Momentum Ag

Healthy Soils Challenge Grant

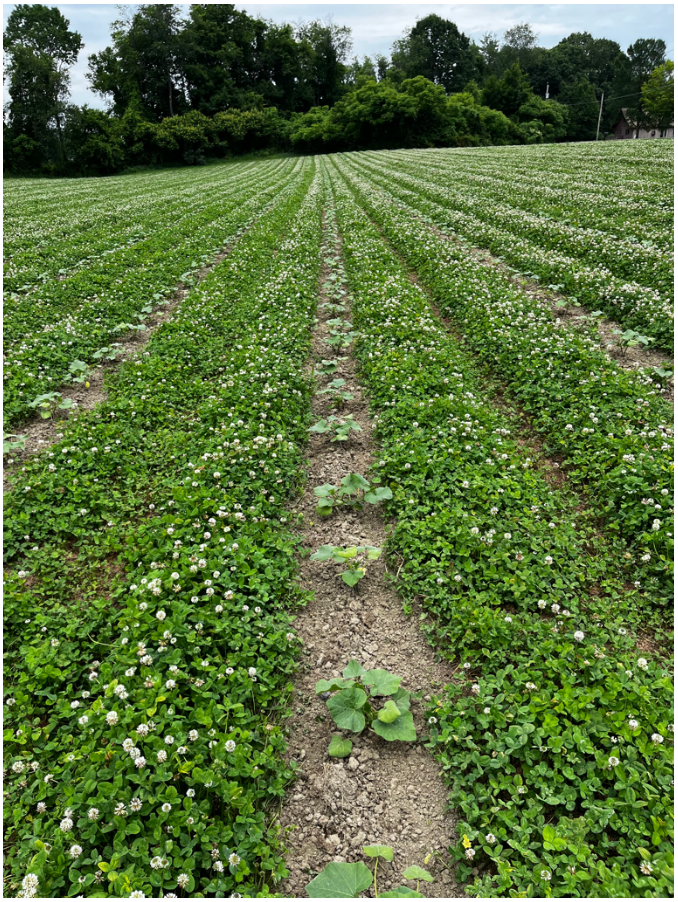
Creating a Community of Carbon Farmers in Massachusetts

In 2024, Momentum Ag received a Healthy Soils Challenge Grant from the Massachusetts Office of Energy and Environmental Affairs. The grant funded on-farm trials at ten farms across Massachusetts, to assess the Clover Living Mulch System (CLMS) in terms 1) soil organic carbon (SOC) sequestration, and 2) practicality, profitability and scalability for commercial farmers. SOC gains were impressive (as measured by the Cornell Assessment of Soil Health test). Significant headway was made on the agronomics, but more work is needed before out-of-network adoption can become a reality. Further agronomic work is critically important to unlock the carbon-sequestering potential of CLMS.

Outline

- Clover Living Mulch Overview
- Trials and methods
- Soil organic carbon and soil health results
- Trial results and Best Management Suggestions
- Barriers to adoption and Future directions
- Deliverables

The Clover Living Mulch System (CLMS).



Winter squash in strip-tilled clover living mulch.

Clover provides physical, chemical, biological and management benefits.

Physical: covers the soil year-round, eliminating erosion, minimizing leaching, increasing infiltration and conserving moisture.

Chemical: sequesters carbon and fixes nitrogen.

Biological: feeds soil organisms year-round and provides pollinator and insect habitat.

Management: establishes easily, overwinters reliably, suppresses weeds, withstands traffic, minimizes planning, and is perennial.

Clover's perenniality drastically reduces tillage, leading to a virtuous cycle of soil health improvements across all metrics.

Living Mulch is a term that refers to any living cover crop that is grown simultaneously with a cash crop. It functions as a mulch in the sense that it covers the ground and suppresses weeds, but it offers three key benefits over plastic or organic mulches. (1) A living mulch is grown in place, eliminating the carbon footprint associated with trucking organic mulches or producing plastic. (2) A living mulch actively feeds above- and below-ground biodiversity with root exudates and nectar. (3) A living mulch actively sequesters carbon and increases SOC.

What problems does CLMS seek to address?

According to the USDA's 2017 Agricultural Census, only 10% of MA's cropland is cover cropped, almost entirely with winter rye. The Healthy Soils Action Plan (HSAP) has an in-depth discussion of barriers to cover crop adoption, based on national research, HSAP listening sessions, and a NOFA report. All of our farmers cover crop to some extent, but generally feel that "Annual cover crops are a perennial headache." Annual cover crops, especially for MA's diverse, high-value crop farms, require burdensome time- and weather-dependent management and do not reliably perform or offer significant soil health benefits. It is critical to note here that these burdens only increase with climate-driven weather variability. *Climate change is likely to reduce rather than increase cover cropped acres in MA, unless we develop new climate-smart cover cropping strategies.*

Relative to annual cover crops, CLMS is easier to manage, offers superior soil health benefits, and is more reliable under extreme weather conditions.

The photo below was taken at after a heavy rainfall in July of 2023, a disastrously wet year for the Commonwealth's farmers.

Right side of photo: Recently transplanted cabbage in CLMS.

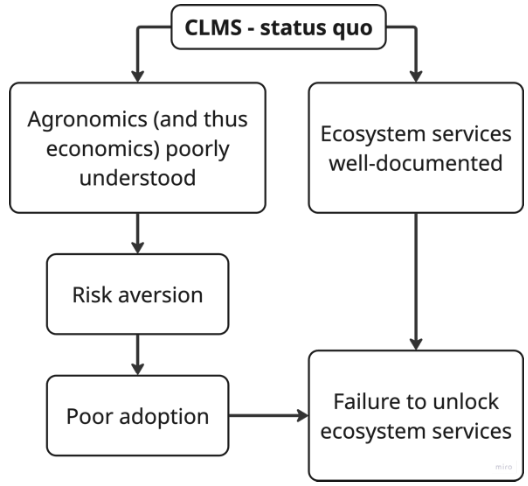
The clover breaks the impact of the raindrops, increases infiltration, slows or eliminates surface runoff, erosion, and nutrient loss, all while putting carbon into the soil.

Left side: Recently transplanted cabbage in bare soil. Though this plot was seeded down to rye after harvest, the bare soil was vulnerable to erosion and nutrient leaching all season long.

