Living Labs Atlantic – Final Report

BMP3: Use of Full-Season Soil-Building Rotation Crops for Building Soil Organic Matter

Report by Ryan Barrett, Prince Edward Island Potato Board

Project Rationale:

Traditionally, most Prince Edward Island potato rotations of three or more years in length include one or more years of forage crops. Historically, many potato farmers also had ruminant livestock and needed hay or silage to feed primarily beef or dairy cattle. Other farmers traded land with cattle producers or sold hay to cattle producers, which necessitated growing these crops. As potato production has become more specialized in recent decades, concurrent with a significant reduction in beef production in PEI in the last twenty years, there has been reduced demand for forages. While many potato producers have continued to include forages such as red clover or clover/grass mixtures in their rotations, there have been increasing questions on whether these traditionally employed forages are the best choice ahead of potatoes.

There are multiple reasons to re-examine whether currently employed forage crops or mixes are the best choices or whether there are other options that may be better suited to precede potatoes in rotation:

- Prior research and survey data in Prince Edward Island indicates that red clover may be a preferred host for root lesion nematodes and *Verticillium dahliae*, which are in turn implicated in potato early dying (PED) complex. This disease leads to the premature foliar wilting of potato plants, leading to reduced tuber size and tuber yield. There are very limited chemical control options to combat PED, and the most effective (chemical fumigation) is not currently permitted in PEI. However, prior research in other regions has indicated that some forage crops (ie. sorghum sudangrass, forage pearl millet, oilseed radish) may help to reduce pest/pathogen number or disease severity.

- Wireworm has been a major crop limiting pest issue in Prince Edward Island for a number of years. Once again, there have been a limited number of pesticide options available to control wireworm, but rotation with crops such as brown mustard or buckwheat have shown to be effective at reducing wireworm damage ahead of potato crops. Conventionally used forages have also been shown to be preferred egg-laying habitats for click beetles (the adult stage of wireworm).

- Despite a number of producers employing a three year rotation with under-seeded forage crops following small grains and ahead of potatoes, we still see a long-term decline in soil organic matter in PEI potato rotations. While that decline appears to have stabilized in recent years (PEIDAL Long Term Soil Quality Monitoring Project), growers are interested to know if there are other crops available that will suit their rotations but that may have an enhanced ability to improve soil organic matter levels.

Therefore, there has been significant interest from producers to assess some alternative annual forage crop or cover crops in comparison with traditionally-employed forage crops for their effect on soil organic matter, soil health, and potato yield and quality.

Project Overview:

In 2019, the Prince Edward Island Potato Board was selected to lead a project under the Living Labs Atlantic initiative to investigate the use of alternative full-season, soil-building cover crops to improve soil organic matter, soil health, and marketable yield of potatoes. For three years (2019-2021), a number of field-scale trials were established on participating farms in the spring, consisting of one or more "treatment" crops along with a "control" crop, consisting of a crop that the producer would normally have planted in that field in the year before potatoes. These fields would then be followed into the next year (2022-2022) when potatoes were planted.

Table 1: Description of data collected in BMP3 field trials over three-year period.

Tests Performed	**Variables**	**Timing of Collection**	**Sampling Intensity**
Soil Chemistry, analyzed at PEI Soil Lab	Organic Matter %, pH, individual nutrients	1. Before or immediately after crop establishment 2. Spring before potato planting	One composite sample per treatment. Exception: four samples per treatment in spring 2022.
Soil Health, analyzed at PEI Soil Health Lab	Active Carbon, Aggregate Stability, Soil Respiration, Biological Available Nitrogen	1. Before or immediately after crop establishment 2. Spring before potato planting	One composite sample per treatment
Root Lesion Nematodes, analyzed at Potato Quality Institute	Root Lesion Nematode counts	1. Before or immediately after crop establishment 2. Spring before potato planting	One composite sample per treatment
Verticillium, analyzed at Agricultural Certification Services	*Verticillium dahliae* counts	1. Before or immediately after crop establishment 2. Spring before potato planting	One composite sample per treatment
Soil Compaction	Soil Resistance (psi) measured by soil penetrometer	1. Spring before potato planting	Ten locations per treatment at multiple depths (6, 9, 12, 15 inches)
Potato Yield and Quality, with grading at Cavendish Farms Central Grading	Total Yield, Marketable Yield, Percent Smalls, Percent > 10 oz, Percent Total Defects, Specific Gravity, Crop Value	Fall of second year, immediately before fields are to be harvested	Four 10-foot samples with an equal number of plants per sample per treatment.

