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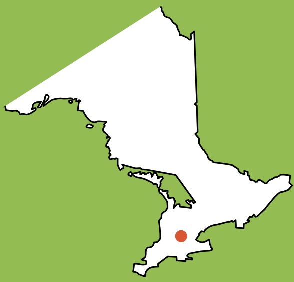

Measuring plant available nitrogen from cover crops

FARMER-RESEARCHERS
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FUNDING
Agriculture and Agri-Food Canada as part of the Living Lab—Ontario project

IN A NUTSHELL

Jesse and Meghan wanted to understand the contribution of spring legume cover crops towards the nitrogen requirements of the following cash crop. They established a randomized block design with low- and high-legume cover crop treatments. They sampled cover crop biomass and used lab analyses paired with a free online calculator from Oregon State University to estimate plant available nitrogen (PAN) from the cover crops (1), and also tested an in-field method to estimate PAN. Finally, they took soil nitrate samples throughout the growing season to better understand the best tools to manage fertility. Overall, Jesse and Meghan found:

- Legume cover crop mixes can supply a lot of PAN, potentially in excess of the needs of some vegetable crops
- Cover crops act as an effective catch crop by reducing soil nitrate early in the season
- Legume content in a cover crop mix moderates in-season PAN as indicated by soil nitrate
- Cover crop biomass sampling coupled with lab analysis and the online calculator provided a simple, cost effective tool for quantifying PAN contribution of cover crops
- Both pre-plant and mid-season soil nitrate-nitrogen sampling were effective tools for predicting PAN availability when Jesse and Meghan compared their results to the literature

MOTIVATION

Milky Way Farm is an ecologically focused four season mixed vegetable farm owned and operated by Meghan Brandenburg and Jesse Way.

Growing on 1.5 acres just south of Woodstock, they follow organic production practices but are not certified, and sell their vegetables through a ~100 member CSA and a year-round online retail store. They utilize a variety of ecologically focused growing practices including cover cropping and diverse crop rotations, low and no-till soil preparation, and the incorporation of perennial fruit trees, berry bushes, and flowers throughout the farm.

This trial stems from on-farm comparisons of high and low nitrogen (N) fertilizer rates in beds that were previously cover cropped and observing no noticeable difference in yield between the two fertilizer rates. They were interested in exploring readily accessible and cost effective tools available for better quantifying cover crop contributions to plant available nitrogen (PAN).

OBJECTIVE

To quantify how cover crops with different legume contents contribute to PAN, therefore enabling use of cover crop PAN for fertility planning.

a) Jesse, **b)** Meghan and Rowan, their youngest son, in the field at Milky Way Farm.

RESEARCH QUESTIONS

1. How do PAN and soil nitrate change over time, and are they sufficient throughout the season to meet crop demand?
2. Are available tools described in the literature (1-3) for quantifying PAN and informing nitrogen fertilizer management applicable to our farm?
3. Are field-based estimates reliable as an indicator of PAN?

METHODS

TRIAL SET-UP

Jesse compared different cover crop mixes and their potential effect on PAN in four replicate blocks (**Figure 1**) with treatments as shown in **Table 1**.

To all plots, Jesse added phosphorus, potassium, sulphur, and boron according to soil test results as shown in **Table 2**.

Jesse terminated the cover crops using a BCS rototiller with a flail mower attachment on June 22nd. He then waited until it rained and covered the area with a silage tarp on June 27th to help facilitate the breakdown of cover crop residue and prevent any weed growth.

On July 7th, Jesse removed the tarp and tilled each bed to ~2" depth using the BCS with a rototiller and Precision-Depth Roller (PDR) attachment, and re-tarped to help further break down cover crop residue and create a stale seedbed before seeding the carrots on July 18th and 24th.

The trial field at Milky Way Farm.

