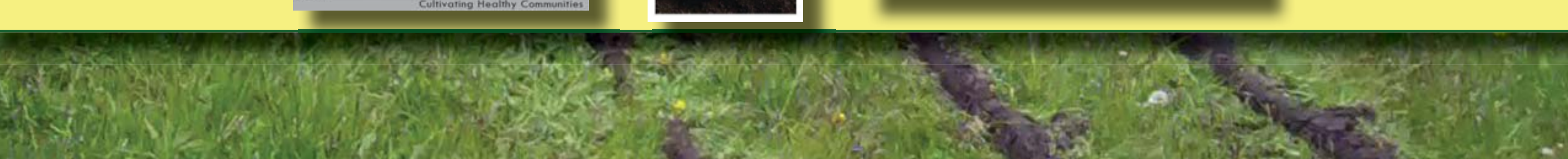
Addressing Pasture Compaction

Weighing the Pros and Cons of Two Options

UVM Center for Sustainable Agriculture
University of Vermont Extension
Cultivating Healthy Communities

Department of Plant & Soil Science

NRCS



UVM Project team: Dr. Josef Gorres, Dr. Rachel Gilker, Jennifer Colby, Bridgett Jamison Hilshey
Partners: Mark Krawczyk (Keyline Vermont) and farmers Brent & Regina Beidler, Guy & Beth Choiniere, John & Rocio Clark, Lyle & Kitty Edwards, and Julie Wolcott & Stephen McCausland

Writing: Josef Gorres, Rachel Gilker and Jennifer Colby • Design and Layout: Jennifer Colby • Photos: Jennifer Colby and Rachel Gilker
Additional editing by Cheryl Herrick and Bridgett Jamison Hilshey

This is dedicated to our farmer partners; may our work help you farm more productively, profitably, and ecologically.

UVM Plant & Soil Science Department
http://pss.uvm.edu

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http://www.vt.nrcs.usda.gov

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Introduction

A few years ago, some grass-based dairy farmers came to us with the question, "*You know, what we really need is a way to fix the compaction in pastures.*"

We started digging for answers.

This simple request has led us on a lively journey. We began by adapting methods to alleviate compaction in other climates and cropping systems. We worked with five Vermont dairy farmers to apply these practices to their pastures, where other farmers could come and observe them in action. We assessed the pros and cons of these approaches and we are sharing those results and observations here. There have been some unexpected results.

Though soil compaction was the driver of our project, *soil quality and health* are more than just compaction. Soil health is a keystone for field management, building a soil that will provide the optimal productivity for a crop, and a soil that can recover from disturbance and stress.

When we set out to alleviate compaction, we measured numerous soil quality indicators, especially organic matter, active soil carbon, and soil organisms. Fostering the complex web of belowground interactions may rejuvenate compacted soil. What we found brought us a whole new round of questions to consider.

Please join us for a tour of soil health, and biological and mechanical tools to address pasture compaction. Then you can decide for yourself what is the best fit for your farm.

Josef, Jenn and Rachel

Soil Health

When talking about soil quality, the first thought is often fertility. This often begins with a soil test. Test results can help formulate recommendations for proper fertility amendments for plants to reach full productivity. While soil testing is an important and recommended practice, the standard soil test doesn't give a complete picture of soil health.

Soils under a Vermont pasture. Note the layers of color and the depth of some roots.

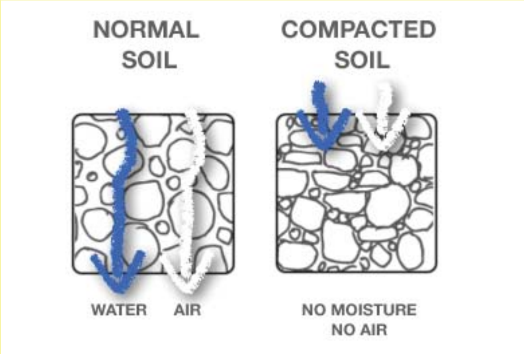
Soil health is the ability of soil to perform many functions, and, importantly, to recover when disturbed. Soil health comes from a range of factors, including chemical (e.g. pH, presence or absence of sufficient micro and macro nutrients, cation exchange capacity), biological (e.g. organic matter, active carbon, root health, soil food web), and physical (e.g. aggregate stability, water capacity, compaction). A decline in any single factor can impact soil health and limit productivity.

Determining what the limiting factors are to soil health (often different from farm to farm) can help farmers decide what next steps to take in order to create greater productivity. For example, a soil test that shows adequate levels of Nitrogen (N), Phosphorus (P) and Potassium (K), and has pH of 6.5 should produce a great deal of plant matter. If not, chances are that the limiting factors are not chemical, but more likely physical or biological.

Physical compaction like this is often seen in high traffic areas where machine or livestock traffic is highest. Compacted soil particles provide a barrier holding air and water from passing through, as well as plant roots.

Determining what causes soils to be unhealthy can help farmers decide what remedial steps should be taken to improve productivity. The limitations usually differ from farm to farm, or even field to field. For example a soil that shows optimum levels of nitrogen, phosphorus, and potassium, and a pH of 6.5 with seemingly ideal characteristics should produce a great deal. If not, the chances are that the limiting factors are not chemical, but may be physical or biological.

Compaction is a great example of a physical limitation to soil health. In pastures, it results in soil layers that are difficult for roots to penetrate and thus interferes with pasture productivity. Soil biologists argue that compaction also disturbs the complex balance between various parts of the soil food web. To understand this, we need to look more closely at what happens during compaction. The volume in a healthy soil is about half solid materials and half pores. The pores are divided into air and water-filled spaces supporting both an aquatic and a soil air-based community made up of microorganisms and soil animals. When soils are compacted, pore spaces become smaller, reducing the available habitat of microbial-feeding nematodes and protozoa. These soil animals cycle nutrients, and when they are not available, nutrient supply can be limited.



Source: www.landscaperesource.com

The traditional fix for compaction is tillage. However, in wet heavy clays, this may have the opposite effect, and may damage soils in the long run. Tillage affects the balance between bacteria and fungi in the soil, which in turn changes the composition of the microfaunal community. More tillage means more bacteria and more bacteria feeders. It also introduces more oxygen into the soil, which allows microorganisms to speed up decomposition of organic matter. speed up decomposition of organic matter. The organic compounds act as glues to bind soil particles together. When they are lost, soil structure is degraded, and soil no longer retains pore space.

