Soil testing an indicator for soil health improvement

PW17001 Final report Appendix 16 Integrated pest management of nematodes in sweetpotato

Mary Firrell August 2023

DAF project team:
Sweetpotato Research - Sandra Dennien, Mary Firrell, Rachael Langenbaker, Jean Bobby and Brett Day.
Nematology - Jennifer Cobon, Wayne O'Neill and Tim Shuey.

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The Department of Agriculture and Fisheries proudly acknowledges all First Nations peoples (Aboriginal peoples and Torres Strait Islanders) and the Traditional Owners and Custodians of the country on which we live and work. We acknowledge their continuing connection to land, waters and culture and commit to ongoing reconciliation. We pay our respect to their Elders past, present and emerging.

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Summary

Introduction

In late 2019 meetings were held with the Department of Environment and Science (DES), Chemistry Centre staff to determine the most useful analyses that may correlate soil health with nematode populations in the Intensive and Extensive trials at Bundaberg Research Facility

Methodology

Analyses undertaken were, pH, Electrical conductivity (EC), Chloride (Cl), Nitrate- Nitrogen (NO_3- N), Total Organic Carbon (TOC), Potassium Permanganate Oxidisable Carbon (POxC), (PPOC), Total nitrogen (TN), Colwell Phosphorous (P) + phosphorus buffer index (PBI_COL) and Particle size analysis. Soil samples were taken just prior to each harvest throughout the life of the trial.

Results and Discussion

Results for the intensive and extensive trial are treated separately below and a comprehensive report at each sampling attached in appendix 16.

Intensive trial

Nimitz, nil and compost treatments showed no significant change in **TOC%** over time. V furrow decreased significantly after the first sampling event, but then remained stable. The Vfurrow results are difficult to interpret due in part to the nature of the amendment application, where a non-homogenous sawdust and chicken manure mixture is applied into a furrow at the top of the bed. In these circumstances, consistent sampling over a 4 -year time period is difficult to achieve. TOC in the Organic Matter showed no significant change over the first three sampling times, but the mean in May 2023 was significantly lower than in July 2021 and June 2022.

For PPOC, V furrow was the only treatment to show a significant change (decrease) from June 2020 to July 2021. All treatments then had a significant decrease from July 2021 to June 2022. From June 2022 to May 2023, only compost and V furrow showed a significant increase with all other treatments having no significant change. As expected, the Nil and Nimitz treatments had significantly less PPOC than the amended treatments.

The mean **pH** was significantly lower in the organic matter treatment than all other treatments. The addition of sawdust and chicken manure seems to have improved soil pH and brought it closer to the ideal level of below 7.

Electrical Conductivity is significantly higher in the organic matter treatment and as this consists of chicken manure and sawdust, a higher EC reading can be expected.

The overall mean **Colwell P** was significantly higher for organic matter compared to all other treatments. The overall mean **PBI** was significantly higher for the nil and Nimitz treatments, and significantly lower for organic matter and V furrow. The higher numbers in the nil and Nimitz treatments are an indication of the higher P binding capacity of these zero-amendment treatments. Organic Matter and Vfurrow amendment had significantly lower PBI thus allowing P to be more available for plant uptake.

The relationship between soil parameters and nematode populations was an interesting finding in the Intensive trial. After the first harvest in 2020, a trend was emerging between low numbers of Meloidogyne spp (RKN) and higher numbers of Total Free Living (TFL) nematodes with higher Organic Carbon. By the second and third harvests in July 2021 and June 2022, the trend was becoming more apparent, with the Organic Matter treatment supporting lower populations of RKN and increased TFL, the beneficial nematodes that are widely believed to predate upon plant parasitic nematodes. Unfortunately, by 2023, the population of Meloidogyne had all but disappeared from the trial block (control plots included) and has made it difficult to be confident in drawing any conclusions for that sampling period. It is not possible to say that TOC is the sole contributor to the change in populations as there are many other components in the soil amendments that may contribute to this relationship. When initially statistically analysed using a correlation analysis, negative correlations were found in each year that data was collected between root knot nematode and EC, NO3N, TOC%, and PPOC%.

This suggests that the count of root knot nematode decreases as these soil components increase. However, when a causal relationship was assumed in the statistical model, the percentage of variance explained is low, suggesting that the models would not be able to predict the nematode counts well.

Extensive Trial

TOC and PPOC were measured at 3 harvests whereas all other soil components were only measured twice (2/06/2020, 15/03/2022) to accommodate budget limitations.