Block 1 - Earlier planting - Bolero - 2021 seed			Block 2 - Earlier planting - Rainbow - 2021 seed			Block 3 - Later planting - Bolero - 2020 seed			Block 4 - Later planting - Bolero - 2020 seed		
H	L	C	C	H	L	C	L	H	L	C	H

Figure 1. The beds were divided into 4 blocks, and each of the three treatments was randomly assigned to a bed within each block in a randomized block design. Each plot was equivalent to a 30" raised bed, 4' on centres, and 50' long. Bolero and Rainbow refer to the variety of storage carrot planted in each block. H = high-legume cover crop; L = low-legume cover crop; C = control with no cover crop.

Table 1. Cover crop mixes and seeding rate for the treatments at Milky Way Farm.

TREATMENT	COVER CROP SPECIES	SEEDING RATE** (G/BED)	SEEDING RATE** (LB/AC)	SEED COST*** ($/BED)
CONTROL	N/A	No cover crop		$0
LOW LEGUME MIX* 25% LEGUME/ 75% CEREAL	Peas	40	31	0.66
	Vetch	10	8	
	Oats	140	107	
	Phacelia	10	7	
	Total	200	~153	
HIGH LEGUME MIX* 75% LEGUME/ 25% CEREAL	Peas	120	~92	0.80
	Vetch	30	23	
	Oats	40	31	
	Phacelia	10	7	
	Total	200	~153	

** Seeding rates are adapted from Johnny's Selected Seeds Recommendations (4).*
*** Seeding rates were calculated using a 125 ft^2 raised bed area (50' * 2.5'); 2.5' being the width of our BCS rototiller that was used for shallowly incorporating the broadcasted seeds. Note: To convert lbs/acre rates from grams/bed, Jesse divided grams by 454 (grams in a pound) and multiplied by 348.48 (the fraction of an acre of a 125 ft^2 raised bed). For example: 40 grams /bed oats = (40/454)*348 = 30.7 lbs/acre.*
****For Jesse and Meghan's mixes, seed costs include Certified Organic peas and oats purchased in spring 2022. They purchased hairy vetch and phacelia seed in 2020, which was not certified organic. As such, they calculated costs for hairy vetch and phacelia using conventional seed prices quoted in December 2022 to get a more up-to-date price.*

Table 2. Nutrient rates for the trial beds at Milky Way Farm. They calculated lb/acre from a bed size of 200ft^2, or the area of one 50′ bed plus path.

NUTRIENT	RATE	SOURCE
Phosphorus*	1760 g/bed = 3.88lbs/bed	Biofert Hi-P 0-8-0 (=68 lbs/acre P_2O_5)
Potassium	220 g/bed = 0.48 lbs/bed	Allganic Potassium Sulphate of Potash 0-0-52 (18% S) (= 55lbs/acre K_2O, 19 lbs/ac S)
Sulphur	40 g/bed = 0.088 lbs/bed	Elemental Sulphur 90% (=17 lbs/acre S)
Boron	40 g/bed = 0.088 lbs/bed	Edidot Boron 20.5% (Etidot-67) (=2.5 lbs/acre B)

** Jesse and Meghan typically apply phosphorus to their system by using compost that also contains nitrogen. For this trial, they used Biofert Hi-P as an organic source of P that did not contain any N even though this is not typically how they apply phosphorus.*

Jesse created 12 plot areas that were each one 50′ bed (30″ raised bed, 4′ on center = 200 ft^2). The beds varied slightly in terms of planting date with blocks 1 and 2 planted on July 18th, and blocks 3 and 4 planted on July 24th. They planted blocks 1, 3 and 4 with Bolero storage carrots and block 2 with Rainbow storage carrots. Accidently, they planted blocks 3 and 4 with older seeds (2020 vs 2021 in blocks 1 and 2) and consequently observed (but did not quantify) slightly lower — but still acceptable — germination than in blocks 1 and 2.