Rotational grazing relies on perennial cover that typically avoids compaction damage and the alterations that go along with tillage. In rotational grazing, it's not usually heavy machinery that causes compaction, but animal traffic. Pugging by hooves, especially in wet soils causes compaction, particularly in the upper soil layers. If compaction is a problem in pastures, how can one maintain a no-till regimen, lengthen the grazing season, and retain the water and soil quality functions of perennial pasture?

We investigated the effect of two practices on pasture health. One of these was Keyline subsoil tillage, a method that cuts through compacted soil to improve infiltration and aeration while redistributing water from wet to dry areas within a pasture. The other technique was biodrilling with tillage radishes. The taproots of Daikon radishes push through the compacted layers of soil. Both methods maintain the no-till status of pasture and the perennial plant cover of a rotational pasture.

Methods

The project team tested and demonstrated the two practices with five farms. For fields that were Keyline plowed, a Yeomans plow was used twice per year for two years. In biodrilled fields, tillage radish was seeded once per year for two years. Both practices came with additional expectations beyond alleviating compaction. In particular, we were interested in learning more about their abilities to sequester carbon. The farmers testing the practices were all dairy farmers, but represented different management styles and soil types. At least one had extremely rocky areas and steep slopes, allowing only the use of forage radishes, as mechanical access was impossible.

From top: Observing tillage radish (pen for scale); gathering soil samples for earthworm counts; using a core sampler to gather whole cores for carbon testing; forage quality and soil testing.

Keyline Plowing

A mechanical method to alleviate compaction, Keyline plowing is a subsoiling practice. It was developed for dryland farming in Australia with the intent of redirecting stormwater by increasing infiltration and channeling water to drier soils. The shape and function of the landscape prescribe the direction of plowing along topographic "keylines". The method considers how water moves within a watershed as influenced by the shape of the landscape.

Keyline plowing uses a specialized tool, a Yeomans plow. The plow is designed to minimally disturb the soil profile, with narrow shanks that have shallow 8° digging blades. Typically having three to five shanks, the Yeomans plow is recommended for use two to three times during the grazing season, over a two-year period, for a total of four to six passes.

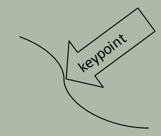
The first pass is usually quite shallow, within an inch or two of the established root growth. Each pass is several inches deeper than the preceding pass, to reach a depth of 14-20" or more. A coulter disc precedes the plow shanks to cut through sod and further reduce soil disturbance. On each pass, the shanks slide through the soil, providing channels for increased water infiltration and root growth. A roller can be attached to follow the shanks, mitigating surface disturbance caused by the shanks. Seeder boxes can be mounted above the shanks, and seeding into the cuts is sometimes done to introduce new forage species or add soil amendments and fertilizers.

The shanks cut macropores connecting soil with subsoil. The blades loosen soils at depth to provide a more permeable soil channel that conducts water below ground along the plow direction. Because of these actions, Keyline plowing is thought to be a topsoil builder, because the macropore structures are explored by roots and more water is available in previously dry soils. Proponents describe Keyline plowing as part of a successful recipe to improving soils; also important to the process is a well-managed grazing system that encourages strong plant growth, plenty of grazing residual and trampling of plant matter to feed soil organisms. In drier landscapes, anecdotally it has been claimed to improve growing conditions and build organic matter. In more temperate climates like Vermont and the Northeast, the organic matter benefit may not be as pronounced as redirecting water in pastures and increasing the ability to graze in variable conditions. However, little scientific evidence exists to support any of the claims of the impacts of Keyline plowing on organic matter building.

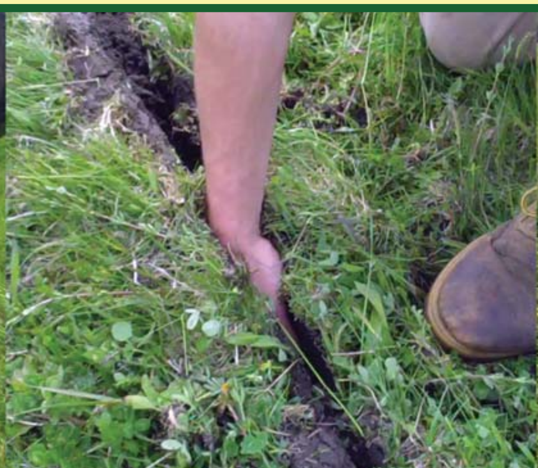
Our project team collected data in an effort to document changes in soil quality and especially organic matter. In demonstrating whether Keyline plowing can be used to break up compaction, change water movement through the soil, sequester carbon or improve soil quality, the farmers and UVM team have identified pros and cons you may wish to consider (see facing page). For more detail about our data sampling results, see Pages 11 through 14.

