ECOLOGICAL FARMERS ASSOCIATION OF ONTARIO

Cover crops to regenerate fallow fields for vegetable production

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FARMER-RESEARCHERS
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IN A NUTSHELL

Over two years, Eric compared five methods of preparing fallow land for vegetable production with respect to soil regeneration and cost of implementation.

- Cover crops with micronutrient amendments increased active carbon, a sensitive indicator of soil health and soil regeneration potential.
- Micronutrient amendments alone did not increase active carbon.
- Eric saw some added benefit of adding chicken manure and woody compost to the diverse cover crop, with respect to yield and cost effectiveness per unit biomass of an indicator crop of sorghum sudangrass.
- Moving forward, whether Eric uses cover crops with or without manure and compost will depend on the return on investment of the following cash crop.

MOTIVATION

The cost of land is high, leading many new and expanding farmers with no other choice but to grow on degraded soil. In many situations, regenerating the soil by raising soil organic matter and balancing nutrient status is necessary before the land can be productive.

One relatively fast way to regenerate degraded soil ahead of production is to add micronutrient amendments and bring in sufficient amounts of compost. Depending on the scale, however, this method is costly such that regeneration is often a balance between speed of recovery and cost of implementation.

Eric has a 1-acre field in a perfect location for intensive vegetable production. It has sandy, well drained soil that warms up well in the spring with good road and water access. However, the topsoil was stripped by a previous owner and the organic matter is very low.

To expand his vegetable operation, Eric would like to assess different methods for regenerating the fallow field while balancing cost of implementation.

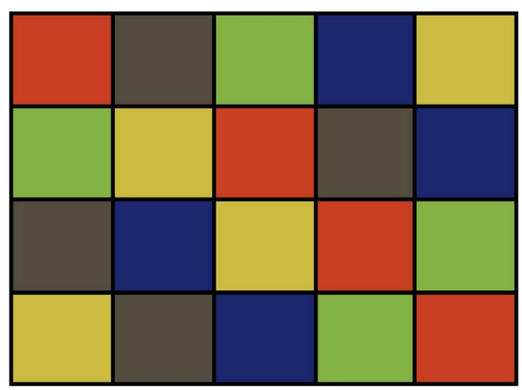


Figure 1. Experimental layout of Eric's trial. He divided a 1-acre field into 20 30'x30' plots. In each row of 5 plots, he randomly assigned one of 5 treatments. Treatments are listed in the text.

Plot preparation in May 2020.

METHODS

FIELD A

In spring 2020, Eric applied five treatments on the 1-acre degraded field in a randomized complete block design with four replicates, as shown in **Figure 1**.

- Mown control (mow)
- Mown + micronutrients (+MN)
- Mown + micronutrients + cover crops (++CC)
- Mown + micronutrients + cover crops + chicken manure (+++CM)
- Mown + micronutrients + cover crops + chicken manure + woody compost (++++WC)

MOWING MANAGEMENT

To manage the aboveground growth including weeds in the plots without cover crops, the cover crop mix, and sorghum sudangrass indicator crop, Eric mowed each plot 2-3 times throughout the season based on the size of the tallest sorghum sudangrass. When the tallest plots reached approximately 48” the entire field was mowed with a 6’ rear mounted rotary mower.

From these plots, Eric took the following measurements:

Spring 2020

- Three soil samples for baseline for complete soil test with micronutrients (A&L Laboratories S1B+S7) and active carbon, across the entire experimental area.
- Eric used this data to apply baseline mineral amendments to plots. He prepared and seeded the plots at the end of May.

Fall 2020

- Soil samples for active carbon from all 20 plots

In spring 2021, Eric divided each plot in two and randomly assign each side to an additional treatment, as follows:

- In 1Y sub-plots, Eric planted an indicator crop of sorghum sudangrass to assess the impact of the original treatment established in 2020.
- In 2Y sub-plots, Eric repeated the treatments for a second year on an area basis. He amended the sub-plots with the same principles as 2020, but based on an updated soil test to account for residual nutrients from the year before.

From these plots, he took the following measurements:

Spring 2021

- Soil samples for a complete soil test with micronutrients (A&L Laboratories S1B+S7) from each treatment (but not all plots, due to budget constraints) to re-calibrate his micronutrient application. This is because the compost and chicken manure provided some nutrients to the plots that received it, so he didn’t want to blanket apply the 2020 amounts in 2021.
- Soil samples for active carbon from all 20 plots.