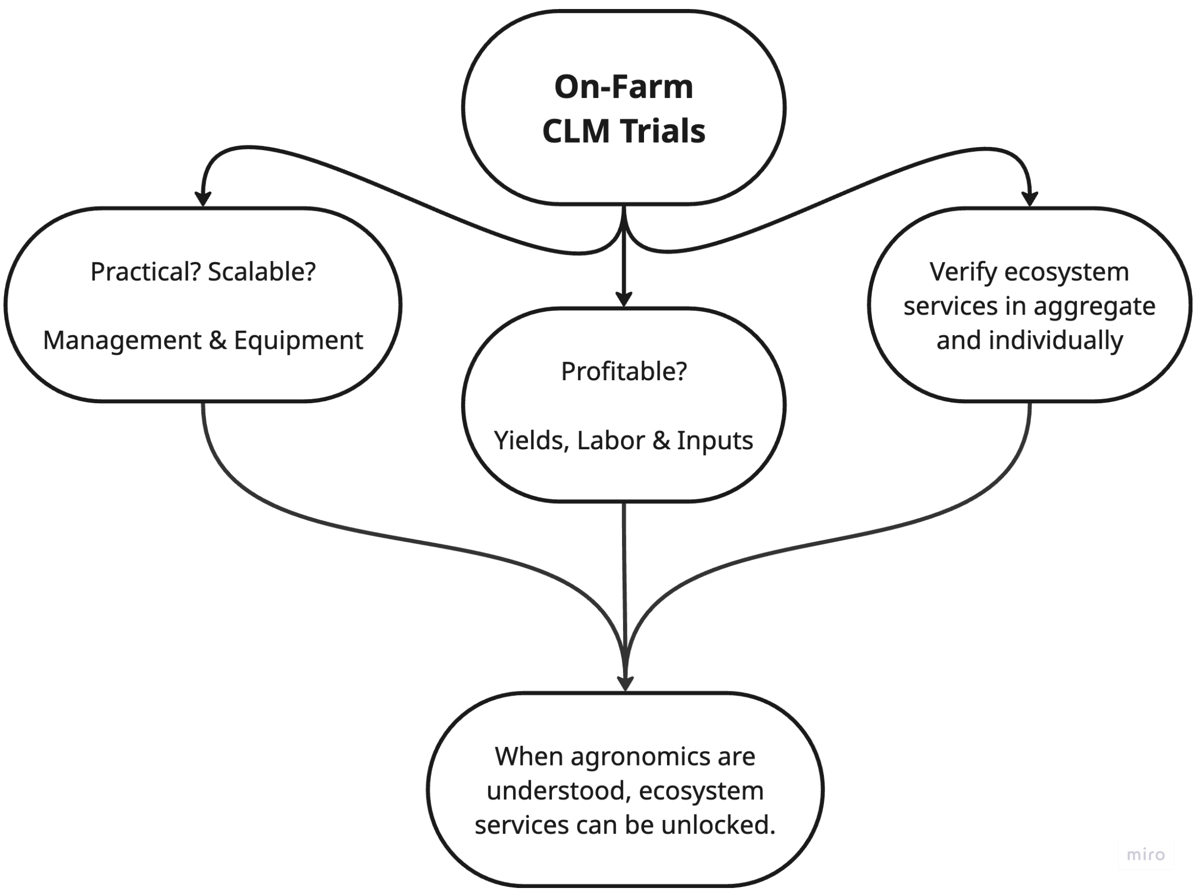
SOC data from these two plots showed a marked divergence by the end of the season: 2.21% SOC in clover vs. 2.05% in bare soil (Cornell Assessment of Soil Health).

If CLMS is so great, why isn't it being adopted?

The ecosystem services of clover living mulches are very well-established in peer-reviewed literature, but the agronomic practices needed to scale it *have never been studied on working farms* (until now!). Peer-reviewed literature admits that more work needs to be done in order to manage the relationship between the clover and the cash crop to achieve reliable yields.



Momentum's Theory of Change. This Healthy Soils Challenge Grant funded the largest set of on-farm CLMS trials ever. Our farmers explored a variety of techniques to manage the clover/cash crop relationship, and to ask whether and how CLMS can be made practical, profitable, and scalable. We gathered soil health data to ensure that our trials were in fact delivering the expected ecosystem services, particularly in terms of SOC gains.



Trials and Methods

Trials took place at ten farms across Massachusetts, from far Eastern MA to the Hilltowns of Western MA; half of the farms are located in prime soils of the Connecticut River Valley.

For all farms, Dutch White clover was established in 2023, either through interseeding into a cash crop, or sowing into or with a small grain cover crop during a fallow year (e.g., frost-seeded into rye, or established during the growing season with a small grain). BMPs for clover establishment are available by emailing Momentum directly (hello@momentumag.org), but have not yet been published as we continue to gather and refine data. Clover seeding rates varied from 8# to 40#, from broadcast to no-till drill, and all seedings were successful by season's end. Some were weedy through the season; weeds were managed through periodic mowings, and pure clover stands resulted in all cases by late summer.

In order to maximize the value of the trials for individual farmers and to create a complex tapestry of data points that are relevant to MA's farmers, trial design was intentionally not standardized across farms. While this approach would be frowned upon in peer-reviewed research, Momentum's mission is to augment the existing research with real-world trials on real farms. On-farm are necessarily messy; we've chosen to embrace that complexity rather than artificially flatten it. We believe that our results – combined with the existing research – are more meaningful to farmers, and more likely to result in widespread adoption of CLMS.

Many farms ran multiple treatments (more below). For each farm, the control was based on that farm's typical production system. In other words, controls were not uniform across farms. MA growers use a wide variety of growing techniques; we determined that it was most important for farmers to assess CLMS by comparing it with their existing system.

Cash crop types varied as well, and included fresh and canning tomatoes, delicata and butternut squash, silage corn, popcorn, grain corn, hemp, and late-season kale and broccoli.

Plot size ranged from a few thousand square feet to a few acres. During the planning phase, we asked farmers to size the trial so that it would be 'economically significant' for their farm – i.e., the potential profit was significant enough that farmers would find themselves compelled to manage it well throughout the season, even as season got overwhelming ("Too important to ignore."). Thus, high-value crops on smaller-scale farms had the smallest plot sizes, and low-value crops on large farms had the largest plot sizes.