Management history was uniform from a fertilizer, crop family and cover cropping perspective but has had some discrepancies in planting and harvesting dates, as well as crop varieties. For example, in 2020 they planted this field block to potatoes with some beds containing shorter maturity early harvested varieties and others containing longer days to maturity storage varieties. In 2021 they planted beds with different varieties of brassicas including cabbages, cauliflower, broccoli, and rutabaga — so, although fertilized the same, nutrient uptake may have varied somewhat across beds due to different varieties and harvest dates.

While carrots aren't a high nitrogen-demanding crop, Jesse and Meghan chose carrots because they fit well with a replicated design and would not require them to make major changes to their current rotation. Carrots seemed less risky as a crop with relatively low N demands, meaning they had confidence that they could still get a reasonable harvest without any in-season nitrogen fertilizer application.

SIDE-BY-SIDE COMPARISON OF SEEDING RATE

In neighbouring plots, Jesse and Meghan also planted unreplicated side-by-side demonstration beds to compare seeding rates of 100 (low) and 200 (high) lbs/ac for a total of four beds, with two seeding rates per cover crop mix. The low and high seeding rates are relative to the ~150 lbs/acre they planted in the main trial.

FIELD MEASUREMENTS

BASELINE SOIL MEASUREMENTS

In early April, Jesse took one composite soil sample test across the entire study area and sent it to A&L Laboratories for analysis of macro- and micronutrients and SOM using their S1B+S7 package; and baseline soil nitrate (NO_3-N) with fertility recommendations. Jesse used this data to amend the trial plots fertility as defined above.

COVER CROP BIOMASS FOR PAN ESTIMATES

To sample cover crop biomass Jesse followed the sampling procedures described in Sullivan et al. (2020). This involved taking one quadrat sample from each replicate bed, by making a 30″ x 30″ square quadrat from greenhouse wiggle wire track, using ground staples to connect each corner of the quadrat and secure it to the ground. The cover crop that fell within the 30″ x 30″ quadrat was cut using a lettuce harvesting knife, leaving about 1″ of stem above the ground to avoid low growing weeds that can potentially have soil adhering to them. Contaminating the samples with soil can inflate DM and reduce N percentage (3).

Jesse collected the harvested cover crop biomass in harvest bins, labeled them in the field and then brought them inside the pack shed for weighing and subsampling.

They weighed each sample using a floor scale with greater than 20 lb capacity and 0.1 lb accuracy. Due to the length of the cover crop biomass, they spread out each sample on a table to be cut into 4 - 6″ pieces, mixed thoroughly and subsampled to obtain a 1 lb sub-sample that they placed in a resealable plastic bag and labeled for lab analysis.

Samples were then brought to A&L Laboratories for analysis of per cent nitrogen (% N) and moisture content, which was subtracted from 1 to obtain per cent dry matter (% DM).

Quadrat sampling for cover crop biomass at Milky Way Farm **a)** before sampling and **b)** after sampling.

Soil sampling for soil nitrate analysis at Milky Way Farm.

Harvesting carrots and using many crates to keep carrots separated by plot during harvest, washing, and weighing at Milky Way Farm.

SOIL SAMPLES FOR SOIL NITRATE

On June 22, one day after taking the cover crop biomass samples and then flail mowing the cover crop, Jesse took soil nitrate samples from all plots. Using a soil sampling probe, he took eight 12" deep cores from each replicate bed and placed the cores into 5 gallon plastic pails or harvest bins. For each plot, he mixed the cores by hand to form a composite sample and took a subsample, which he placed into a resealable plastic bag and brought to A&L Laboratories for lab analysis of soil nitrate-nitrogen (NO_3-N) on the same day of sampling.

Throughout this report, we refer to soil nitrate samples taken on June 22nd as 'week 0' in reference to having been taken the week of the cover crop termination, i.e. 0 weeks after termination. Jesse took additional soil samples on July 21st 'week 4', Sept. 1st 'week 10', and Oct.19th 'post-harvest'.

Jesse and Meghan designed the timing of soil sampling to be compatible with the Oregon State University (OSU) cover crop calculator predictions of PAN at four weeks and ten weeks after cover crop termination.