There was no significant change in TOC% over time for grass/brassica and grass/legume with incorporated amendment, nematicide and nil. The result for nil and nematicide is unsurprising as no amendments were added over the life of the trial and this gives us a good measure of consistent sampling in a homogenous standard soil. The two double amendment treatments showed a significant decrease at the second sampling event but by the third sampling had returned to the first sampling levels and had significantly higher means than all other treatments. Grass/brassica with V furrow had a significantly higher mean TOC% at the third sampling event, while grass/legume with V furrow decreased significantly after the first sampling event. This could in part be due to the nature of the amendment application, as described in the Intensive trial. There were no differences between the brassica and legume cover crops.

Overall, it has been difficult to consistently improve TOC levels above an initial gain. The nil and nematicide treatments represent the base level soil C with no amendments and only cover cropping between sweetpotato crops. The double amendments initially showed dramatic increase in June 2020 but by May 2023 had not improved significantly beyond the initial level of 2.5 – 2.6%. This level of 2.5% is good for a Bundaberg farming system, as losses of Carbon through tillage practices and crop removal often result in much lower levels of TOC, as evidenced in our grower survey results where 2.35% was the absolute highest achieved by a best practice grower and our survey of undisturbed vine scrub forest sites on a similar soil type gave a maximum of 7.2%.

Mean Colwell P increased significantly from June 2020 to March 2022. The addition of amendments such as Chicken manure can add significant amounts of P to the soil. The question is how much is too much. Researchers in the USA have worked on nutrient addition and often use 100 units of P but they have different practices to Australian growers, so it is difficult to extrapolate their findings to Australian requirements. More research needs to be conducted on nutrient requirements under Australian conditions.

Key Points

Intensive trial. Plots treated with organic amendments had a significantly higher mean TOC % over all the samplings than the nil and nematicide treatments, with organic matter and v furrow being significantly better than compost.

pH, P and PBI were significantly improved in the organic matter treatment.

There is a possible correlation between lower root knot nematode and increased EC, NO3N, TOC%, and PPOC%. Initial statistical analysis indicates this however this becomes increasingly uncertain as further modelling is done.

Introduction

In late 2019 meetings were held with the Department of Environment and Science (DES), Chemistry Centre staff to determine the most useful analyses that may correlate soil health with nematode populations.

Methodology

The suite of analyses most suited to our needs was determined as the following;

- 1:5 water extractions: pH, electrical conductivity (EC), chloride (Cl) and nitrate-nitrogen (NO3 -N)
- Total organic carbon (TOC)
- Permanganate oxidisable carbon (PxOC), (PPOC)
- Total nitrogen (TN)
- Colwell phosphorous (P) + phosphorus buffer index (S_PBI_COL)
- Particle size analysis (PSA) and air dried moisture content (ADMC)

Below are the official methods used by the Department of Environment and Science - Chemistry Centre

Table 1 Methods of Analysis used by the Department of Environment and Science.

Method	Analyte	Name	Unit	Method Description
S_ADM_105 v1	ADMC	Air dry moisture content (105ºC)	%	Soil: Moisture air dry
S_AQ4_AA v2	Cl	Chloride	mg/kg	Soil: Cl NO3-N Aqueous (1:5)
S_AQ4_AA v2	NO3-N	Nitrate nitrogen	mg/kg	Soil: Cl NO3-N Aqueous (1:5)
S_AQ4_EL v1	EC	Electrical conductivity	dS/m	Soil: pH EC Aqueous (1:5)
S_AQ4_EL v1	pH	pH	-	Soil: pH EC Aqueous (1:5)
S_COLWELL v2	P	Phosphorus (Colwell)	mg/kg	Soil: P extractable 0.5M NaHCO3 AA
S_DUM_CN v5	TC	Total carbon	%	Soil: C N total Dumas
S_DUM_CN v5	TN	Total nitrogen	%	Soil: C N total Dumas
S_DUM_TOC v3	OC	Organic carbon	%	Soil: Total Organic Carbon; Combustion
* S_PBI v5	PBI col	Phosphorus buffer index (Colwell)		Soil: Phosphorus Single Point Buffer Index
* S_PBI v5	PBI unadj	Phosphorus buffer index (unadjusted)		Soil: Phosphorus Single Point Buffer Index
S_PSA v1	Clay	Clay: hydrometer <2 µm	%	Soil: Particle size analysis
S_PSA v1	Coarse sand	Coarse sand: Sieve 0.2 – 2.0 mm	%	Soil: Particle size analysis
S_PSA v1	Fine sand	Fine sand: Sieve 0.02 – 0.2 mm	%	Soil: Particle size analysis
S_PSA v1	Silt	Silt: hydrometer 2 – 20 µm	%	Soil: Particle size analysis

Results and discussion

Bundaberg Long Term Trials

Soil samples were taken just prior to each harvest throughout the life of the trial for analysis by DES with a comprehensive report at each sampling attached in the appendix. Results were statistically analysed by the DAF Senior Biometrician using analysis of variance (ANOVA) and repeated measures ANOVA to investigate the treatment effect on the soil components over time. All significance testing was performed at the 0.05 level and the 95% protected least significant difference (lsd) was used to make pairwise comparisons. For each table throughout this report, means with a letter in common are not significantly different at the 0.05 level.