Strategies for managing the relationship between clover and cash crop also varied. Many trials 'zippered' in transplanted vegetables – i.e. minimal clover disturbance, maximal clover coverage. Others created various strip widths in the clover to allow cash crops to put on vigorous growth before encountering clover competition. Others suppressed the clover with herbicide, plastic or organic mulches in strips where the cash crop was planted. (More on this below.)

Farmers collected pictures and qualitative notes through texting, farm visits, and virtual meetings. Farms quantitatively tracked profitability through labor, inputs, and yields. The quantitative data was useful but inconclusive, because almost every farmer – even those whose trials were more profitable than the control – concluded that they would tweak CLMS in significant ways going forward. While we could report out the quantitative data, it comes with so many caveats that we decided it would only provide a sheen of validity, and would likely mislead out-of-network farmers.

We developed the Best Management Suggestions as a group at a day-long Winter Meeting.

Soil Organic Carbon and Soil Health Results

The major headline of our study from a climate perspective is that CLMS plots sequestered a significant amount of SOC compared with control plots.

Samples were taken at the end of the season, as a pair, comparing CLMS to the control. We did not measure change over time; instead we measured how the two management systems had *diverged* at season's end. The question we asked was, "How much more carbon is in the soil in CLMS than in the control?" We don't know how much of this divergence was due to additional carbon sequestered by the clover, versus carbon lost in the control. Differentiating between these two potential sources of divergence is interesting, but either way, CLMS clearly *has* more carbon.

Soil samples were analyzed at Cornell, using the Cornell Assessment of Soil Health test. SOC is reported as a percentage of total soil weight.

CLM vs. Control	**Percent SOC**
CLM – median	2.1395375%
Control – median	2.02054%
Median difference	**0.1189975%**
CLM – average	2.238624193%
Control – average	2.11265298%
Average difference	**0.125971213%**

These appear, at first glance, to be vanishingly small differences – a 6% increase. *(CLM value – control value / control value.)* But the top 6" of topsoil in an acre weighs 2 million pounds, so even a slight percent increase means many more pounds of carbon.

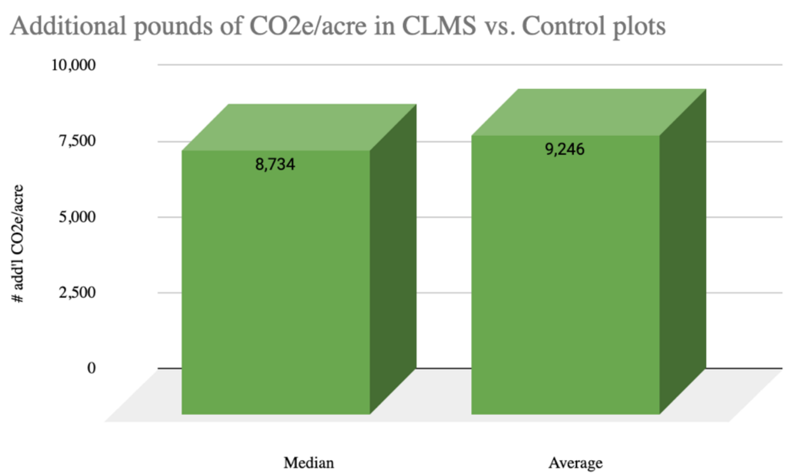
(We'll be using the median difference in the calculations below because it's the more conservative number.)

A 0.1189975% increase in carbon adds 2,380 pounds of carbon per acre.

(0.1189975% / 100 = 0.001189975 * 2,000,000 = 2380)

This is pure carbon; to convert to CO^2 equivalent CO^2e, we multiply by 3.67 (most of the molecular weight of CO^2 is the O^2).

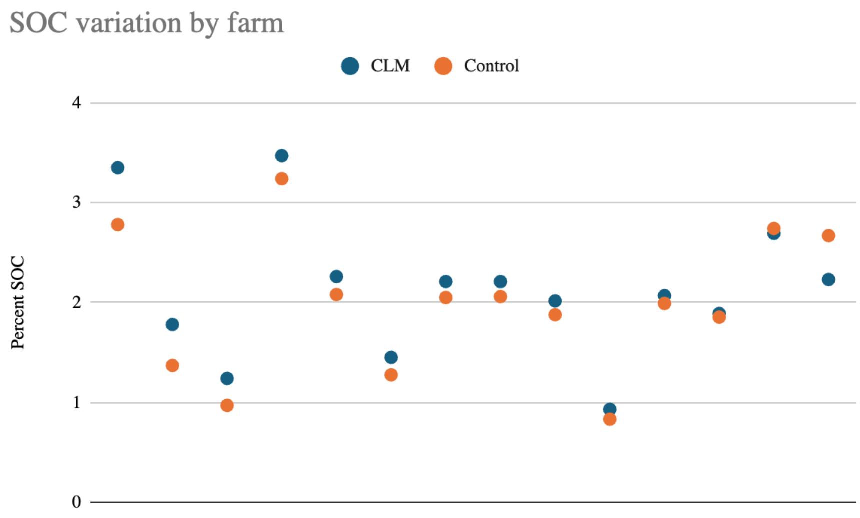
2380 * 3.67 = 8,734 pounds of CO^2e sequestered per acre = 3.96 metric tons.



Per acre of CLM, this is equivalent to *not* burning 400 gallons of diesel. We included median and average increases to indicate that these are clearly sensitive numbers. While we're not ready to hang our hat on a specific number, the overall trend is clear.