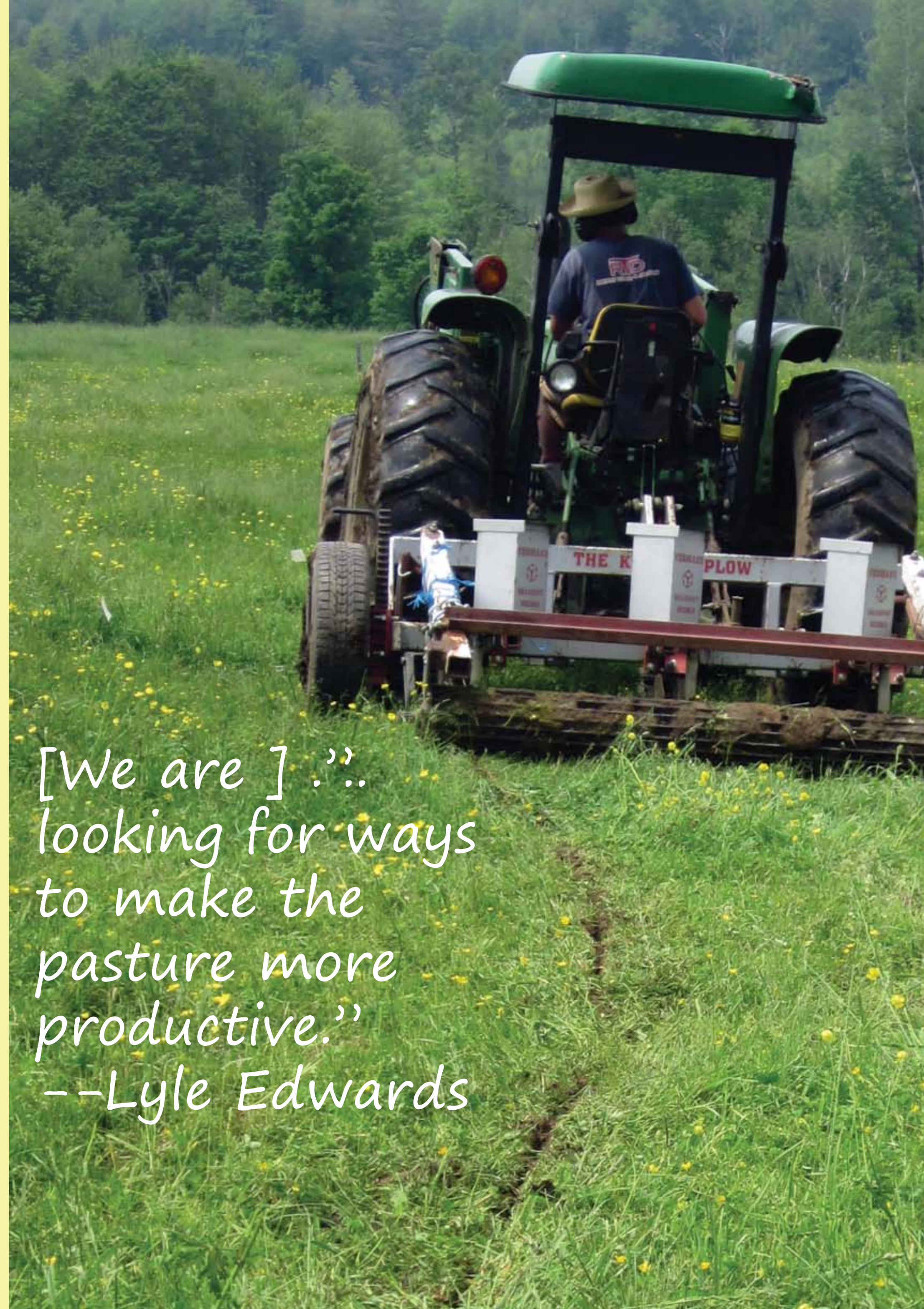
How Keyline Plowing works

Keyline plowing ideally follows the keyline of a landscape, the contour line that passes through the keypoint where the valley profile changes from a convex to concave shape.



The keyline has a unique geographic quality. Plowing parallel to the keyline, both above and below, will redirect water outwards and slightly down hill towards the ridges. This will more evenly distribute water, helping to drain the valleys and bring water to the higher regions, which are typically drier.





> [We are] . . .
> looking for ways
> to make the
> pasture more
> productive."
> --Lyle Edwards

From left: Plow shanks just before demonstrating the subsoiling technique; after the first plow pass participants check the depth and feel of the post-plowed soil; Rachel Gilker and Lyle Edwards discussing the effects of plowing at his farm; Extension Agronomist Dan Hudson checking out the seed boxes.
Above: Keyline plow specialist Mark Krawczyk subsoiling at the Edwards farm.

Farmer Reports

Pros:

Water Redistribution

- Participants generally liked the effects of drying some areas and moving water into droughty areas.

Paddock Resiliency

- At least one farmer reported increased ability of his subsoiled area to handle excess water during a high-rainfall period due to the improved drainage.

Full disclosure: the farmer knew that the plow would be returning for an additional pass.

Cons:

Water Redistribution

- One participant found the water draining so well that his pastures dried out too quickly during a dry period.

Price

- The cost per acre for plowing the recommended four times came to $160 per acre, without the tractor, and $280/acre with the tractor.

Uneven Surface

- 3 out of 4 farmers were dissatisfied with the bumps created along the subsoil line. Addition of the roller (see photo above) improved the surface, but may not comfortable driving for pasture alternately hayed and grazed.

Machinery Requirements

- The minimum power recommended is about 80 hp, or 11 hp per plow shank. This can vary by soil type and depth of plowing. The number of shanks may be reduced to adjust.

Unsuitable for Rocky Areas

- Areas with large or numerous rocks may just not work for keyline plowing. "Snap off" pins may be used in order to avoid damaging the plow shanks.

Tillage Radish

The roots of certain plants can penetrate or "biodrill" through compacted soil. The most well studied and publicized biodrilling plant is the forage radish (*Raphanus sativus L.*). It is also known as Daikon radish, an edible root sold in grocery stores. As tillage radish, they offer a host of benefits to improve pasture quality. They make a nutritious fodder, promote beneficial nematode populations, and scavenge nutrients that would otherwise leach in fall and winter rains, carrying them over for use by spring crops. Because of these unique characteristics, the forage radish can provide many different benefits to the farmer, the soil, and the environment. We wanted to see if these benefits fit into a pasture system while combating compaction.

The forage radish is called a biodrill, because when the plant dies, the roots decompose leaving vertical holes in the soil as well as cracks in pan-like layers of soil. These holes act as conduits for water, air and roots to enter the soil profile more easily the following spring and summer. Although they are winterkilled, forage radishes are hardy plants that reach maturity in 8 to 10 weeks, with lush growth and several inches of radish root visible aboveground. The radish tops provide a large quantity of highly digestible, carbohydrate and protein-rich forage in the autumn. The large, deep, penetrating taproots can be as thick as your forearm, and reach depths of 8-16". A finer root may extend a foot or deeper into the soil (see illustrations on facing page).

While the radishes are growing, their roots support and enhance populations of beneficial nematodes that improve nutrient cycling. Earthworm populations also increase near the radishes. When temperatures drop below 20° F for a few days, the radishes dies. Their roots decompose rapidly in the spring and release nutrients absorbed by the roots during the growing season. These nutrients are then available for uptake by new crops or forage growth.

In demonstrating tillage radish, the farmers and UVM team have identified pros and cons you may wish to consider (see facing page). For more detail about data sampling results, see Pages 11 through 14.