NITRATE STRIPS

Modifying the method described by Sullivan et al. 2019, Jesse and Meghan used in-field soil nitrate strips (WaterWorks Nitrate/Nitrite Nitrogen Test Strips) at week 4 and week 10 to compare to the lab analysis of soil nitrate to see if a less time consuming method could be reliably used in-field.

The recommended method of using field nitrate strips includes using a chemical extractant but for their field testing Jesse modified the method to use the nitrate strips on water-extracted soil. The rationale was that water-extraction is more practical than chemical extraction because water extraction does not require specific chemicals or equipment (i.e. precise scales and mixing equipment).

To take the in-field sample, Jesse used the remaining soil from the composite samples taken for lab analysis. He added soil to the first line of a red dixie cup (~110g soil) and added water to the second line of the cup (~270g water). He then mixed the soil and water thoroughly for 30 seconds and left it to settle for five minutes. After five minutes, he dipped the nitrate strip into the water, let it rest for 60 seconds, and compared the colour on the strip to the indicator chart from the manufacturer.

CARROT YIELD

On October 19th and 20th, Jesse and Meghan harvested and washed all carrots from blocks 1 and 2, one replicate bed at a time. After washing, they spread out the carrots in harvest crates and allowed them to air dry for at least one hour before weighing them for yield. On October 26th and 27th, they repeated this process for blocks 3 and 4.

PAN CALCULATIONS

FROM LAB ANALYSIS

To estimate the PAN for their carrot crop, Jesse and Meghan used the fresh weight of cover crop biomass that they measured on-farm after sampling; % DM of the biomass from lab results; and % N content of the cover crop from lab results. They input these values into OSU's cover crop calculator, a free downloadable excel spreadsheet available at: https://smallfarms.oregonstate.edu/calculator (1).

They calculated total N of the cover crop lbs/acre by multiplying the DM (lbs/acre) by the % N content from the lab analysis; and DM in lbs/acre by multiplying the DM (tonne/acre) — as provided by the online cover crop calculator — by 2000.

SHORTCUT METHOD

Jesse and Meghan also estimated PAN from a "shortcut method" that doesn't require lab analysis and uses fresh weight of cover crop biomass along with estimates of % DM and % N. For this trial, they used estimates of 18% DM and 4.6% N for the high legume cover crop and 19% DM and 3.8% N for the low legume cover crop.

Note that the shortcut method for this year used % DM and % N averages from their lab analyses. The literature recommends running lab tests for % DM and % N for a couple of years to compile site specific data to use for the shortcut method. In this way, Jesse and Meghan will use this year's data, along with future year's data, to compile estimates for their farm.

DATA ANALYSIS

To evaluate the effect of cover crop mix on the lab analysis and shortcut estimates of PAN from cover crops, we used a paired t-test to calculate a p-value based on the difference we observed between the two cover crop treatments.

To evaluate the effect of the cover crop treatments on soil nitrate and carrot yield compared to the controls without cover crops, we used an analysis of variance (ANOVA) to calculate a p-value based on the difference we observed among treatments.

For both t-tests and ANOVAs 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 with the ANOVA, we conducted another ("post-hoc") test to determine where the differences occurred between treatments. We could make these statistical calculations because Jesse's experimental design involved replication of the treatments.

FINDINGS

PLANT AVAILABLE NITROGEN AND SOIL NITRATE

Both high- and low-legume mixes accumulated a similarly high amount of biomass (P=0.14; **Figure 2**). Although similar, Jesse observed greater variability in-field weights within the low-legume cover crop, with a range 4.84 lbs - 8.36 lb, compared to tighter biomass yields in high-legume treatment with a range of 5.72 - 7.04 lb.

Cover crops acted as an effective "catch crop" by reducing soil nitrate early in the season. At the time of cover crop termination (week 0) average soil nitrate without cover crops was 19 ppm (**Figure 3**). This amount was much higher than soil nitrate values in the cover crop plots, which ranged from 2-4 ppm (P<0.001).