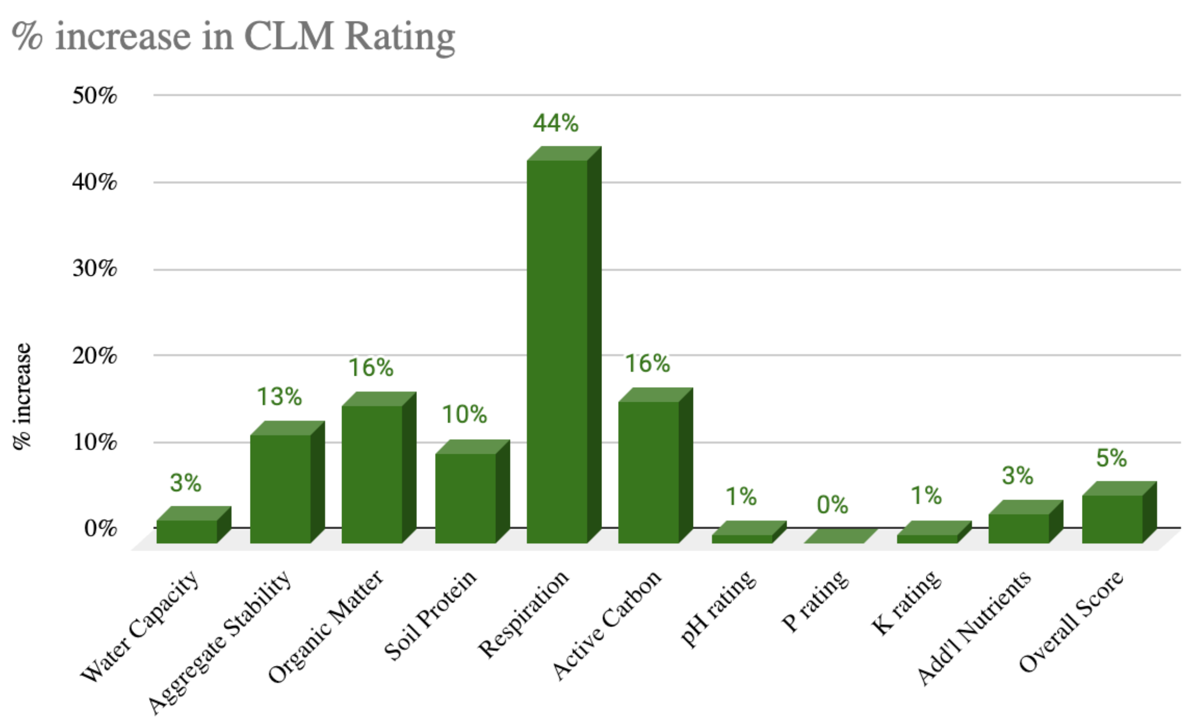
Conventional cropland is a net emitter without conservation practices (-0.1 tons/acre, USDA Farm Bureau). Cover-cropped and/or no-tilled cropland sequesters 0.3 – 1.2 tons/acre (Project Drawdown, Paustian et al (2016), Peoplau & Don (2015)). So even if further studies reduce our current estimate of 3.96 tons/acre, CLM is still head and shoulders above other options for cropland management.

This small, but significant increase in SOC held true across all farms, with just one exception. Each pair of dots is the CLM vs. the control test on an individual farm.

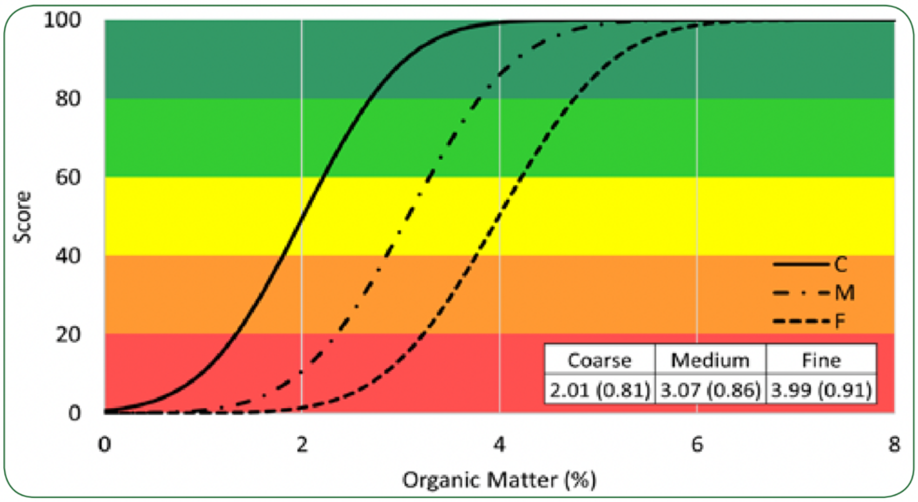


We think it is very reasonable to conclude that adopting CLMS leads to SOC gains.

Other soil health gains were equally impressive. Soil protein, respiration and active carbon are considered ‘biological indicators,’ and the increases there point to significantly more abundant soil biology in CLMS than in controls.



Note that these numbers are based on the *rating,* not the *value.* The relative proportions of sand, silt and clay in a soil make it easier or harder to increase SOM, for example. Coarse, sandy soils have fewer binding sites than fine silts and clays. Recognizing this, Cornell has normed values by soil type to arrive at a rating. In the example below, a fine soil with 3% SOM would receive a rating of 15, whereas a coarse, sandy soil with 3% SOM would receive a rating of 90.



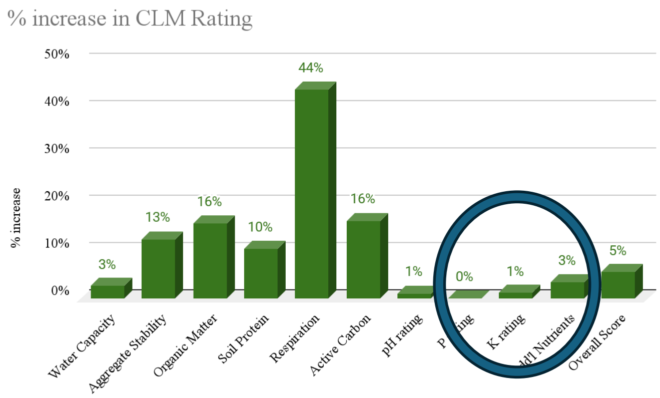
This concept is important to grasp when analyzing aggregated CASH tests. Aggregated results are best assessed by using the ratings to account for soil type variation. But for a more granular analysis (as we did above with SOC), each farm's values have to be expressed as a percent difference or increase.

There is one other issue with ratings. For nutrients, Cornell assesses a minimum adequacy to arrive at a rating. As long as that minimum is achieved, a rating of 100 is assigned (this is a bit of an oversimplification, but is sufficient for understanding what follows).