Summer 2021

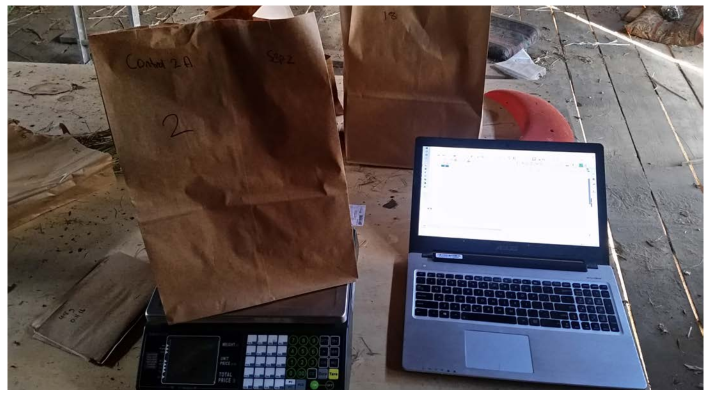
- Biomass samples of sorghum sudangrass from the 20 1Y subplot on July 26th, September 2nd and October 27th.
- His general rule for both years was to cut when the sorghum sudangrass reached around 4’ tall, which usually meant three cuttings per year.

Fall 2021

- Soil samples for active carbon from all 20 plots. The laboratory misplaced his original samples so Eric sent in two sets of samples. The first set was eventually found and analyzed so we have replicated data of active carbon at this time point.
- Biomass samples of sorghum sudangrass from the 20 1Y subplots in late October.

In spring 2022, Eric removed subplots 1Y from the trial and planted them back to a cover crop to prepare for vegetable production in future years, and treated the 2Y subplots as follows:

Bags labeled after soil sampling.


The process of weighing biomass of the indicator crop.

- Eric planted an indicator crop of sorghum sudangrass to assess the impact of the two years of treatment.

From these subplots 2Y, he took the following measurements:

Spring 2022

- Soil samples for active carbon from all 20 subplots.

Summer 2022

- Eric had planned on taking biomass measurements but because of slow growth due to drought conditions he skipped these sampling points.

Fall 2022

- Biomass samples of sorghum sudangrass from the 20 2Y subplots in October.

FIELD B

After seeing the results from 2020, Eric expanded his research question to also ask:

“Do cover crops provide a similar increase in active carbon in established fields that are currently productive?”

To answer this question, Eric added a new treatment based on the cover crop mix (+ micronutrients) treatment in a field that was already in good shape and was in its cover crop year as part of its three-year rotation for organic vegetable production. The value would be to repeat some of the measurements in an area that has received regular nutrient amendments for vegetables.

In 2021, he conducted the following side-study:

- Eric planted the cover crop mix with no additional amendments and marked 4 randomly chosen areas (~ same size as Field A plots) for soil sampling.
- He also marked 4 randomly chosen areas (~ same size as Field A plots) for soil sampling in a neighbouring field that was in its vegetable year as part of its three-year rotation.

From these plots, he took the following measurements:

Spring 2021

- One soil sample each from the cover cropped field and the for baseline active carbon.

Fall 2021

- Soil samples for active carbon from the 4 plots in the cover crop field and 4 plots in the production field.

AMENDMENT DETAILS

Micronutrients: Eric applied 50 lb per acre sulfur equivalent and 200 lb per acre Mg-K-Sulp based on soil tests and consultation with Ken Laing. He used a surface application with shallow incorporation for Treatment 2, and he used tillage to incorporate the micronutrients for Treatments 3-5.

Cover crops: Mix of rye (5), oat (5), vetch (5), phacelia (5), pea (11), crimson clover (4), radish (3), fava (7), sunflower (1), sorghum sudangrass (5), flax (2). Numbers in parentheses are in lbs/acre equivalent; recipe based on mix 20 (**1**). Eric seeded by drilling for larger seeds and broadcasting with a spin seeder for the smaller seeds.

Chicken manure: 100 lb N/acre equivalent granulated chicken manure from Acti-Sol.

Woody compost: 10 ton/acre equivalent high-C compost for treatments with woody compost that he made on-farm using wood chips, straw and well aged horse manure.

MEASUREMENTS

ACTIVE CARBON

Eric used permanganate (KMnO4) oxidizable carbon, or active carbon as his indicator for soil regeneration (**2**). This lab analysis uses permanganate to react (oxidize) labile carbon, which are carbon compounds that are readily used by soil microorganisms. The oxidation process produces a pink/purple colour, the intensity of which is measured on a spectrophotometer. The darker the colour, the greater the amount of labile carbon in the sample. While not a complete picture of labile carbon or soil health, active carbon has been shown to be a reliable and sensitive indicator of soil health on organic farms in Ontario (3).