Uptake of soil nitrate was reflected in total N of the biomass of both high- and low-legume cover crops. Total N was high, as calculated from total biomass (lb/acre) and % N from the lab, averaged 339 lb/ac among all plots (**Figure 4**). While absolute values of total N in the cover crop were statistically similar, per cent N content was higher in the high-legume cover crop (P=0.08; **Figure 5**).

Much of the nitrogen in the cover crops became available throughout the growing season. The high-legume cover crop had relatively more PAN (P<0.08) at weeks four and ten, and trended towards higher absolute values (**Figure 6**). Compared to requirements for vegetable crops (2,5) , both the high- and low-legume cover crops provided adequate PAN for Jesse's carrot cash crop, without the need for any additional N fertilizer.

Soil nitrate increased in all plots and was moderated by legume content of the cover crops. Soil nitrate remained highest in the control plots without cover crops; lowest in response to low-legume cover crops (average soil nitrate of 19 ppm); and intermediate in response to high-legume cover crops (average soil nitrate of 28 ppm) (P<0.001; **Figure 3**).

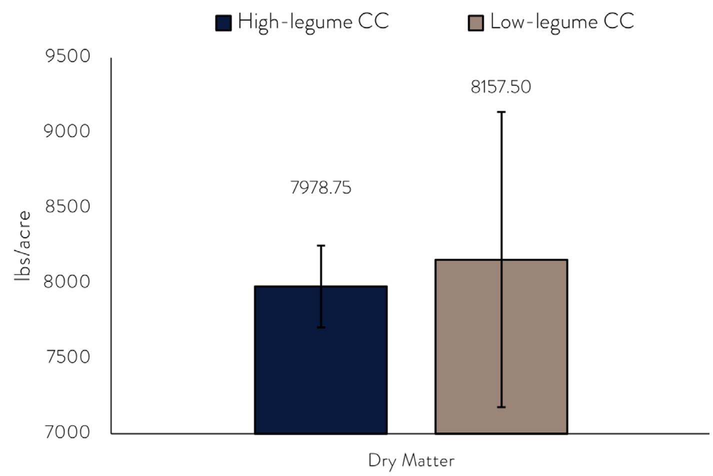

Figure 2. Dry matter of cover crop biomass in lbs/acre from the trial at Milky Way Farm.

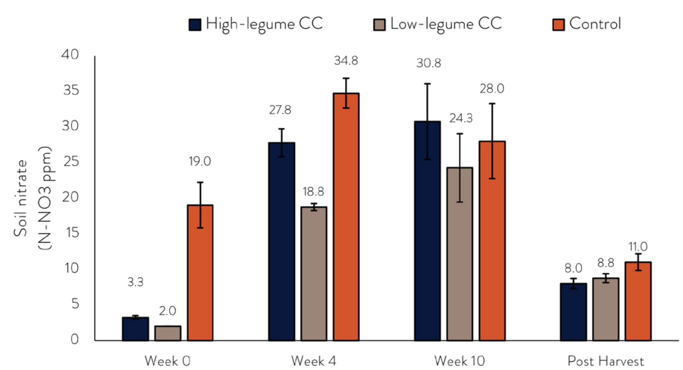

Figure 3. Soil nitrate from the two cover crop treatments and control plots throughout the season.

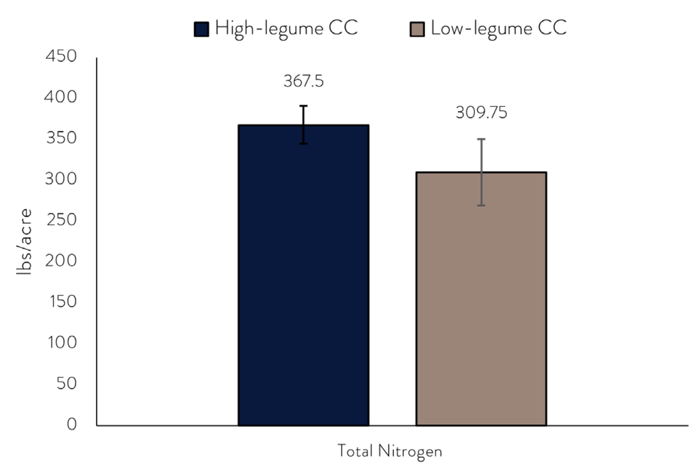

Figure 4. Total N from high- and low-legume cover crops (CC) at termination.

