Crops.* November 2019).

Richard Tudor (UK) *Soil health and fertility in grasslands: an essential component in improving upland beef and sheep productivity and sustainability*. July 2018.

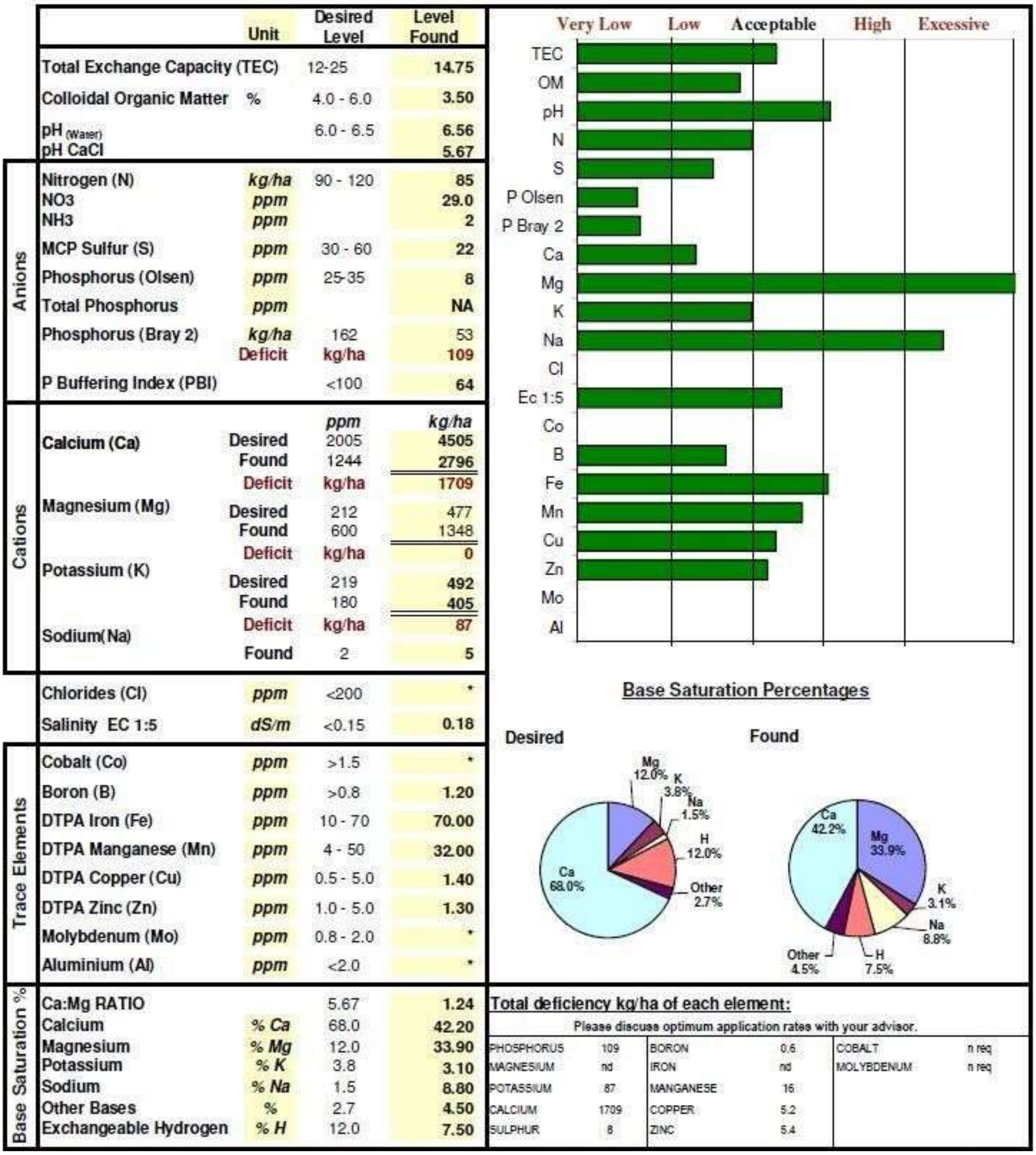
Robin Tait (Australia) *Regenerative Agriculture Principles in High Value Cropping Rotation.* October 2019.