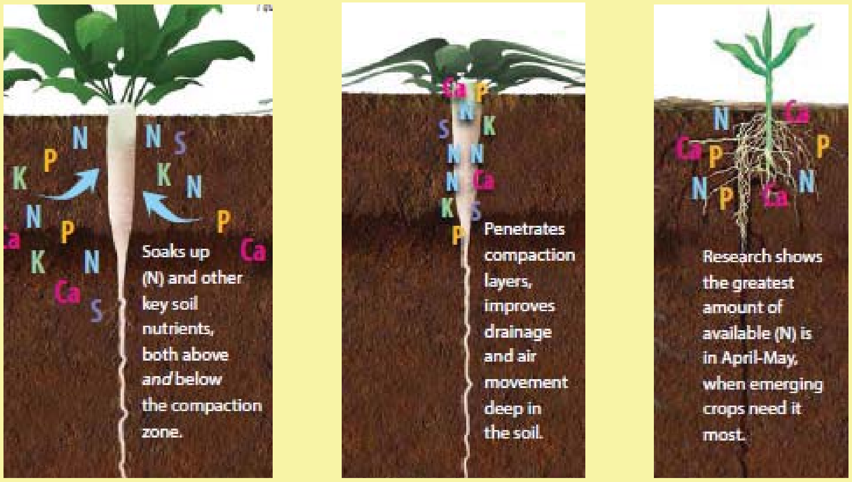
Tips for Growing Forage Radish

Acquiring Seed
Forage radish (also called tillage radish) seed can be purchased for between $2.50 and $5.00/lb. Sources include Bird Hybrids, Lancaster Agricultural Supply, Ernst Conservation Seed (Cedar Meadow forage radish), and Seedway (GroundHog) among others.

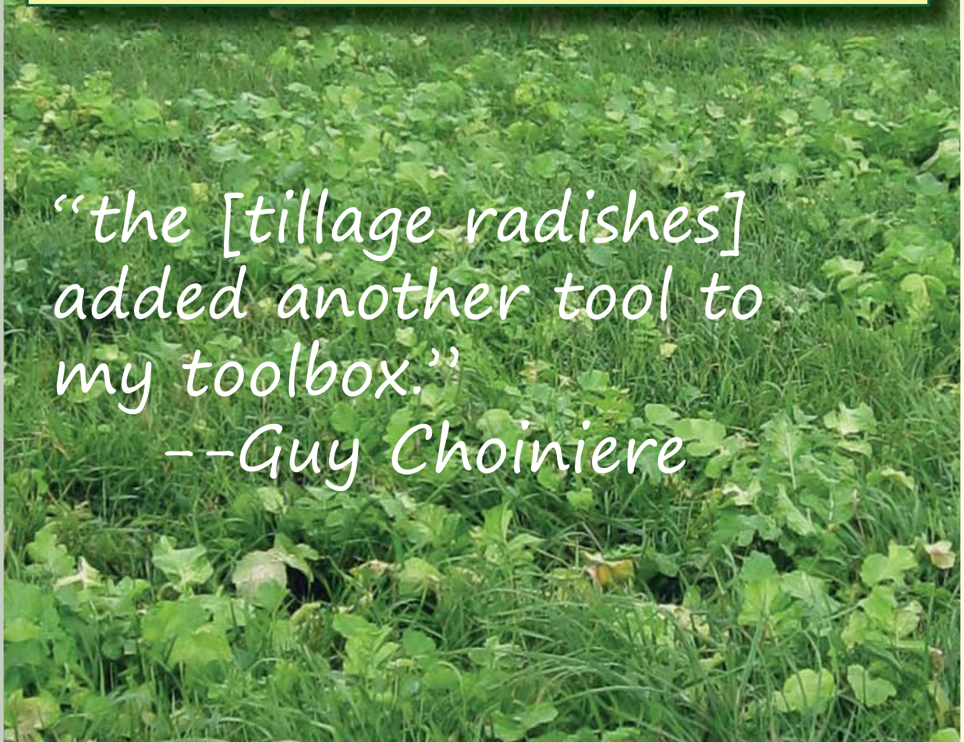
Planting Date
We recommend planting seeds in late June and early July. Try to time the seeding to be followed by rain.

Broadcast Seeding
Germination is challenged by healthy forage growth and reduced seed-to-soil contact. We recommend seeding directly after grazing (8-10 lbs/acre). Grazing livestock decrease competition by other forages and incorporate seed into the soil. If a seed drill is accessible, its use is recommended. Forage radishes usually emerge within 3 days in warm, moist soil.

Grazing the Radish
To achieve maximum benefits, wait at least 8 weeks before allowing cattle to graze the radish tops. If you desire multiple grazing, allow animals to only graze the top one-third of the radish.



These illustrations from *The Tillage Radish Resource Guide* describe the process of how radishes absorb and release nutrients over multiple seasons in a year. Source: www.covercropsolutions.com



"the [tillage radishes] added another tool to my toolbox."
--Guy Choiniere

From left: Tillage radish expressing its habit; of pushing out of the ground as it grows a radish pulled from the ground by curious cows; two freshly pulled radishes; graduate student Bridgett Jamison Hilshey measuring the depth of the roots. **Above:** Interseeded perennial pasture and radish mix at the Choiniere Family Farm.

Farmer reports

Pros:

Equipment Optional

- Farmers using tillage radish were able to no-till, broadcast with a spinner, or hand seed. It worked well in systems with tractors and without tractors.

Flexible Grazing

- The radish was a flexible tool allowing farmers to either leave the radish alone for deep root penetration, or graze the top 1/3 of the plants. The ability to address compaction without totally removing the pasture from production was an added benefit.

Late Season Benefit

- The carbohydrate storage in the roots help radish plants stay green and growing later in the season than other pasture forages, and maintain quality longer. Cows were observed eating the tops and in some cases, pulling the roots up to eat them.

Price

- At $3/lb., the recommended seeding rate cost $24-$30 per acre. The low cost made this an attractive tool to try.

Terrain

- Some farms had steep slopes and rocky terrain that made mechanical tillage or planting methods difficult or unsafe. Tillage radish worked for all terrains.

Cons:

Germination

- 3 out of 4 farms testing this practice had challenges with seed germination. Adequate moisture and seed-to-soil contact was essential to success. Planting just after a late June/ early July grazing, particularly in a place the animals will walk through (pressing seeds down), improved germination.

One Farm's Story: Too Much of a Good Thing?

Above, Josef Gorres and student, standing in a highly compacted area where 3X the typical rate of tillage radish has been applied. Right, in the following spring, the former radish area showed much bare ground.