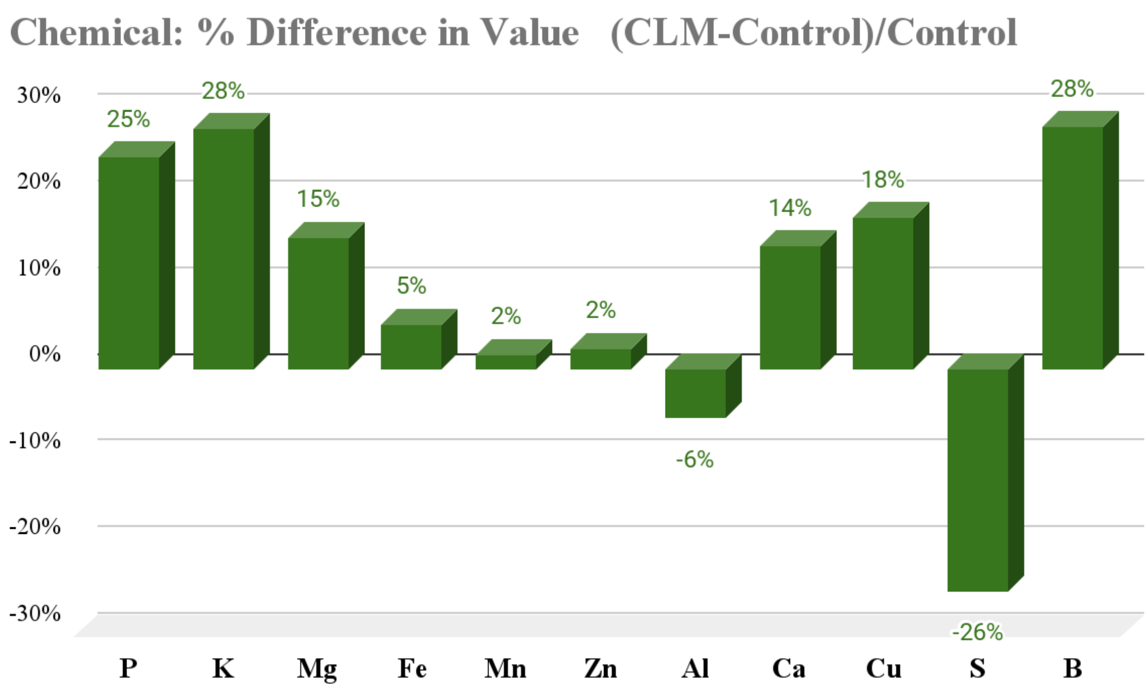
The table to the right shows a variety of phosphorus values in the lefthand column. Despite the differences, all samples received a rating of 100.

p	p_rating
8.6	100
5.1	100
10.5	100
10.4	100
7.3	100
7.7	100
21	100
7.5	100
21.7	100
19.7	100
5.4	100
4.9	100
5	100
5.7	100
10	100

Rating scores misleadingly convey insignificant differences between nutrient levels in CLM vs. control.



When we compare *values* between CLMS and control, a very different picture emerges:



Clearly, most nutrients are more abundant and/or available in CLMS. Existing literature indicates that arbuscular mycorrhizal fungi in CLMS form associations with cash crops readily and ‘feed’ them phosphorus. The same may be true for other nutrients. It’s also likely that by eliminating erosion and decreasing leaching, more nutrients stay in the soil.

Increases in P are worth noting, as P emissions from agriculture are a major contributor to nutrient pollution and the destruction of freshwater ecosystems.

P, K and Ca input reductions can have a significant positive impact on farms' profitability.

Taken as a whole, these results indicate that CLMS can simultaneously sequester carbon, reduce off-farm nutrient pollution, foster soil biology, and reduce farmers' fertilizer bills.

Whether CLMS can be practical, profitable, and scalable for MA farmers will determine whether we can unlock these benefits at scale, and we turn our attention to that question next.

Trials Results and Best Management Suggestions

The agronomics of CLMS are poorly understood. There is no cookbook. Instead, each farm made individual decisions to optimize outcomes. Our farmers have a combined 400 years of farming experience, and they drew on their own experience and that of the group's to design and implement trials that played to their strengths and skirted their weaknesses. This resulted in a wealth of excellent qualitative data – a series of case studies, essentially – and a wealth of suspect quantitative data.

When Best Management Practices (BMPs) have been determined for CLMS, it will be more useful to aggregate hard data on profitability – labor, inputs and yield. But given the current state of knowledge, capturing timely, nuanced and detailed answers to the following three questions seemed to us the best, quickest path towards the development of those BMPs:

1) What did you do?
2) Was it successful?
3) What will you change going forward?

Farmers were assisted in answering these questions through individualized case studies that summarized and narrativized the texts, photos, conversations, and site visits from the previous season. In essence, Momentum served as a memory dump for farmers throughout the season, and farmers were presented with their own case study at season's end, which they edited as they saw fit.

Then, as a group, we searched for patterns in those answers. What we present below is best understood as common themes that emerged, and a set of Best Management Suggestions

(BMSs), rather than BMPs. For farmers looking for specific advice about implementing CLMS, we encourage you to get in touch with us directly for targeted advice, or to connect with a farmer whose farm/crops/equipment/soils are most like your own. We can also share webinars, slide decks and photos. (hello@momentumag.org)

What did you do?

Most trials employed one of two techniques: Zip (no-till, left) or Strip (a strip of clover-free bare soil around the cash crop, right). More on management below. Zip vs. strip is an important distinction when asking 'What did you do?', as it affects management and Best Management Suggestions (BMSs) throughout the season.

Hard to see, but there are tomato transplants in there!

Strips prepped for winter squash.

Was it successful?

Given the plethora of caveats in the quantitative data, farmers felt the best approach to assessing the trials was based on individual farmers' qualitative impressions. Success largely overlapped with yield/profitability, but encompassed a great deal more. In particular, many farmers called their trial successful if it felt like it was firmly on the path *towards* success. In other words, they wouldn't scale 2024's exact trial to their entire farm, but they could imagine tweaks and felt that it was a successful first attempt. Most farmers mentioned soil health gains (both from the CASH tests and observationally) as an important metric for success. Many also mentioned aesthetics, improved working conditions, a feeling of progress towards soil health/ecological goals, and farming in line with their values.

Best Management Suggestions.