In 2019, ten trials were established, with eight field trials carried through to completion. These included:

- Comparing tillage radish and brown mustard treatments with a timothy/red clover control treatment.
- Comparing a 10 species cover crop mixture with an annual ryegrass control treatment.
- Comparing sorghum sudangrass and faba beans treatments with an annual ryegrass control treatment.
- Comparing an 8 species cover crop mixture and sorghum sudangrass treatments with an oats control treatment
- Comparing a sorghum sudangrass/pearl millet/peas mixture with an annual ryegrass control treatment
- Comparing buckwheat and hemp treatments with a timothy/red clover control treatment.
- Comparing a sorghum sudangrass treatment with an annual ryegrass control treatment.
- Comparing sorghum sudangrass/mustard, 10 species cover crop mix, mustard/radish, and tillage radish with a brown mustard control treatment.

In 2020, nine trials were established, with seven field trials carried through to completion. These included:

- Comparing buckwheat with a timothy/red clover control treatment
- Comparing a sorghum sudangrass/pearl millet/oilseed radish mixture with an annual ryegrass control treatment
- Comparing Caliente Rojo mustard/arugula mixture and Ikarus radish treatments with an annual ryegrass control treatment
- Comparing sorghum sudangrass and Ikarus radish treatments with an annual ryegrass control treatment
- Comparing sorghum sudangrass and oilseed radish treatments with annual ryegrass control treatment
- Comparing a 13 species cover crop mixture with an annual ryegrass control treatment
- Comparing sorghum sudangrass with an annual ryegrass control treatment

Two 2020 trials that were established but ended up not being planted with potatoes until 2022. Some data was still collected from these trials but their potato yield data is not included in analysis with the other trials. They are:

- Comparing a 10 species cover crop mixture and a Caliente Rojo mustard/arugula mixture treatments with an annual ryegrass control treatment.
- Comparing brown mustard (evaluated both as a harvested crop and a green manure) and sorghum sudangrass treatments with a barley control treatment.

In 2021, seven trial fields were established, with six trials carried through to completion. These included:

- Comparing treatments of Caliente Rojo mustard/arugula, pearl millet/sudangrass, radish/sudangrass, mustard/radish, and brown mustard with an annual ryegrass control treatment.

- Comparing a sorghum sudangrass/brown mustard mixture with an annual ryegrass control treatment.
- Comparing forage pearl millet with forage grass (timothy, ryegrass) control treatment.
- Comparing treatments of Caliente Rojo mustard/arugula and Ikarus radish with an annual ryegrass control treatment.
- Comparing an Ikarus radish treatment with mixed legume/grass forage control treatment.
- Comparing forage pearl millet with a red clover/grass forage control treatment.

Over three years, treatment crop frequencies were:

- Sorghum sudangrass = 7 treatments
- 2 or 3 species mixtures = 8 treatments
- 8 to 13 species mixtures = 5 treatments
- Oilseed (Ikarus) radish = 5 treatments
- Brown mustard = 3 treatments
- Pearl millet = 2 treatments
- Tillage radish = 2 treatments
- Buckwheat = 2 treatments
- Hemp = 1 treatment

While the producer was able to choose a control crop similar to what would have normally used in that field, we attempted (especially after the first year) to encourage using annual ryegrass or a clover/grass forage mixture. Fourteen of the trials had an annual ryegrass control treatment, while six trials had a mixed forage control treatment. Five of the six mixed forage controls had legumes (red clover primarily) as part of the mixture.

Due to the diversity of treatment crops and control crops employed in these trials, there is not a sufficient number of observations for all treatment crops to perform statistical analysis. In addition, while "treatment crops" and "control crops" are grouped together for comparison purposes, it should be recognized that there is significant diversity in those two categories.

Soil Nutrients and Soil Health:

Table 2: Comparing soil health metrics for full-season soil-building crop treatments compared with control treatments from spring sampling from 2020 to 2022.