Simon Mattson (Australia) *Making the Most of Your Soil's Biological Potential: Farming in the next Green Revolution.* June 2016.

Tom Sewell (UK) *Moving from Sustainable to Regenerative Agriculture using No-Till systems*. July 2014.

Appendix 2: Example soil test reports

Initial soil test for land in transition to an Albrecht/biological system. Courtesy Terry Hehir.



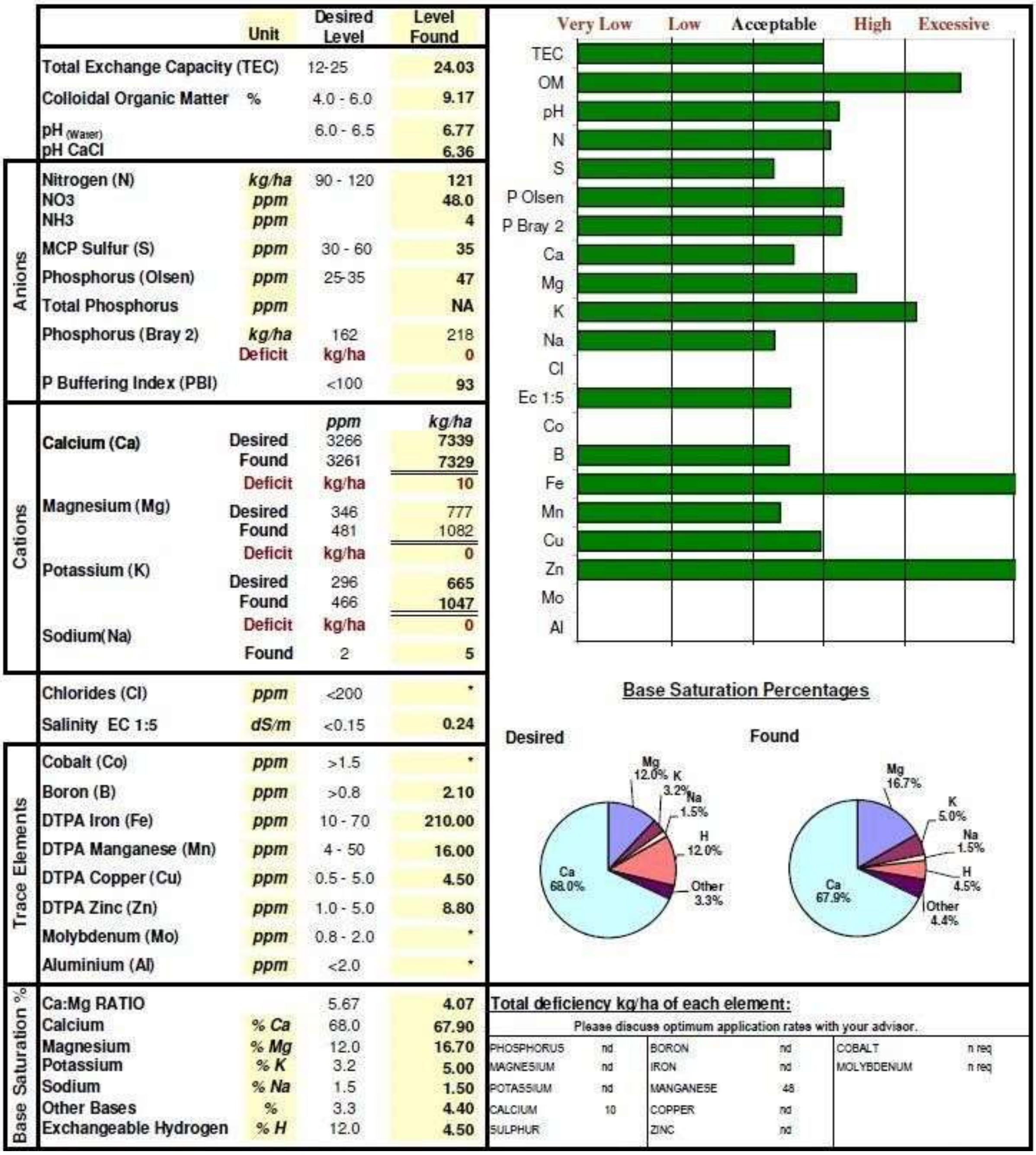
		Unit	Desired Level	Level Found
	Total Exchange Capacity (TEC)		12-25	14.75
	Colloidal Organic Matter	%	4.0 - 6.0	3.50
	pH (Water)		6.0 - 6.5	6.56
	pH CaCl			5.67
Anions	Nitrogen (N)	*kg/ha*	90 - 120	85
	NO3	*ppm*		29.0
	NH3	*ppm*		2
	MCP Sulfur (S)	*ppm*	30 - 60	22
	Phosphorus (Olsen)	*ppm*	25-35	8
	Total Phosphorus	*ppm*		NA
	Phosphorus (Bray 2)	*kg/ha*	162	53
		Deficit	kg/ha	109
	P Buffering Index (PBI)		<100	64
Cations			*ppm*	*kg/ha*
	Calcium (Ca)	Desired	2005	4505
		Found	1244	2796
		Deficit	kg/ha	1709
	Magnesium (Mg)	Desired	212	477
		Found	600	1348
		Deficit	kg/ha	0
	Potassium (K)	Desired	219	492
		Found	180	405
		Deficit	kg/ha	87
	Sodium(Na)	Found	2	5
	Chlorides (Cl)	*ppm*	<200	*
	Salinity EC 1:5	*dS/m*	<0.15	0.18
Trace Elements	Cobalt (Co)	*ppm*	>1.5	*
	Boron (B)	*ppm*	>0.8	1.20
	DTPA Iron (Fe)	*ppm*	10 - 70	70.00
	DTPA Manganese (Mn)	*ppm*	4 - 50	32.00
	DTPA Copper (Cu)	*ppm*	0.5 - 5.0	1.40
	DTPA Zinc (Zn)	*ppm*	1.0 - 5.0	1.30
	Molybdenum (Mo)	*ppm*	0.8 - 2.0	*
	Aluminium (Al)	*ppm*	<2.0	*
Base Saturation %	Ca:Mg RATIO		5.67	1.24
	Calcium	*% Ca*	68.0	42.20
	Magnesium	*% Mg*	12.0	33.90
	Potassium	*% K*	3.8	3.10
	Sodium	*% Na*	1.5	8.80
	Other Bases	%	2.7	4.50
	Exchangeable Hydrogen	*% H*	12.0	7.50