One of our partnering farmers had a highly compacted and bare area around his stationary water trough. The farmer wanted to try rehabilitating it with a super-dose of radishes, along with some rye seed. He estimates that he spread 30 lbs per acre, or 3 times the recommendation, for the radish seed. He did a similar rate for the rye grass. The following May, the ground was bare again. The winterkilled radishes had smothered any other growth, including the ryegrass, and the farmer was back to square one- a watering trough with bare ground. The space was not taken over by weeds and did eventually fill in with pasture grasses.

We are left to wonder: radishes are often credited with root exudates (juices) that deter weed growth. Could it be that they did this here? Had they smothered the ryegrass or outcompeted it because those radishes germinated so very quickly? Would fewer radishes have done the trick?

When the radish was seeded into the pasture, at the right seeding rate (8-10 lbs. per acre), growth looked vibrant the next spring. The farmer reported that the pasture greened up faster and showed a stronger green than other pastures, which had not had radishes planted in them.

Above left is a more typical tillage radish seeding into pasture. Right, the same pasture showing spring flush.

Findings

Soil and forage samples were collected twice per year at each farm, in the early and late periods of the grazing season.

Data collected:

- Traditional soil samples, assessing soil fertility, pH, and cation-exchange capacity;
- Organic matter, including active carbon (to determine the presence of microbial activity and carbon sequestration);
- Soil strength, including penetrometer readings to assess compaction pressure, or soil resistance to penetration;
- Bulk density, the mass of soil in a given cylindrical volume;
- Forage quality, using typical wet chemistry analyses; and
- Earthworm community composition (to determine the number and type of worms present).

With all the data we collected, for both keyline plowing and radishes, we saw no significant changes in

- soil penetration resistance (Figure 1)
- active carbon
- organic matter (Figure 2)
- bulk density
- forage NDF (neutral detergent fiber)

This was somewhat unexpected. Keyline plowing has been reported, anecdotally, to increase topsoil. Where it was developed, in dry climates, the practice may improve growing conditions and build organic matter. In more temperate climates, it may not be as effective at building organic matter for many reasons, including that by drying out fields, more oxygen is available, which leads to more decomposition. Other research has shown that subsoiling may increase carbon sequestration, especially on soils that have not been tilled for long periods

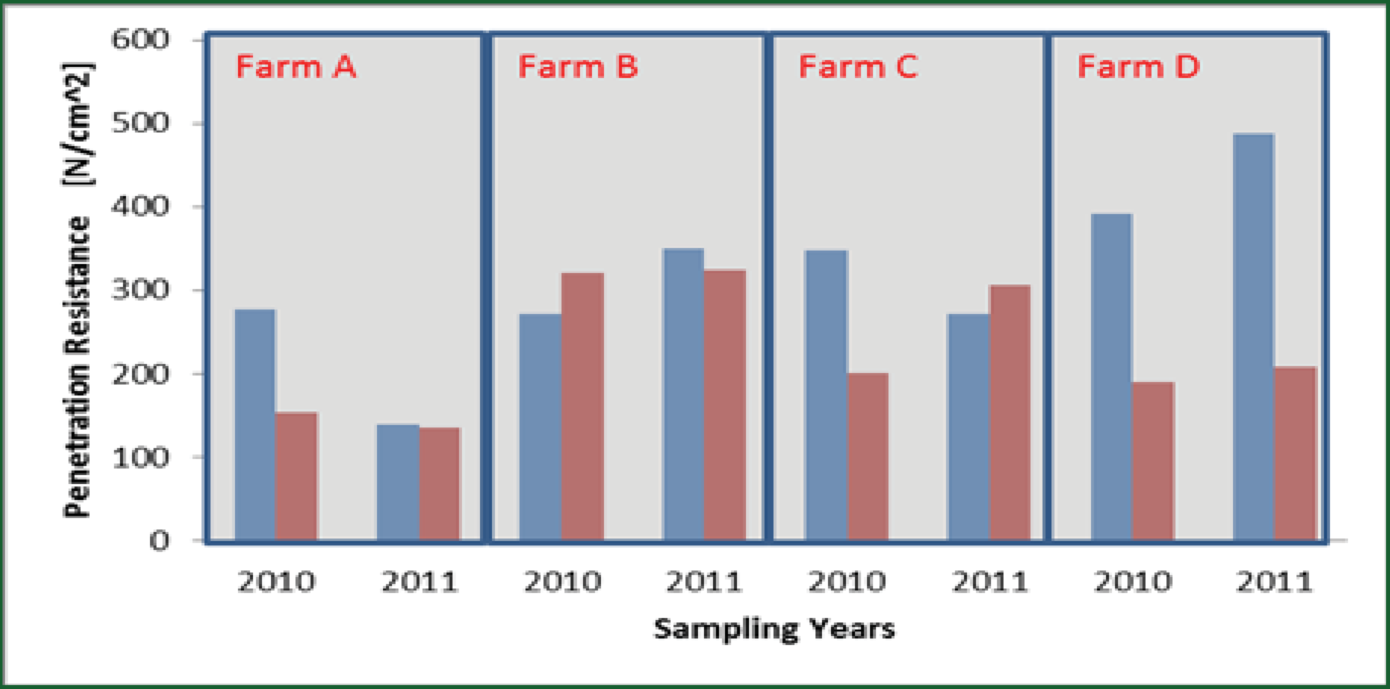


Figure 1. Blue are data from Control Areas, Red from Keyline Areas. Note: Farm D is the site where management intensive grazing was not regularly practiced in the test and control areas.