Few of these suggestions were true in every case. Farmers will understand that what works on one farm won't necessarily work on another. But implementing a new technique, whether CLMS or otherwise, requires starting somewhere. We think this list is a good place to start. *(Note: Momentum also works with and/or monitors CLMS trials in other Northeastern states and in the Midwest. Our BMSs are based on all growers' input, but the graphs and stated numbers below refer* only *to our Massachusetts trials. In general, we found little difference between MA farmers' experiences vs. those elsewhere.)*

1) **Plant into a pure stand of clover.** Annual weeds were not a problem from a yield perspective. In general, they failed to emerge through the clover canopy, and in cases where they did, it tended to be later in the season and posed little threat to cash crops. Most farmers mowed off weeds before they went to seed.

   However, farmers varied widely in their tolerance for weeds (within reason…none of them were big fans). Some expect weed pressure over the course of the season and manage weeds primarily to mitigate their impact on cash crop productivity; others have a zero tolerance policy. For the latter group, CLMS was challenging. A plan for more frequent, more accurate mowings will be necessary for those farmers (more on mowing equipment below).

   Annual weeds can be largely deterred through bare fallowing and/or frequent mowings in the clover establishment year. During cash crop production, clover will suppress the vast majority of annual weeds, but managing escapees is challenging.

Perennial weeds, on the other hand, can emerge vigorously through the canopy early in the season, and can withstand multiple mowings. Clover stands with perennial grasses reliably saw reduced yields.

Don't establish clover for CLMS in a field with a perennial weed problem, and if perennial weeds emerge before cash crop planting, use the strip technique, rather than the zip.

2) **Reduce fertility and incorporate**, if possible. Fertilizer reduction varied, but all farms reduced NPK because rather than broadcasting over the entire field, they focused fertility in and around the cash crop zone. Many of MA's farmers apply the first, largest application of fertility broadscale, across the entire field. So while many zip and strip zones had somewhat more fertilizer per square foot than the control, there were fewer pounds of fertilizer per acre.

   Reducing overall N/acre by 30% seems not to affect yield. This is an admittedly mushy number. The variety of fertility strategies was mind-boggling to document. This is because fertility was focused on the band directly around the cash crop but also, we think, due to greater nutrient release/availability in CLMS (supported by existing literature and our soil health results).

   Farmers agreed that incorporation was beneficial for reducing weeds/weed growth, and placing the fertilizer where it was most likely to be accessed by the cash crop rather than the clover. This was far easier to do in strip trials, as the fertilizer could be worked into the strip using standard equipment. There were, however, many successful zip and strip trials where fertilizer was surfaced applied. A few farmers were able to apply dry fertilizer subsurface with drop tubes immediately following a ripper shank, or liquid with standard disc opener setups.

3) **Ensure adequate sulfur…and other nutrients.** Sulfur (S) is the only nutrient that reliably shows up lower in CLMS than in the controls; clover is hungry for S. In CLMS, it's important to remember that nutrient levels must be adequate to grow two crops. While we found higher nutrient levels across the board in CLMS (with the exception of S) and believe nutrient retention and availability is an important benefits of CLMS, *testing your soil after clover establishment (once clover has had time to incorporate the nutrients it needs in its living tissue) but before cash crop planting is critical to catch any deficiencies that might hinder the growth of one or both species.*

4) **Strip early.** Making strips early in spring allowed time to kill clover in the strip, and to kill weeds in the strip with additional passes or apply pre-emergent herbicide, reducing tricky cultivation passes post-planting. Making strips later introduced uncertainty and created tight timing windows: strip as early as possible. *Extra passes before planting are passes saved after planting.*

5) **Mow close, but not too close.** Mowing the clover before planting in zip allows the cash crop to grow without photosynthetic competition for a longer window, hopefully allowing the cash crop to overtop the clover without a second mowing. The lower the clover is mown, the longer that takes. However, a couple growers used flails or brushhogs, and scalped the clover, exposing bare soil where weeds germinated. In strip, mowing may not be necessary at all (especially if the strip is >12"); if it is, there is no need to mow as low as possible given the physical distance between the clover and the cash crop.

6) **Mow only when necessary.** Trials led to an interesting conclusion. Mowing frequently did not have a positive correlation with yields. In fact, it may have suppressed yields. We *think* that clover forages more aggressively for nutrients as it regrows and/or during the vegetative rather than reproductive phase of its lifecycle. Dutch White clover does not have super distinct vegetative vs. reproductive phases, but in general, it grows vegetatively and vigorously in the cool, wet spring. As it moves into seed production in late spring and early summer, its growth slows. Not mowing seems to allow it to move through this cycle to our benefit. However, a second mowing was frequently necessary for photosynthetic competition in zip trials. And mowing to keep weeds low and to keep them from setting seed is good practice and may be necessary 1-3 times over the course of the season. Finally, mowing increases labor and decreases profit, so it should be avoided when possible. In summary, *mow only when the benefit is clear: immediately before transplanting, just before germination (for direct-seeded crops), if the clover is threatening to overtop the cash crop, or if weeds are going to set seed/compete with the cash crop.*

7) **Ensure large, healthy seed and healthy transplants.** Clover competition is most intense when cash crops are young. Healthy, rapidly growing cash crops are most likely to succeed. This is true for both zip and strip, but most important in zip.

8) **Ensure good seed/rootball to soil contact.** Planting into a zip requires care. The soil is not friable, so time must be taken to verify that the seed furrow is closed or that the transplant is firmly set. This is not an issue in strips, because the loose, worked soil in the strip allows for normal planting conditions.

9) **Irrigation is nice, but not necessary.** 2024 was a rare 'normal' season with adequate rainfall, and results would have been different in 2022, for example There were many successful trials in unirrigated fields.

10) **Irrigate early.** If you do irrigate, be aware that clover can transpire large quantities of soil moisture, even in cool weather, so early irrigation has a benefit – as farmers this runs contrary to our normal irrigation patterns. On the other hand, during the hotter, drier months, the shading effect of the clover leads to greater soil moisture and irrigation may be unnecessary in weather conditions that would normally require irrigating. Studies have borne this out in similar climates: CLMS plots have lower moisture levels in spring, and higher levels in summer. *Put your hands in the soil in CLMS plots; moisture levels will*

differ from what you're used to and you'll need to adjust irrigation accordingly. When in doubt during crop establishment, irrigate.