To sample soil for active carbon, he used a shovel to take multiple soil slices (1" wide x 8" deep) per plot, which he mixed thoroughly in a plastic bucket. Within a day of sampling he sent 1-cup samples from each plot to A&L Canada Laboratories Inc. for their analysis of "reactive carbon".

A diverse and dense cover crop stand in October 2021.

In November 2020 the cover crop of mostly oats and radish was still green and the control plots had died off. This is compared to the third photo on page 4, which had more biomass in all plots.

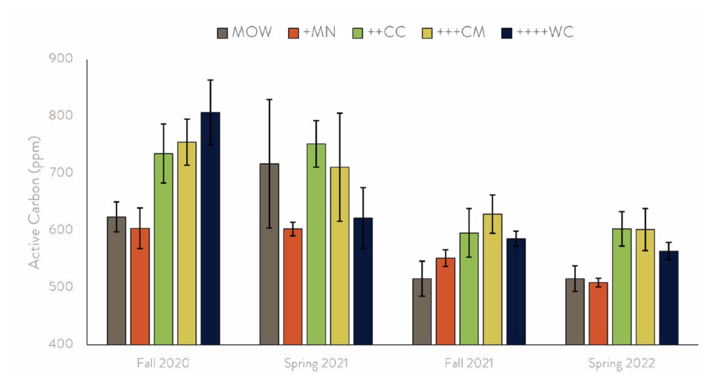


Figure 2. Active carbon in each of the five soil regeneration treatments. Bars represent means and lines represent standard error. The least significant difference needed to detect a difference in active carbon among treatments was 97 ppm. The least significant difference needed to detect a difference in active carbon between fall and spring was 92 ppm.

BIOMASS

Eric constructed a 12" square quadrat out of PVC held together with a shock cord (which allowed Eric to stretch the quadrat over the biomass. Eric found that the most practical way to sample was to cut the material with a scythe under the quadrat. He tried with other tools thinking the scythe would be too imprecise but working slowly with the scythe was still better than the other cutting tools he had.

He haphazardly placed this quadrat within the plots to delineate an area from which to clip the biomass of sorghum sudangrass, the indicator crop. He placed clipped biomass in pre-labeled paper bags, which he dried in his barn. Once dry, Eric weighed the biomass (accounting for bag weight).

In 2021, Eric collected biomass at three sampling times throughout the season (July 26, September 2 and October 27). Since similar trends among treatments were seen at all sampling times and for their cumulative weight, Eric sampled only once in 2022 on September 1 to reduce sampling labour.

DIVERSITY AND PLANT HEALTH

Throughout each season, Eric visually assessed the cover crop treatments to look for the presence or absence of the different species in the mix, general plant health, and disease pressure.

COST

Eric tracked labour hours, tractor hours, material cost, and total cost to establish all treatments in 2020.

DATA ANALYSIS

To evaluate the effect of the soil treatment on regeneration, we used an analysis of variance (ANOVA) to calculate a p-value based on the difference we observed among treatments. The ANOVA included mineral amendment, cover crop, chicken manure, woody compost, and block as treatment effects.

We used a cut-off value of 0.05, meaning we wanted to have 95% confidence in any difference we observed. If the p-value was less than the cut-off value, we had confidence to say the treatment produced differences. If the p-value was more than the cut-off value, we concluded there was no statistical difference. If we detected a difference among treatments, we conducted another test (i.e. a post-hoc test) to determine where the differences occurred between treatments.

We could make these statistical calculations because Eric's experimental design involved replication of the treatments.

FINDINGS

Among all the treatments tested, cover crops with mineral amendments had the most consistent and long-lasting effects on soil regeneration at Eric's farm.

SOIL HEALTH

Eric detected higher active carbon in plots with the diverse cover crop mix. Plots with cover crops had higher active carbon than the controls without cover crops (+MN), as shown in **Figure 2**. Active carbon in cover crop plots was not statistically higher with the additional chicken manure (+++C) and wood chips (++++WC).

Active carbon represents a pool of labile, or readily usable, carbon available for microbes to process organic material. This microbial activity can, in turn, build organic matter. Therefore, greater active carbon levels reflect greater potential to build soil organic matter and regenerate soil health with cover crops in this context (**4**).

The sorghum sudangrass indicator crop in 2022 was over 8' tall in most WC plots.

All plots were green in July.

In the fall, the control plots without cover crops died earlier. In this photo, the control plots without the cover crop look like brown rectangles.

Eric observed a less diverse cover crop established, primarily sorghum sudangrass, radish, and oat regrowth, in plots with chicken manure.