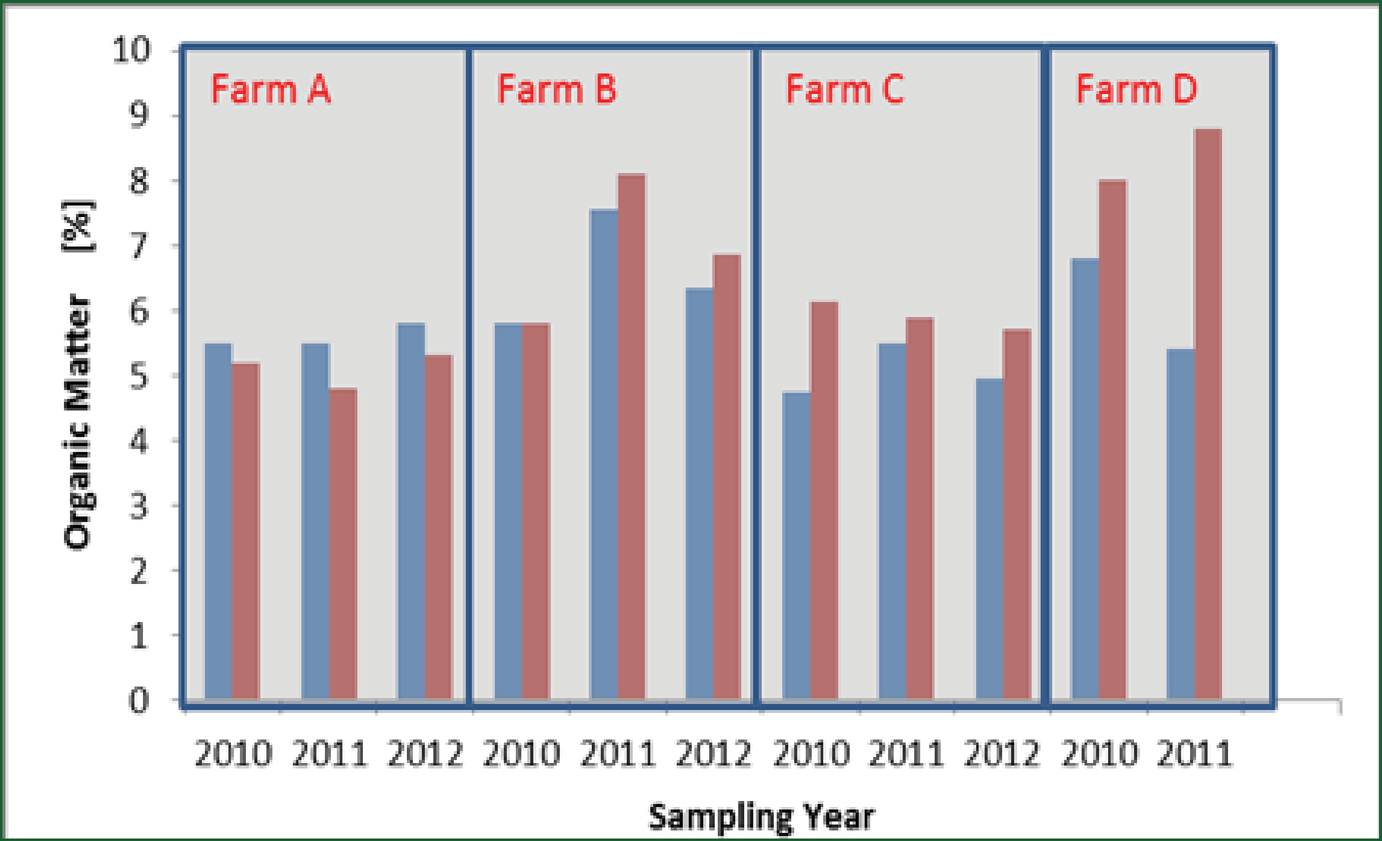


Figure 2. Blue bars are control and red are Keyline plowed. Note: Farm D is the site where management intensive grazing was not regularly practiced in the test and control areas.

of time (Purakayastha et al., 2008). This is presumably due to a response in plant and root growth as well as enhanced microbial activity.

Because of these reports, we had anticipated finding more organic matter in the Keyline-plowed areas, but we did not. As you can see in these figures, there was some variation between sampling events, and farms, but there was no statistical difference as a result of the Keyline plowing, meaning that we could not promise any effect from using the practice. We found a similar lack of impacts from the radishes, with lots of variation between farms and sampling events, but no effects we could count on.

The changes we did observe were in soil moisture distribution for Keyline plowing and in earthworm numbers for both the plowing and the radishes. Moisture values were lower in the fields which were plowed with the Keyline method. This demonstrated that Keyline plowing redistributed water, potentially increasing infiltration. This can lengthen the time animals can spend grazing during wet periods, since pastures can dry out more quickly. In dry periods, though, this may reduce water availability.

Greater earthworm densities are indicators of better soil health in agriculture. Their abundance captures the result of many soil processes, such as enrichment in their food resources. That invariably means changes in active carbon, microbial biomass, soil-water relations etc. This indicator may thus capture some of the positive changes better than any of the other factors we measured but it cannot distract from the fact that organic matter content did not significantly increase over the few years that we monitored these practices.

There are three main types of earthworms: endogeic, epigeic, and anecic. The endogeic and the epigeic remain above and close below the soil surface. They accelerate decomposition and will reduce thatch and help decompose cow pats and plant residue. Anecic earthworms burrow deep into the ground. Their deep burrows are conduits for water flow and thus they may enhance infiltration and percolation which improves the water status of the pasture during large storms. This supports the effect of forage radish or Keyline plowing on infiltration and may thus further reduce the potential for compaction during a rainy spring. The flip side of such burrows can mean lost nutrients that also travel through the large burrows, deep below the root zone.

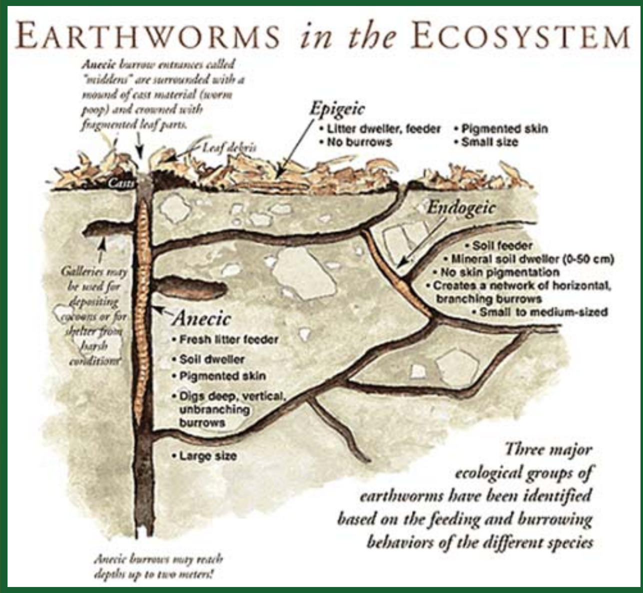
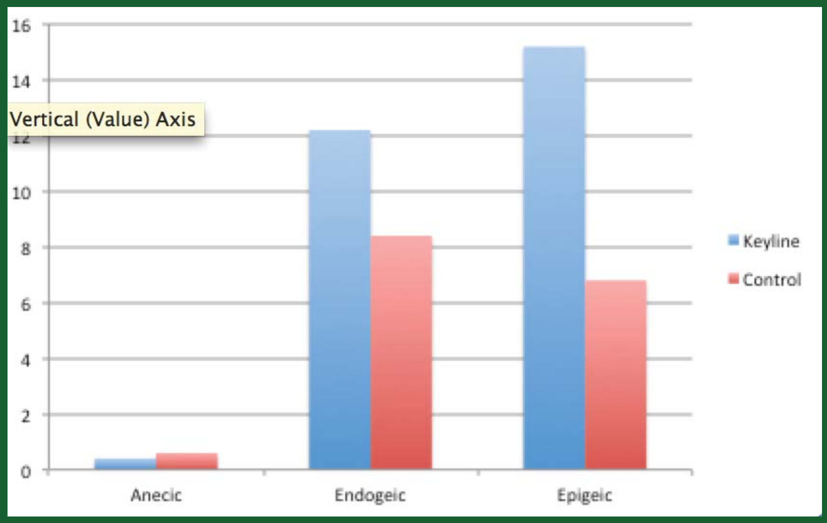