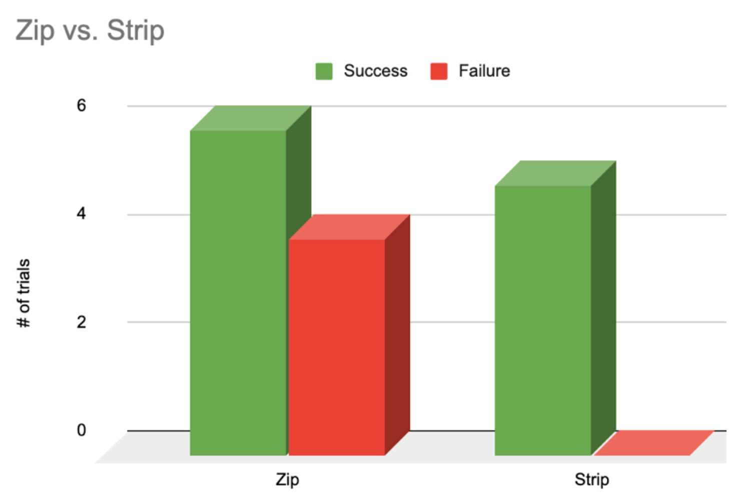
11) **Be patient.** In most cases, early cash crops growth in CLMS lagged behind the control before catching up.

12) **Pests and diseases were not affected – and possibly reduced – in CLMS.** Most farmers had concerns about pests and diseases proliferating in the dense, moisture-laden clover foliage, but we did not observe any cases where this borne out, and in some trials, cash crops in CLMS were less affected. Slugs were the only exception. They were more abundant in CLMS than in the control in some trials. They did not cause significant damage, but theoretically could.

13) **Clover persistence was unreliable.** Clover persistence through the season and into 2025 was unreliable. Squash seems to dominate clover – not just through shading, but by some other competitive mechanism. In some cases, the clover died during the growing season in squash plots, and in others it did not recover enough post-harvest to overwinter. For all other crops, clover persisted enough to form a dense cover through the winter – eliminating the need for a fall cover crop – but some of those stands were spotty or weedy in the spring of 2025, while others were still strong. *For now, treat CLMS as a one-season system for rotational purposes. Clover is established in year one, cash crops are planted into it in year two, and it may need to be terminated prior to planting in year three. For farmers who are comfortable with adaptive management, the decision about whether to terminate or plant into clover in successive years can be determined in spring, as clover is easy to terminate through tillage and/or herbicide.*

14) **Put residue on the ground post-harvest.** Clearly, mowing crop residue immediately after harvest led to stronger clover stands, as the clover had more light and opportunity to grow prior to winter, increasingly the likelihood of a second year of CLMS planting.

15) **Strip requires more tractor passes, but it produced more reliable yields.** This graph makes it look like strips are a no-brainer, and we think that for a grower looking for immediate success, strips are the best bet. However, in our successful zip trials, management requirements were extremely minimal. In most cases, after mowing and planting, only one or two additional mowings were necessary. If we can make zip reliably yield well, it could be quite profitable.



16) **Cash crop species matters – in general, and specifically in choosing zip vs. strip.** Tomatoes and hemp work well in zip (probably in strip as well, but we haven't run those trials). Late brassicas generally produce well in zip, but may benefit from strip. Corn and squash generally prefer a strip. Other trials we have tried or tracked in previous years and/or from out-of-state trials bear these conclusions out, and we chose those five crops because of their likelihood of success. *Tomatoes, late brassicas, and hemp are worth trialing in zip CLMS; other crops are more likely to yield successfully in strips.*

    Here are a few other out-of-state species findings: beans may work in zip, and produce well in strip (limited trials). Experiments with overwintering small grains drilled directly into clover are early but promising. Most results are from the U.K., where weather conditions confound the comparison. Twin row wheat in strips is working (limited trials). No one has tried alliums to our knowledge, because the transplants are not competitive, with the exception of two garlic in zip CLMS trials in 2025. Limited trials indicate that peppers, eggplant, summer squash (and potentially other heat lovers) perform poorly in zip, perhaps because of cooler soil temperatures. We have not tried them in strips, but imagine they will do well in a strip >12". We have not tried early brassicas because clover growth is so vigorous in late spring. They may work in strips, but probably not in zip. There is little time to prep strips for early crops unless strips are made in fall.

Barriers to Adoption and Future Directions

Barriers and future directions are one-in-the-same. There are two primary barriers: lack of equipment, and lack of experience. The future will require public investment to de-risk CLMS, and to make it practical, profitable, and scalable for farmers.

Equipment.

Pre-plant and post-harvest mowing equipment is relatively straightforward. Farmers used brushhogs, flails, hay mowers, riding mowers and lawnmowers. Personally, I like sicklebar mowers, because they lay the clover down with a single cut, and the cut clover forms a mulch that suppresses new growth for a few extra days. But in practice, all of the above options are workable.

Post-plant mowing equipment is significantly trickier. Farmers used BCS center-mount sickle bar mowers, lawnmowers and weedwhackers to mow between rows: this is not scalable beyond a few acres. Three strip trials and one zip trial managed without any post-plant mowing, but an inter-row mowing option for weed escapes will be necessary long-term. Cornell has designed a (heavy, expensive) inter-row mower, and two of the out-of-state farmers Momentum works with have built their own 4-row mowers that mostly work, most of the time. At smaller scales, adjustable width, lightweight wheeled sickle bar mowers seem the most promising, but need to be developed further. At larger scales, mowbots are the most likely solution. There is some work being done to develop these mowers, but the level of R&D investment is miniscule. For growers without RTK guidance on their equipment (nearly all MA growers), we'll need a teach-andrepeat mowbot, where the farmer manually drives the mowbot on the first pass, and the mowbot remembers that path (and can adjust off as the crop matures) for future passes. The technology exists, but the pieces haven't yet been put together. It's relatively simple, but, again, requires investment, and requires a skill set outside of most farmers' expertise.

No-till (zip) planters work well for direct-seeded crops without modification. **No-till *transplanters***, though commercially available, generally require heavy modification before they can operate reliably in CLMS. Two of our farmers have made significant headway and with relatively minimal additional investment: future modifications could follow their design.