	# samples	Soil OM %	Active C µg/g	Soil Respiration mg/g	Aggregate Stability %	Bio. N Availability mg/kg
Soil Builder	38	2.28	384.9	0.441	38.1	19.7
Control	23	2.26	375.8	0.431	27.3	17.9
Difference		0.02	9.1	0.010	10.8	1.8
p value		0.872	0.664	0.809	0.391	0.277

No significant differences were observed for the soil health metrics listed in Table 2. On average, the "soil builder" crops did not perform better than the control treatments for these soil health metrics.

However, given the diversity in crops included, it is useful to pull out more specific averages for some of the more frequently used treatments.

Table 3: Comparing soil health metrics for C4 grasses (sorghum sudangrass and pearl millet) compared with control treatments from spring sampling from 2020 to 2022.

	# samples	Soil OM %	Active C µg/g	Soil Respiration mg/g	Aggregate Stability %	Bio. N Availability mg/kg
C4 grasses	13	2.39	432.9	0.452	25.2	20.0
Control	12	2.42	416.5	0.464	25.2	18.5
Difference		-0.03	16.4	-0.012	0.0	1.5
p value		0.898	0.534	0.750	0.998	0.519

Table 4: Comparing soil health metrics for radish treatments compared with control treatments from spring sampling from 52020 to 2022.

	# samples	Soil OM %	Active C µg/g	Soil Respiration mg/g	Aggregate Stability %	Bio. N Availability mg/kg
Radish	6	2.02	367.8	0.452	35.2	23.7
Control	6	2.05	353.0	0.447	29.7	20.6
Difference		-0.03	14.8	0.005	5.5	3.1
p value		0.882	0.748	0.904	0.333	0.212

Table 5: Comparing soil health metrics for mustard treatments compared with control treatments from spring sampling from 2020 to 2022.

	# samples	Soil OM %	Active C µg/g	Soil Respiration mg/g	Aggregate Stability %	Bio. N Availability mg/kg
Mustard	7	2.27	363.3	0.409	26.7	19.4
Control	5	2.30	371.0	0.420	29.1	18.9
Difference		-0.03	-7.7	-0.011	-2.4	0.5
p value		0.846	0.856	0.869	0.616	0.838

Table 6: Comparing soil health metrics for diverse cover crop (8-13 species) treatments (MSM) compared with control treatments from spring sampling from 2020 to 2022.

	# samples	Soil OM %	Active C µg/g	Soil Respiration mg/g	Aggregate Stability %	Bio. N Availability mg/kg
MSM	5	1.98	292.8	0.596	27.4	20.1
Control	5	1.80	294.0	0.364	23.8	14.9
Difference		0.18	-1.2	0.232	3.6	5.2
p value		0.769	0.982	0.237	0.575	0.463

For none of these comparisons did we observe any statistically significant differences. In most cases, there is very little difference in mean observations for most metrics. The two comparisons the come the closest to a significant difference at p = 0.1 are biological available nitrogen in favour of the radish treatments and soil respiration in favour the multi-species mixture treatments. It is likely that for the multi-species mixtures, the presence of one or more legumes in those treatments is likely to be increasing soil respiration in comparison to the largely ryegrass control treatments. However, the high degree of variability has made those differences not statistically significant.

Table 7: Comparing soil pathogen populations and soil compaction readings for soil-building crop treatments compared with control treatments from spring sampling from 2020 to 2022.

	# samples	**RL Nematodes #/kg**	**V. dahliae cells/g**	**Compaction at 6 in psi**	**Compaction at 9 in psi**	**Compaction at 12 in psi**
Soil Builder	38	4888	3000	106.1	218.3	317.3
Control	23	6784	2588	83.7	182.4	296.6
Difference		-1896	412	22.4	35.9	20.7
p value		0.196	0.535	0.339	0.222	0.161

When we group the soil-builder crops together, we do we trend toward suppression of root lesion nematodes, though still not at a statistically significant level. Given the high degree of variability it root lesion nematode testing, it is often hard to show significant differences in suppression for these crops. When breaking out C4 grasses, radish, mustard and multi-species mixes like in Tables 3 through 6, we still don't see any significant differences for root lesion nematodes; however, we do see the lowest numbers follow mustard treatments, which is consistent with what has been found in other studies where mustard has been used as a biofumigant crop. There was also no significant differences observed for *V. dahliae* counts in any of the crop categories.