Illustration courtesy of ecoserv.weebly.com.

There were an average of 27 endogeic and epigeic worms per square foot in the keyline-plowed pastures, versus the 15 per square foot in the control. Since an acre has 43,560 square feet, an extra 12 worms per square foot translates to 522,720 more worms per acre in the keyline-plowed pastures. The presence of more worms suggests faster turnover of nutrients and better aeration.

The cost of keyline plowing was about $280/acre, or 1867 worms for every dollar. Since we didn't find any increase in forage, forage quality or other soil quality indicators, we're left wondering if opening up the soil to more worms is worth it. More worms have usually been considered a good thing, and at almost 20 worms for a penny, those worms seem like a great price.

There was similar trend in the radishes. Radish treatments had significantly more epigeic and endogeic earthworms than the control treatments. But, it also had greater anecic populations. The total number of earthworms was increased by about a million per acre. That is twice as much



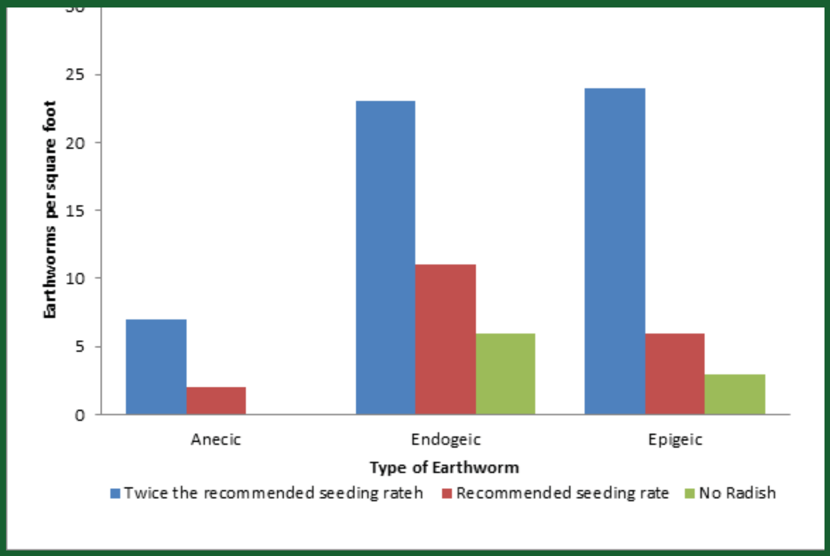


Figure 3. Data showed significant increases in worm counts with both practices.

increase as in the keyline treatment. This is likely a result of the additional radish roots supplying food for the earthworms.

Examining these data with an eye on the services that earthworms provide, we expect that there would be greater cycling of nutrients in the fields that were treated with either the tillage radish or the keyline plow. There may also be an increase in infiltration.

Speaking of water, we found that Keyline-plowed fields were drier than those that had not received treatment. For one field we investigated more exhaustively after a large rainfall, we measured approximately 30% less moisture. That can be a real benefit, if excessive water is a problem, as it suggests that soil moisture is quickly reduced to a level where the herd is less likely to cause compaction. What is more, the low moisture regions in the Keyline graph (Figure 4) were associated with the incisions made by the Yeomans plow. The variations in moisture were more random in the untreated field. The Keyline treatment can therefore have a real effect on when you can let the cows out to pasture. The faster decomposition rates expected at lower moisture and greater earthworm densities may also explain why we did not find greater organic matter content.

What's so great about earthworms?
Here's a partial list:

- The castings (manure) produced by earthworms are more nutrient rich than the orginal material they consumed, thanks to the biological activity within their guts.
- Earthworm burrow (drilosphere) linings and casts represent 'hotspots' of microbial and faunal activity in soils.
- Earthworm-affected soils have enhanced rates of nutrient turnover particularly of N and P, released through mineralisation of organic residues. There can be 5 times as much nitrogen and 7 times as much phosphorus in worm-plentiful soils.
- Earthworms cycle surface carbon and nutrients to plant roots and feed the soil microbes who build soil structure, as well as encouraging water and air access.