Total deficiency kg/ha of each element:

Please discuss optimum application rates with your advisor.

PHOSPHORUS	109	BORON	0.6	COBALT	n req
MAGNESIUM	nd	IRON	nd	MOLYBDENUM	n req
POTASSIUM	87	MANGANESE	16		
CALCIUM	1709	COPPER	5.2		
SULPHUR	8	ZINC	5.4		

Soil test for similar land farmed with an Albrecht/biological system for 18 years (Courtesy Terry Hehir).



		Unit	Desired Level	Level Found
	Total Exchange Capacity (TEC)		12-25	24.03
	Colloidal Organic Matter	%	4.0 - 6.0	9.17
	pH (Water)		6.0 - 6.5	6.77
	pH CaCl			6.36
Anions	Nitrogen (N)	kg/ha	90 - 120	121
	NO3	ppm		48.0
	NH3	ppm		4
	MCP Sulfur (S)	ppm	30 - 60	35
	Phosphorus (Olsen)	ppm	25-35	47
	Total Phosphorus	ppm		NA
	Phosphorus (Bray 2)	kg/ha	162	218
		Deficit	kg/ha	0
	P Buffering Index (PBI)		<100	93
Cations			ppm	kg/ha
	Calcium (Ca)	Desired	3266	7339
		Found	3261	7329
		Deficit	kg/ha	10
	Magnesium (Mg)	Desired	346	777
		Found	481	1082
		Deficit	kg/ha	0
	Potassium (K)	Desired	296	665
		Found	466	1047
		Deficit	kg/ha	0
	Sodium(Na)	Found	2	5
	Chlorides (Cl)	ppm	<200	*
	Salinity EC 1:5	dS/m	<0.15	0.24
Trace Elements	Cobalt (Co)	ppm	>1.5	*
	Boron (B)	ppm	>0.8	2.10
	DTPA Iron (Fe)	ppm	10 - 70	210.00
	DTPA Manganese (Mn)	ppm	4 - 50	16.00
	DTPA Copper (Cu)	ppm	0.5 - 5.0	4.50
	DTPA Zinc (Zn)	ppm	1.0 - 5.0	8.80
	Molybdenum (Mo)	ppm	0.8 - 2.0	*
	Aluminium (Al)	ppm	<2.0	*
Base Saturation %	Ca:Mg RATIO		5.67	4.07
	Calcium	% Ca	68.0	67.90
	Magnesium	% Mg	12.0	16.70
	Potassium	% K	3.2	5.00
	Sodium	% Na	1.5	1.50
	Other Bases	%	3.3	4.40
	Exchangeable Hydrogen	% H	12.0	4.50