Soil nitrate availability responded to crop uptake, which was affected by timing between cover crop termination and cash crop planting. Because Jesse planted blocks 1 & 2 one week earlier than blocks 3 & 4, we also analyzed the data to see if there was a difference in soil nitrate depending on when the crops started to take up nitrogen. From this analysis, Jesse observed significantly lower soil nitrate (average 19 ppm) in the plots where he planted carrots earlier; and significantly higher soil nitrate (average 35 ppm) in the plots where he planted carrots one week later ($P<0.001$; **Figure 7**).

Relatively high in-season soil nitrate values in all plots indicate a good base level of soil N mineralization in these beds at Milky Way Farm. According to the literature, soil nitrate values above 25 ppm at pre-plant sampling are sufficient for good crop growth and result in "little chance of crop response to additional PAN" (2). Using 25 ppm as an in-season threshold the soil had sufficient nitrate for crop growth without additional PAN from the cover crops (**Figure 3**).

The relatively high soil nitrate (**Figure 3**) in the control plots surprised Jesse, as he did not expect soil nitrate levels to be so high with no in-season nitrogen additions of any kind, and expected to see N deficiencies in the control treatment. The presence of a good amount of soil nitrate may be due to management history that included cover crops, compost, and minimal tillage for the four years previous, preceded by decades of no-till perennial pasture.

Cover crops in the trial growing at Milky Way Farm.

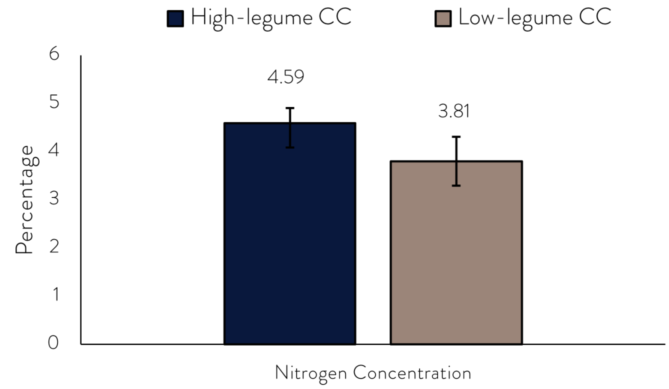

Figure 5. Per cent N from high- and low-legume cover crops (CC) at termination.

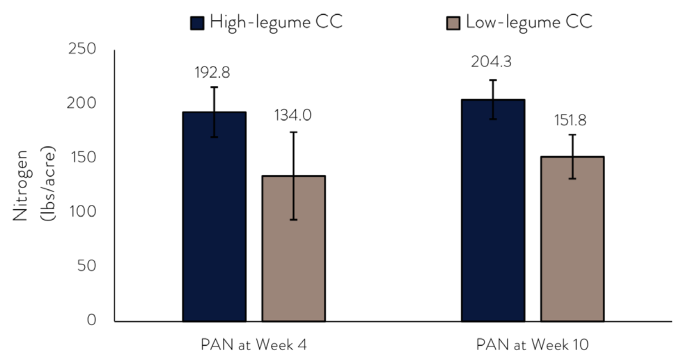

Figure 6. PAN from high- and low-legume cover crops (CC) at four and ten weeks after cover crop termination, as predicted by the OSU online calculator (1).