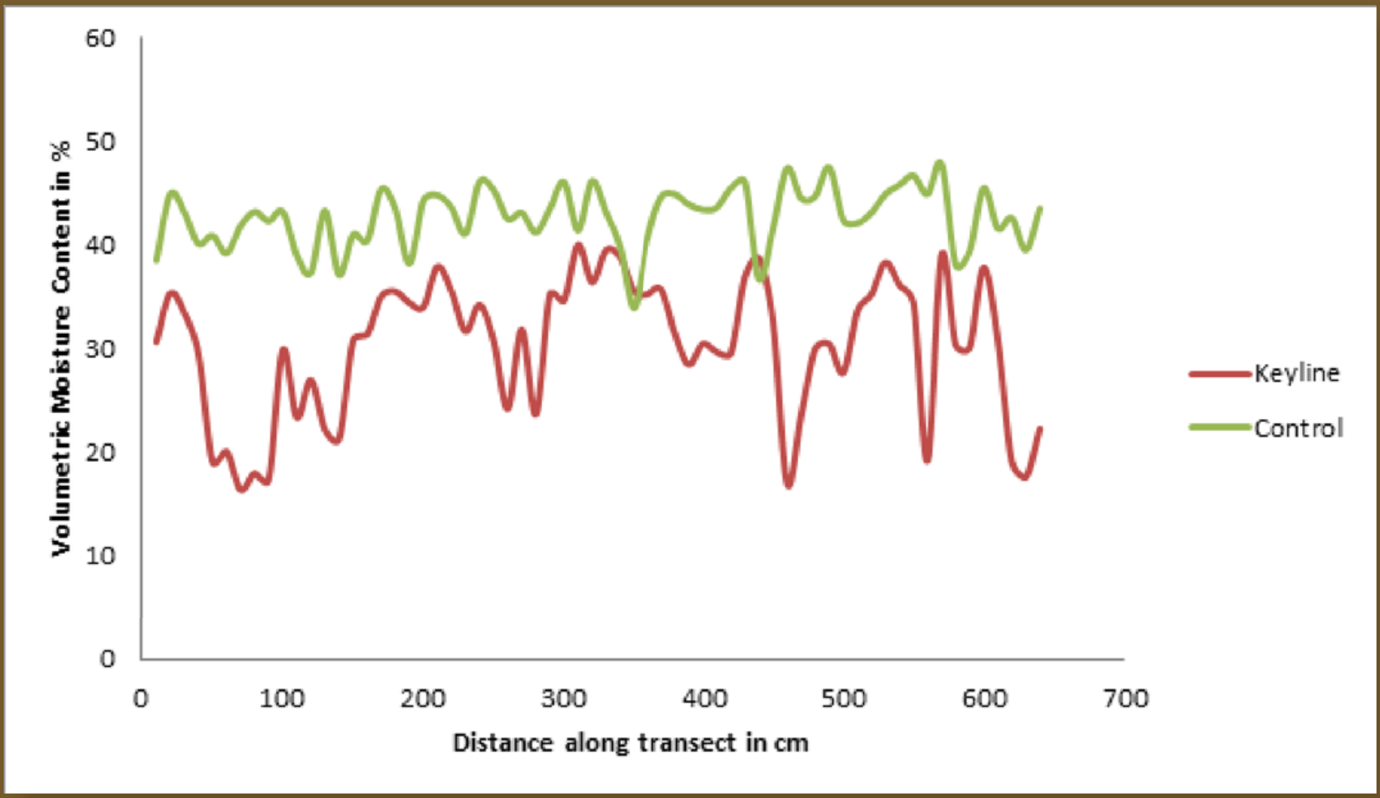


Figure 4. Variations in moisture within keyline-plowed pastures.

What Does This Mean for Your Farm?

We hope that our data and farmer experience will help you choose the appropriate practices for you. Our data did not show the expected significant soil building or carbon sequestration results from Keyline plowing or the radishes. However, participating farmers all experienced the water-movement effects of the Keyline plowing, in some cases beneficially, and in other cases, drying the pasture too much. If the limiting factors on your farm are more closely related to low earthworm numbers, you may find tillage radishes more appropriate.

"Sustainability is about creating a system that works well in good years and in bad."
--Guy Choiniere

Think about both of these practices not so much as cutting through a compaction layer but reducing moisture, which is really a treatment for preventing compaction in the first place. And, given that earthworms and nematodes are great indicators of soil health in agricultural settings, think about the potential for greater nutrient cycling and how that may impact your pasture management. Faster cycling of nutrients can translate into faster growth of forage and a shorter recovery period after grazing.

What new questions will the project team be looking at?
Every good project stimulates more questions to consider. In our study we often looked at well managed pastures and the effect of the treatments may not have been as great as they might have been in poorer pastures.

The soils in our study were loamy soils. Here are a few guiding possible future projects:

- How would the two practices improve pastures on clay and clay loam soils where compaction and water relations are more prevalent?
- Could these practices improve the resilience of a pasture that is in flood or drought prone lands?
- Could the effects of these practices be more visible when "snapshots" were taken more often during the year and in more locations of the pasture? Or, could increases in carbon be seen when long term sampling is done over 5 to 10 years?
- How does grazing management interact with tillage radish and Keyline plowing in the soil-building aspects of Keyline plowing?
- Should we set up replicated studies in areas where tillage radish has been used in the previous season to better understand the implications on specific forage species?
- Can cocktails of tap-rooted plants provide greater forage diversity and more pasture functions? What is a good seeding rate for radishes?
- Would subsoiling along the contour instead of the keyline give the same effects as Keyline plowing? What about using a more typical subsoiler, rather than a Yeomans plow?
- What are the long(er) term effects, benefits, challenges of increasing earthworms populations in pastures?

A separate VT CIG project, focused on demonstrating regenerative agriculture through pasture management, is continuing to collect data on keyline plowing. Data collection began in 2013 and will continue through 2015. For more information visit www.uvm.edu/pasture.

We welcome any comments, observations and suggestions. Feel free to contact any member of the project team, on the back page.

Resources

UVM Extension Center for Sustainable Agriculture's Pasture Program:

http://www.uvm.edu/pasture

UVM Plant & Soil Science:

Pasture improvement:
http://pss.uvm.edu/vtcrops/?Page=pasturegrazing.html

Soil testing:
http://pss.uvm.edu/ag_testing/

VT NRCS

http://www.vt.nrcs.usda.gov

UVM Extension State Office:

http://www.uvm.edu/extension
800-571-0668 (Toll Free in Vermont) or 802-656-2990

Other Useful Sites:

Cornell Soil Health Assessment:
http://soilhealth.cals.cornell.edu/extension/test.htm

From Ohio State University: The Biology of Soil Compaction
http://ohioline.osu.edu/sag-fact/pdf/0010.pdf

Building Soils for Better Crops: Sustainable Soil Management
Fred Magdoff and Harold van Es

USDA-NRCS Soil Specialist Ray Archuleta's soil videos:
http://vimeo.com/channels/raythesoilguy

Keyline plowing and tillage radish videos from Vermont:
http://www.youtube.com/user/acrossthefenceUVM

On Pasture online newsletter, including pasture, keyline plowing and tillage radish articles
www.onpasture.com

Contact:

Dr. Josef Gorres
Associate Professor
Department of Plant & Soil Science
63 Carrigan Drive, Jeffords Hall
Burlington, VT 05405
802-656-9793
Josef.Gorres@uvm.edu

Jennifer Colby
Pasture Program Coordinator
Center for Sustainable Agriculture
University of Vermont
23 Mansfield Avenue
Burlington, VT 05401
802-656-0858
Jennifer.Colby@uvm.edu

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