Table 1. Cost breakdown of the five treatments to regenerate a fallow field for vegetable production. Eric mowed all plots twice.

TREATMENT	PER 4 REPLICATE PLOTS COMBINED				PER ACRE
	LABOUR HOURS	TRACTOR HOURS*	MATERIAL COST	TOTAL COST	TOTAL COST
MOWN CONTROL (MOW)	0.0	0.3	$0.00	$12.60	$152.46
MOWN + MICRONUTRIENTS (+MN)	0.5	0.5	$52.50	$85.64	$1,036.26
MOWN + MICRONUTRIENTS + COVER CROPS (++CC)	1.8	1.1	$52.50	$142.98	$1,730.00
MOWN + MICRONUTRIENTS + COVER CROPS + CHICKEN MANURE (+++CM)	2.3	1.1	$80.00	$183.81	$2,224.08
MOWN + MICRONUTRIENTS + COVER CROPS + CHICKEN MANURE + WOODY COMPOST (++++WC)	2.7	2.4	$80.00	$248.14	$3,002.51

*Tractor hours = fuel, depreciation and maintenance. Cost of tractor hours calculated at $42/hour.

Eric observed this cover crop effect on active carbon in fall 2020, fall 2021, and spring 2022; but not in spring 2021. Eric posits higher active carbon in cover crop plots was detectable in spring 2022 but not in 2021 because the cover crop that established in 2021 had better germination of the smaller seeds and better overall growth of all the species. This growth led to more perennial and biennial components of the cover crop mix—and their roots, that survived the winter—which could have contributed to active carbon in the spring of 2022. Eric's thinking is further supported by his observation of better soil tilth, as demonstrated by much easier soil sampling and surface organic matter in the cover crop plots compared to control plots in 2022. All plots with cover crops were noticeably "softer" to sample into — so much so that he had to calibrate his shovel force to keep sampling depths equal.

BIOMASS GROWTH

With respect to aboveground effects, the indicator crop of sorghum sudangrass grew better in plots that received the cover crops and fertilizer amendments. Growth of the sorghum sudangrass responded most to the complete treatment of cover crops, chicken manure, and wood chips (++++WC); and there was also more growth in all the cover crop plots compared to the control plots, as seen in **Figure 3**.

Eric observed these effects at both individual sampling times and for cumulative biomass during the first year of treatment (2021) and at the end of the season during the second year of the treatment (2022). This result is consistent with Eric's observations, who noted the ++++WC treatments had the tallest sorghum sudangrass and the woodiest biomass samples.

He also noted that sorghum sudangrass in the cover crop with chicken manure plots was robust, and had foliage that was greener and looked more nitrogen-rich. Despite this observation, we were unable to detect a difference in biomass as a result of the addition of chicken manure. This might have been due to higher variability in these plots.

Similarly, Eric observed the diverse cover crop mix outlasted the weeds in the control plots, and continued to grow with good biomass into the late fall in 2020 and 2021.

Table 2. Cost per pound of indicator crop.

TREATMENT	2021	2022
MOWN CONTROL (MOW)	$0.03	$0.02
MOWN + MICRONUTRIENTS (+MN)	$0.18	$0.13
MOWN + MICRONUTRIENTS + COVER CROPS (++CC)	$0.14	$0.10
MOWN + MICRONUTRIENTS + COVER CROPS + CHICKEN MANURE (+++CM)	$0.12	$0.07
MOWN + MICRONUTRIENTS + COVER CROPS + CHICKEN MANURE + WOODY COMPOST (++++WC)	$0.13	$0.06

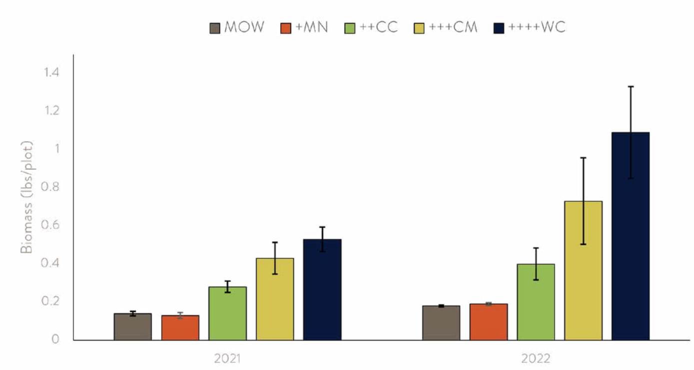


Figure 3. Aboveground biomass of the sorghum sudan indicator crop taken in 2021 and 2022. Data from 2021 represents cumulative biomass from three sampling dates and data from 2022 represents a single sampling in September.