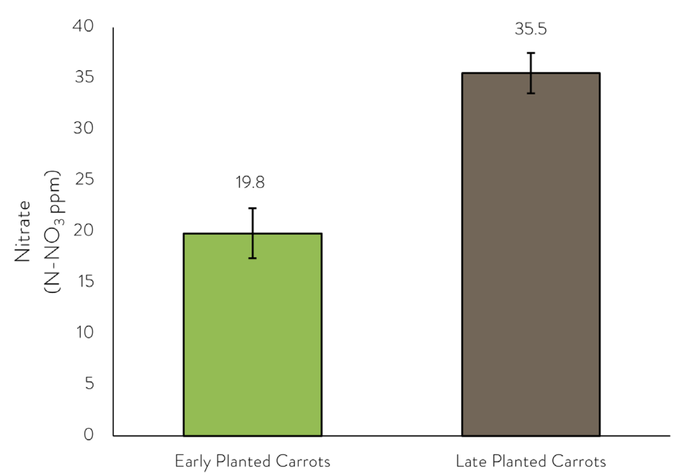

Figure 7. Soil nitrate at week 4 in early planted blocks compared to later planted blocks.

CARROT YIELD

High mineralization in all plots was consistent with the fact Jesse and Meghan detected no yield difference between the control and cover crop treatments (**Figure 8**). In fact, average carrot yield from the low- and high-legume cover crops was within their ideal range at ~ 180 lb/bed. Post-harvest, soil nitrate values dropped in all plots (**Figure 3**), potentially due in part to a decrease in soil temperature — a major driver of nitrate mineralization (2,3,5).

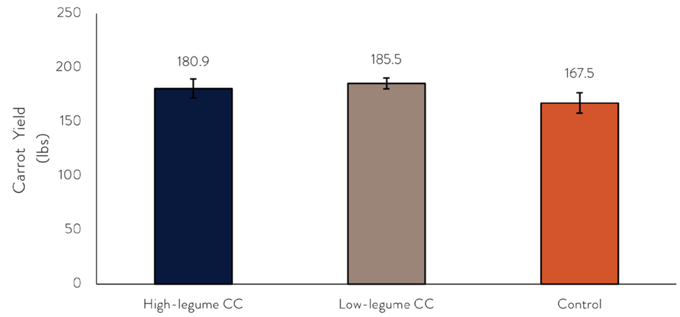

Figure 8. Carrot yield in response to the cover crop treatments. Note: 175-200 lbs per bed is the farm's target yield. Yields greater than 200 lbs per bed are associated with lower quality because individual carrots are larger than ideal for their market.

NOTES ON SEEDING RATE

Observations from his unreplicated side-by-side trial comparing seeding rate of his high-legume and low-legume cover crop mix indicate that a seeding rate over 100 lbs/acre does not affect weight of cover crop biomass.

Total biomass collected and % N from the biomass were within range of the averages he observed in his replicated trial, as shown in **Figure 9**. This indicates that Jesse can get good residue and N benefit with a reduced seeding rate.

IN-FIELD NITRATE TESTS

For both the week 4 and week 10 samples, field strip readings were consistently lower than the lab analysis of nitrate-nitrogen levels. This was not unexpected, given Jesse and Meghan did not use an extractant. Compared to the lab analysis, the in-field "shortcut method" soil nitrate values at week 4 soil nitrate ranged from 45%-68% of their respective lab analysis values; and at week 10 soil nitrate values ranged from 10% - 37% of their respective lab analysis values. Due to the low sensitivity of the field nitrate strips using water extraction, Jesse and Meghan did not use the post harvest soil sampling.

Storage carrots grown in the trial looked beautiful!

NEXT STEPS

In 2023, Jesse and Meghan plan to continue to do lab testing on % DM and % N to estimate PAN on their farm. Specifically, they are interested to test other cover crop mixes they grow, like overwintered cover crop of rye (with lower total N in biomass) and vetch and summer blends of sorghum sudangrass/sunn hemp/cowpeas/sunflower.