While there is no significant differences observed for compaction at three different depths, there is a trend toward lower compaction in the control treatments compared to the soil builder treatments. For these metrics, it should be noted that there is in many fields a difference in tillage frequency between treatment and control. For biofumigant treatments like mustard, there is a required tillage event that is not done for the control. This may explain why we see some difference in compaction metrics. Likewise, some of the control treatments (forage grasses under-seeded under barley) have been established for two years compared to annual soil building crops that have had tillage performed before establishment. This makes it difficult to assess the effect of compaction in any meaningful fashion. What is evident is that in most fields, the degree of compaction in both treatment and control is generally quite high (> 300 psi) at 12 inches of depth.

Potato Yield and Quality:

Table 8: Comparing potato yield and quality variables for soil-building crop treatments compared with control treatments for fields from 2020 through 2022.

	# Samples	Total Yield cwt/ac	% Defects	% Smalls	% > 10 oz	Spec. Gravity	Market. Yield cwt/ac	Crop Value $/acre
Soil Builder	118	334.6	3.1	9.0	14.9	1.084	300.4	4072
Control	81	320.6	2.9	9.0	15.7	1.083	287.9	3865
Difference		14.0	0.2	0.0	-0.8	0.001	12.5	207
p value		0.262	0.716	0.938	0.704	0.297	0.318	0.294

In comparing all soil building treatment crops with all control treatments, there were no statistically significant differences observed for yield and quality variables. While there is a slight trend toward higher yield for the soil builder treatments, the degree of variability as well as the diversity in the treatments themselves makes it very difficult to recognize any true trends here. We then broke out soil building treatments compared to either a ryegrass control or a legume/grass control:

Table 9: Comparing potato yield and quality variables for soil-building crop treatments compared with annual ryegrass control treatments for fields from 2020 through 2022.

	# Samples	Total Yield cwt/ac	% Defects	% Smalls	% > 10 oz	Spec. Gravity	Market. Yield cwt/ac	Crop Value $/acre
Soil Builder	77	356.8	1.7	8.3	16.1	1.084	324.0	4393
Ryegrass	52	331.5	2.3	9.2	14.7	1.083	298.6	3986
Difference		**25.3**	-0.6	-0.9	1.4	0.001	**25.4**	**407**
p value		**0.086**	0.232	0.309	0.499	0.232	**0.070**	**0.082**

In comparing only those fields where a soil building crop was grown next to an annual ryegrass control, we do see significant differences (at $p < 0.1$) for total yield, marketable yield, and crop value in favour of the soil building crops. While there is diversity in these soil building crops, all were selected on their potential to either increase soil health or reduce soil-borne pests and disease. In almost all cases, there was the same tillage frequency between treatment and control crops, so that should not be a confounding variable in the comparison.

Table 10: Comparing potato yield and quality variables for soil-building crop treatments compared with legume/grass forage control treatments for fields from 2020 through 2022.

	# Samples	Total Yield cwt/ac	% Defects	% Smalls	% > 10 oz	Spec. Gravity	Market. Yield cwt/ac	Crop Value $/acre
Soil Builder	23	352.8	6.6	5.7	20.8	1.085	316.3	4213
Ryegrass	20	341.4	5.5	5.4	14.5	1.083	310.5	4191
Difference		11.4	1.1	0.3	-3.7	0.002	5.8	22
p value		0.485	0.662	0.827	0.462	0.661	0.776	0.959

The same trend is not replicated when comparing those soil builder crops grown in direct comparison with legume/grass forage mixes as the control. There was a negligible difference in yield or quality observed in these trials. It should also be noted that for both of these comparisons, there is again a difference in tillage frequency between the soil building crops (annual crops seeding following tillage) and the legume/grass forage control treatments, which were largely under-seeded and left undisturbed for a year. This difference in tillage frequency may mask any advantage of the soil building crops.

In digging into some of the comparisons of individual crops, all of the differences observed between treatment crops and control were not statistically significant at p = 0.1; however, there are two categories where trends were observed that are worthy of additional discussion.

Table 11: Comparing potato yield and quality variables for forage pearl millet treatments compared with control treatments for fields in 2022.