Most of our farmers used a simple coulter/ripper setup on a toolbar for zip transplanting, and then followed the furrow with a waterwheel transplanter or by hand. This setup is workable on small scales.

Strip-till equipment is commercially available and two of our farmers used this equipment to make strips. In general, though, for MA vegetable farms these strip tillers are oversized and unwieldy.

Andrew Woodruff, of Island Grown Initiative on Martha's Vineyard, has been working on a homemade strip-tiller for a number of years and used it very successfully in CLMS trials for both zip and strip. He presented on his design at a Momentum-hosted webinar. See deliverables for the link. A few farmers are building a version of Andrew's strip tiller.

Hooded sprayers spray herbicide in a tight (12") band to kill a narrow strip of clover. Early results indicate that in our climate, working the strip may be necessary in addition to spraying, in order to work and warm the soil. Building a homemade hooded sprayer is not hard for a farmer with the right skill set.

For organic growers especially, **cultivating the strip** before and after planting is somewhat challenging, but with dedication, most farmers were able to set up a toolbar to work the edges and middle. A standardized toolbar setup would help future adopters save time and money.

Applying fertilizer in bands is surmountable, but farmers need a plan. Identifying high-flow, high accuracy, high capacity spreaders is a priority. Farmers use a wide variety of fertilizers and spreaders; a list of good, better, best options for different fert types and scales would be very useful for future adopters.

Experience.

More trials are needed. We are at the very beginning of exploring CLMS management. 20 trials isn't enough. 200 trials isn't enough. 2,000 would be a good place to start. The farmers involved in this project are definitively Innovators on the adoption curve. They are comfortable with uncertainty and adaptive management. Early Adopters will need a level of reliability to de-risk CLMS adoption. As we run more trials, risk decreases and recommendation reliability increases.

We must continue working towards reliable recommendations in the following categories:

Modifying and trialing equipment is a slow process, best explored through on-farm trials.

Continuing to determine **which species** work best in CLMS is critical, and determining which require strips to succeed and which can thrive in zip. We have observed important differences in **variety performance** as well. Varieties trials are time consuming and finicky, but as we aggregate data, we will slowly hone in on varieties that produce well in CLMS.

Fertilizer reduction recommendations will also take some time. Doubtless, these will vary farm-to-farm, but as farmers gain familiarity with CLMS, they will optimize fertility on their farms (as they do with all cash crops), again generating solid recommendations over many trials and a few years. University research can assist in this process (and in the variety trials mentioned above).

As we continue to experiment with strips, **strip width recommendations** will emerge. They will likely vary by crop. At the moment, 12” seems like a good starting point to reliably reduce the clover competition. Wider strips may work better for certain cash crops, and narrower strips are likely possible for others. The interaction with strip equipment will be important in determining the width.

Most problems can be solved with time and money, and CLMS is no exception. What makes CLMS unique is that, once it has been de-risked through experience and equipment, its ecosystem services are unparalleled in annual cropping systems.

We would like to sincerely thank the MA Healthy Soils Challenge Grant program for making an early investment in on-farm CLMS trials. This is the first robust set of on-farm CLMS trials in the nation, and an important first step towards widespread CLMS adoption.

Deliverables

We hosted three on-farm events, an additional in-person learning event, and three webinars. By our count, we reached 222 people through these events, the majority MA farmers, with a sizable contingent of TAPs and state-level stakeholders. An additional five webinars for out-of-state audiences provided opportunities to share these findings with well over 100 farmers.

In collaboration with the Community Involved in Sustaining Agriculture (CISA), UMass Extension, and the Hampshire/Hampden Conservation District, Momentum Ag hosted a farm tour at Atlas Farm, in Deerfield, MA on July 15th, 2024. We described Atlas’ two trials (squash and tomatoes) in great depth, looked at all the relevant equipment, and fielded farmers' questions. We had exactly 50 attendees. (37 farmers and 13 TAPs.)

In collaboration with NOFA-MA, we hosted an event at Waltham Fields Community Farm in Waltham, MA. We spent two hours talking as we walked through their squash and tomato trials. Ruben Parilla (NOFA-MA) shared his deep knowledge of soil microbiology and made soil observations in CLMS vs. control. There were 55 attendees, nearly all farmers with the exception of some NOFA-MA staff.

On September 16th, 2024, we had another event at Atlas Farm (also CISA-sponsored), where we hosted MA Climate Chief Melissa Hoffer and highlighted the CLMS trials and the importance of radical innovation through on-farm trials to adapt to and mitigate climate change. A number of state Representatives and staff members were also in attendance, in addition to representatives from many local non-profits, NRCS, MDAR, and local farmers. As far as we know, no one did a head count (there were reporters and Atlas Farm crew buzzing about – generally very busy), but there were easily 50 people in attendance.

On January 13th, Momentum held its Winter Meeting, where results were shared with farmers and the BMSs above were generated. Every single MA farm sent at least one representative to the six-hour meeting. The dedication of our farmer-partners continues to astound us.

On February 12th, Andrew Woodruff of Island Grown Initiative on Martha's Vineyard co-presented a webinar to talk about his zip/strip tiller design. There were twelve farmers in attendance, about half already in Momentum's network, and half new to CLMS. Webinar recording is available here.

On March 27th, Andrew spoke to a class and a few farmers at Hampshire College (8 students, 3 farmers). In the following weeks, the class built a strip-tiller, and Hampshire's farmers are currently using it for CLMS strip trials.

On April 8th, CISA co-sponsored a 2.5 hour webinar with 44 attendees (who stayed the whole time!), where we shared the soil health results of our CLMS trials. Bob Schindelbeck, head of the Cornell soil health lab, was a special guest and added a tremendous amount of texture to our findings. His thoughts were important to creating this final report. Webinar link here.

In addition, I have presented these findings to well over 100 out-of-state farmers through webinars hosted by Vermont Veg and Fruit Growers Association, The Connecticut River Watershed Farmers' Alliance, UWisconsin's Tillage Reduction Community of Practice, a U.K.-based non-profit called the Organic Farmers' Alliance, and to the Lighthouse Keepers – a group of living mulch researchers convened by the Ontario Soil Health Network.

We hope you consider the grant funds well spent and continue to fund our CLMS efforts in the future.