Base Saturation Percentages

Total deficiency kg/ha of each element:

Please discuss optimum application rates with your advisor.

PHOSPHORUS	nd	BORON	nd	COBALT	n req
MAGNESIUM	nd	IRON	nd	MOLYBDENUM	n req
POTASSIUM	nd	MANGANESE	48		
CALCIUM	10	COPPER	nd		
SULPHUR		ZINC	nd		

Appendix 3: Precipitation rates

A 25-year, 24-hour precipitation event refers to the maximum 24-hour precipitation event that has a probability of occurring once every 25 years, as defined by the United States National Weather Service. An example of 25-year, 24-hour precipitation depths for Iowa is shown Table 4 below, adapted from the Iowa Stormwater Management Manual.

Table 4. Precipitation depth of 25-year 24-hour rainfall events in various regions of Iowa.

Location (Iowa)	Depth (inches)	Depth (mm)
Northwest	5.50	140
North Central	5.67	144
Northeast	5.56	141
West Central	5.59	142
Central	5.44	138
East Central	5.44	138
Southwest	5.86	149
South Central	5.90	150
Southeast	5.62	143

The National Oceanic and Atmospheric Administration’s Hydrometerological Design Studies Center Maintains a website where precipitation-frequency information can be found for any U.S. location here: https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html

Plain English Compendium Summary

Project Title:	**A Farming System for the 21st Century: How regenerative agriculture can heal agroecosystems and feed the world**
Nuffield International Project No.:	1801
Scholar:	Brian Dougherty
Organisation:	Nuffield International Telephone: (+61) (0) 3 54800755 Facsimile: (+61) (0) 3 54800233 Mobile: (+61) (0) 412696076 Email: jimgeltch@nuffield.com.au Address: PO BOX 586, Moama, New South Wales, Australia 2731
Objectives	Provide background information about RA concepts. Investigate the mindset and approaches of RA practitioners in Iowa and in different parts of the world. Explore how Iowa farmers can use the RA approach to improve the health and resiliency of their so Explore how RA can improve economic, social, and environmental outcomes for Iowan farming communities and how these principles may apply to other regions of the world.
Background	Agriculture is fundamentally important to the state if Iowa. It is imperative that barriers to production and environmental enhancement are identified and solutions are developed. This report details the efforts of farmers and researchers from around the world to regenerate healthy soil and improve profitability. Farmers that can regenerate healthy soil in an economically advantageous way will be the farmers that thrive in the 21st century.
Research	Research was conducted in the Netherlands, Italy, USA, Canada, Argentina, Chile, New Zealand, Australia, France, UK, and Ireland on different trips totalling 16 weeks. Numerous personal interviews were conducted, and information was gathered and enhanced through literature review of peer reviewed journal publications, books, and other sources.

Outcomes	This report outlines the principles of regenerative agriculture and discusses how those principles can be applied to Iowa agriculture. The techniques and ideas contained in this report may prove useful to farmers in Iowa as they work to improve their farming operations, revitalize their local communities, and prepare for the future.
Implications	Agricultural production practices in Iowa are under constant scrutiny of their environmental performance. This is especially true regarding water quality, which is directly linked to how soil is managed. This report outlines a production model that could significantly enhance the ecosystem services provided by farmland while improving the long-term economic viability of farmers in Iowa.