Seasonal variations in precipitation, soil moisture, and temperature may impact these values: their dataset will be strengthened with additional seasons of lab analysis. After a couple years of lab analysis, site specific values can be used with the shortcut method, reducing a long term dependence on lab testing.

Other questions they have to continue this work include comparing variables such as planting date timing (i.e. for over winter rye/vetch) or termination method (i.e. flail mow and incorporate vs flail and mulch vs roller crimp) to better understand how these variables affect total PAN contribution and timing of nitrogen availability. Finally, they are interested in better understanding when soil nitrate peaks — to know if/when Jesse and Meghan have adequate PAN with cover crops alone, and whether there are times in the season when there is a greater risk for nitrate leaching.

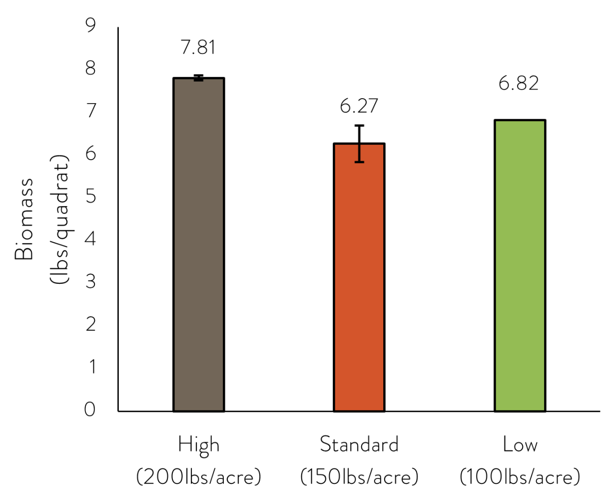

Figure 9. Cover crop biomass as a result of different seeding rates in the unreplicated side-by-side comparison.

TAKE HOME MESSAGE

HOW DO PLANT AVAILABLE NITROGEN AND SOIL NITRATE CHANGE OVER TIME, AND ARE THEY SUFFICIENT THROUGHOUT THE SEASON TO MEET CROP DEMAND?

By increasing legume content in a diverse cover crop, Jesse and Meghan increased plant-available N from cover crops, which in turn increased soil nitrate mid-season.

PAN from the legume cover crops, and from soil mineralization alone, was sufficient to meet the carrot crop's N needs, as seen in good carrot yield across the treatments and control. While they didn't explicitly test this, their results indicate that additional N, beyond contribution from both low- and high-legume cover crops, would not result in significantly greater yield for carrots.

Overall, these data showcase the nuances of managing N with cover crops in organic systems. With data from this trial, Jesse and Meghan can confidently refine their cover crop strategy by lowering the legume content (and seeding rate) of their cover crops — and therefore lower seed cost in two ways — while knowing they have lots of N mineralization even without cover crops. Because nitrate is mobile, these data also reiterate to them the importance of timing between when they terminate their cover crop and plant their cash crop.

ARE AVAILABLE TOOLS DESCRIBED IN THE LITERATURE (1-3) FOR QUANTIFYING PAN AND INFORMING NITROGEN FERTILIZER MANAGEMENT APPLICABLE TO OUR FARM?

Both the Oregon State University cover crop calculator (1) for predicting PAN and in-season soil nitrate testing were useful tools for understanding the quantity and timing of cover crop and soil contributions to the cash crop and, therefore, informing N fertility management at Milky Way Farm.

- The time series of soil nitrate demonstrates the applicability of both the pre-plant and mid-season soil nitrate tests for informing cash crop nitrogen requirements, when the results were compared to the research from the Oregon team

ARE FIELD-BASED ESTIMATES RELIABLE AS AN INDICATOR OF PAN?

- The in-field "shortcut method" was consistent with estimates using lab analysis. Moving forward, Jesse and Meghan will continue to collect lab data (% DM and % N) to continue to refine the "shortcut method" with hope to use it exclusively in the future.
- Water extraction is not sufficient for measuring in-field measurements of soil nitrate using strips.

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