	# Samples	**Total Yield cwt/ac**	**% Defects**	**% Smalls**	**% > 10 oz**	**Spec. Gravity**	**Market. Yield cwt/ac**	**Crop Value $/acre**
Pearl Millet	8	424.3	1.5	4.3	18.3	1.088	403.5	6085
Control	8	395.4	2.5	5.0	22.5	1.086	373.4	5650
Difference		28.9	-1.0	-0.7	-4.2	0.002	30.1	435
p value		0.177	0.234	0.471	0.402	0.557	0.155	0.218

Two trial fields were established in 2021 comparing forage pearl millet with a forage mix control, with potatoes subsequently harvested in 2022. In both of these fields, there was a trend toward higher marketable yield following pearl millet, despite the pearl millet treatments have additional tillage performed in comparison to the control treatments. This trend would be worthy of follow-up investigation with increased sampling density and/or increased number of fields in future years. These results are also consistent with results from Dr. Judith Nyiraneza's plot-scale work completed under Living Labs, where pearl millet was associated with some of the highest yields when comparing a number of soil-building crops prior to potatoes.

Table 12: Comparing potato yield and quality variables for 2 or 3 species crop mixture treatments compared with control treatments for fields in 2020 - 2022.

	# Samples	**Total Yield cwt/ac**	**% Defects**	**% Smalls**	**% > 10 oz**	**Spec. Gravity**	**Market. Yield cwt/ac**	**Crop Value $/acre**
Mixes	16	388.0	1.1	7.9	13.6	1.087	355.6	5090
Control	12	353.2	1.0	9.0	14.6	1.085	322.0	4583
Difference		34.8	0.1	-1.1	-1.0	0.002	33.6	507
p value		0.182	0.770	0.521	0.777	0.619	0.213	0.255

For three fields where 2 or 3 species crop mixes were compared with a ryegrass or mixed forage control, there is a trend toward higher total yields and marketable yields for those mixtures. Most of these mixtures were comprised of one or more C4 grasses (sudangrass or pearl millet) and a brassica crop like mustard or radish. While the number of fields and observations, as well as the differences from field to field in crop mixtures, does not allow us to draw any firm conclusions, it does highlight an area of potential future study. A study performed by Dr. Aaron Mills at AAFC Charlottetown from 2018 to 2021 also indicated that limited cover crop mixtures may out-perform more diverse cover crop mixtures with relation to resultant potato yield the following year. The key for producers will be identifying crop species that are positively associated with potato production (disease suppression or soil health improvement) and assessing them individually as well as in combination.

Discussion and Next Steps:

The nature of potato rotations is continuously changing in Prince Edward Island. New cash crops and cover crops are being experimented with each year. Trying to identify rotation sequences that promote improved marketable yield of potatoes while also improving soil health is a constant goal of most producers.

From our research in this project, there are very few if any hard conclusions to be made, but a few trends became evident when analyzing the data:

1. It appears that it is less important what soil-building cover crop is grown ahead of potatoes than how often that soil is disturbed/tilled. For some fields, the detrimental effects of red clover (increased pest/pathogen pressure) may be counter-acted by its ability to fix nitrogen as well as the reduced frequency of tillage when it is grown in three year rotation. For future study, it will be important to assess a total rotation effect of alternative rotations, factoring in the level of cover cropping and tillage that is being performed.

2. There may be an advantage to some alternative soil-building cover crops over annual ryegrass. This is one of the few comparisons where we saw statistically significant differences in yield response; however, we did not see any real differences with regards to soil health or disease suppression. In some other Board-supported research, root lesion nematode counts have also tended to be high following ryegrass compared to other crops. Ryegrass also forms a dense sod that can require additional nitrogen to break down following termination. These may be two factors which account for some of observed difference in this trial.

3. Biofumigant mustards did not provide any significant level of increased yield or improved soil health compared to control treatments.

4. Ultra-diverse (8 to 13 species) cover crop mixes did not show any significant level of increased yield or improved soil health compared to control treatments.

5. Further study is recommended for the use of forage pearl millet and two or three species mixture of complementary species ahead of potato production.

6. Future studies should include a higher sampling density per field to increase the statistical power of analysis.

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