All plots were green in July. In the fall, the control plots without cover crops died earlier, as seen by the brown rectangles in the photo on page 4.

In terms of species composition of the cover crop mix in response to different treatments, Eric observed more diversity at the end of the season in the cover crop mix with only mineral amendments compared to the cover crop mix with chicken manure, as shown in photos on page 4 and 6.

The extra nitrogen in the manure may have changed the dynamics within the cover crop community away from leguminous components, towards grasses and brassica, favouring a less diverse mix.

Similarly in his cover crop only split plots in 2021, Eric noticed sorghum sudangrass grew better in the cover crop mix compared to as an indicator crop, as shown in the bottom photo on this page. These plots were treated the same, so Eric's top theory to describe the difference is the result of nitrogen fixation from the cover crop mix, and maybe also a synergistic effect from the diversity.

Finally, Eric observed weed pressure was far lower after two years of cover crops. Plots the year(s) following the diverse crop crops had minimal weeds compared to the plots without cover crops and compared to other strategies he has used. This observation was most notable after two successive years of cover crops. Eric notes this could be related to the drought he experienced in 2020 and 2021 but he didn't observe this elsewhere on the farm.

COST EFFECTIVENESS

Averaging across all plots, Eric found the cost (total cost, labour cost, material cost and tractor time) of implementing the treatments increased from the control (treatment 1) to the most comprehensive treatment (treatment 5), as shown in **Table 1**. He did not track cost on a plot level so we were unable to run statistics.

When Eric evaluated the cost of each treatment relative to the biomass of indicator crop produced in 2021, 2022, he found that the intensive treatments produced biomass at a more cost effective rate than simply using cover crops **Table 2**. In other words, if the only measure used was total above ground productivity in the subsequent year, woody compost plus chicken manure plus micronutrients plus cover crops (the intensive treatment) produced the highest biomass at the most cost effective rate on a cost per pound basis. Depending on the expected marginal value of the following crop, this may be an argument for the intensive treatment. It would be interesting to know to what degree the residual nutrients from the treatments influenced the increase in biomass as opposed to the soil health improvement that they caused (as measured by active carbon in this study).

DEGRADED FIELDS VS PRODUCTION FIELDS

While Eric detected a significant and consistent effect of cover crops on degraded soil, he did not detect an effect of cover crops in his production fields with good soil health and nutrient status.

This is not unexpected, since Eric works hard to maintain his production area in top condition with the addition of compost, balanced fertility/micronutrient application, minimal tillage, crop rotation including cover crops.

Eric observed diversity in cover crop plots that did not receive chicken manure. This photo shows sorghum sudangrass, vetch, crimson clover, oat, radish, and fava.

On the left there's a cover crop with sorghum sudangrass as a major component and and on the right is a monoculture of sorghum sudangrass as the indicator crop.

To Eric, the lack of effect of cover crops in his production fields reinforces the idea that diverse cover crop mixes can be an economic strategy to regenerate worn out, or degraded, land; and as a strategy to maintain soil already in good condition.

NEXT STEPS

Balancing cost and soil health benefits, Eric will focus on micronutrient application and diverse full season cover crops in areas that require regeneration; but he will use compost and heavy amendments to continue regeneration when the land is in production.

"You can't bootstrap healthy soil in one year", says Eric. Even with gains in active carbon, production areas in other parts of the farm that have had nutrient balancing and organic amendments over years looked better than the highest input treatment he compared.

Eric is also thinking hard for ways to fit two years of diverse full season cover crops into his rotation.

TAKE HOME MESSAGE

Even with the tillage passes required to amend the soil and establish the cover, cover crops played an important part in regenerating Eric's fallow field by promoting active carbon belowground and, in turn, presumably building soil.

Eric also observed that diverse full season cover crops maintained soil health on his productive land, and helped cleaning up weeds.

Compared to the cheapest strategies tested, like adding micronutrients and letting a field go fallow, planting a diverse full-season cover crop mix on soil that is mineral-balanced is a resource extensive way to regenerate degraded or "worn out" sandy soil.

Compared to the intensive treatment with manure and woody compost, using the diverse cover crop mix alone was less cost effective per unit biomass of the indicator. His choice of method moving forward, therefore, will depend on the return on investment of the following cash crops.

Overall, these findings support previous research that shows that cover crops sustain soil quality and productivity by enhancing soil C, N, and microbial biomass (**5**) and increase active carbon and soil organic matter relative to continuous corn (**6**); and that active carbon is a sensitive indicator of soil health (**3, 7**).

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