Intensive Trial

Soil samples were taken just prior to each harvest throughout the life of the trial for analysis by DES with a comprehensive report at each sampling attached in the appendix. After the final harvest, each analyte was statistically analysed for comparison over the 4 sampling events of June 2020, July 2021, January 2022, May 2023. It is worth noting the rainfall in the 5 months of the crop growth stage.

Table 2 Rainfall during the 5 month growing period preceding crop harvest

Rainfall in the 5 months preceding harvest		
Intensive Trial	period	rainfall (mms)
June harvest 2020	Jan - May 2020	525
July harvest 2021	Feb- June 2021	312
June harvest 2022	Jan - May 2022	851
May harvest 2023	Dec - April 2023	423

Total Organic Carbon (TOC)

The interaction of treatment and sampling time was significant for TOC% ($p < 0.001$). Nimitz, nil and compost treatments showed no significant change in TOC% over time. V furrow decreased significantly after the first sampling event, but then remained stable. The Vfurrow results are difficult to interpret due in part to the nature of the amendment application, where a non-homogenous sawdust and chicken manure mixture is applied into a furrow at the top of the bed. In these circumstances, consistent sampling over a 4 -year time period is difficult to achieve. TOC in the Organic Matter showed no significant change over the first three sampling times, but the mean in May 2023 was significantly lower than in July 2021 and June 2022. The figures below are back transformed means after the data was analysed using a $\log_{10}$ scale. The Organic matter and V furrow amendment showed the greatest increase in Carbon.

Table 3 Total Organic Carbon mean percentage by treatment over all harvest samplings

Treatment	TOC%
Compost	2.039 b
Nil	1.763c
Nimitz	1.751c
Organic matter	2.29a
V furrow	2.183a

The table below displays the back transformed means of the TOC results over the 4 year sampling period. Means with a letter in common are not significantly different at the 0.05 level so although Vfurrow was significantly higher than all other treatments in June 2020, it was also not significantly different from the Nil treatment in June 2022, supporting the idea of amendment application and sampling inconsistency.

Table 4 Total Organic Carbon mean percentage by year and treatment

	Treatment TOC%				
Sample Date	Compost	Nil	Nimitz	Organic matter	V furrow
June 2020	2.086 de	1.707 hi	1.731 hi	2.283 bc	2.784 a
July 2021	2.037 de	1.828 fgh	1.794 ghi	2.427 b	2.076 de
June 2022	2.049 de	1.815 ghi	1 .803 ghi	2.346 b	1.937 efg
May 2023	1.985 def	1.707 hi	1.677 i	2.115 cd	2.02 de

Potassium Permanganate Oxidisable Carbon (PPOC)

The interaction of treatment and sampling time was significant for PPOC% ($p = 0.001$). V furrow was the only treatment to show a significant change (decrease) from June 2020 to July 2021. All treatments then had a significant decrease from July 2021 to June 2022. From June 2022 to May 2023, only compost and V furrow showed a significant increase with all other treatments having no significant change. As expected, the Nil and Nimitz treatments had significantly less oxidisable carbon than the amended treatments.

Table 5 Potassium Permanganate Oxidisable Carbon by treatment over all harvest samplings. These means are back transformed after being analysed on a log10 scale.

Treatment	Mean PPOC (mg/g)
Compost	1.635 a
Nil	1.406 b
Nimitz	1.347 b
Organic matter	1.635 a
V furrow	1.878 a

Table 6 Potassium Permanganate Oxidisable Carbon mean percentage by year and treatment

	Treatment PPOC (mg/g)				
Sample Date	Compost	Nil	Nimitz	Organic matter	V furrow
June 2020	2.04 b	1.76 cd	1.36 defgh	2.58 ab	3.35 a
July 2021	2.02 bc	1.66 cd	1.62 cde	2.46 b	2.03 bc
June 2022	1.06 gh	1.1 fgh	1.18 fgh	0.97 h	1.08 fgh
May 2023	1.4 def	1.22 fgh	1.27 efgh	1.16 fgh	1.69 cd

The figure below, graphs TOC% on the right axis and PPOC on the left, as a visual representation of the tables above. Although the scale for each is different, it's interesting to note the change in the proportion of PPOC to TOC. PPOC is more sensitive to changes in management practices (Culman et al) and is a more water soluble component of the Carbon pool so changes in the relative proportions suggest that Carbon is being apportioned into different pools.

It is important to note that both TOC and PPOC are graphed as percentage while the PPOC figures in the table above are in mg/g as reported by DES in 2022 and 2023, after refining their analytical method. PPOC% equals PPOC mg/g divided by 10.

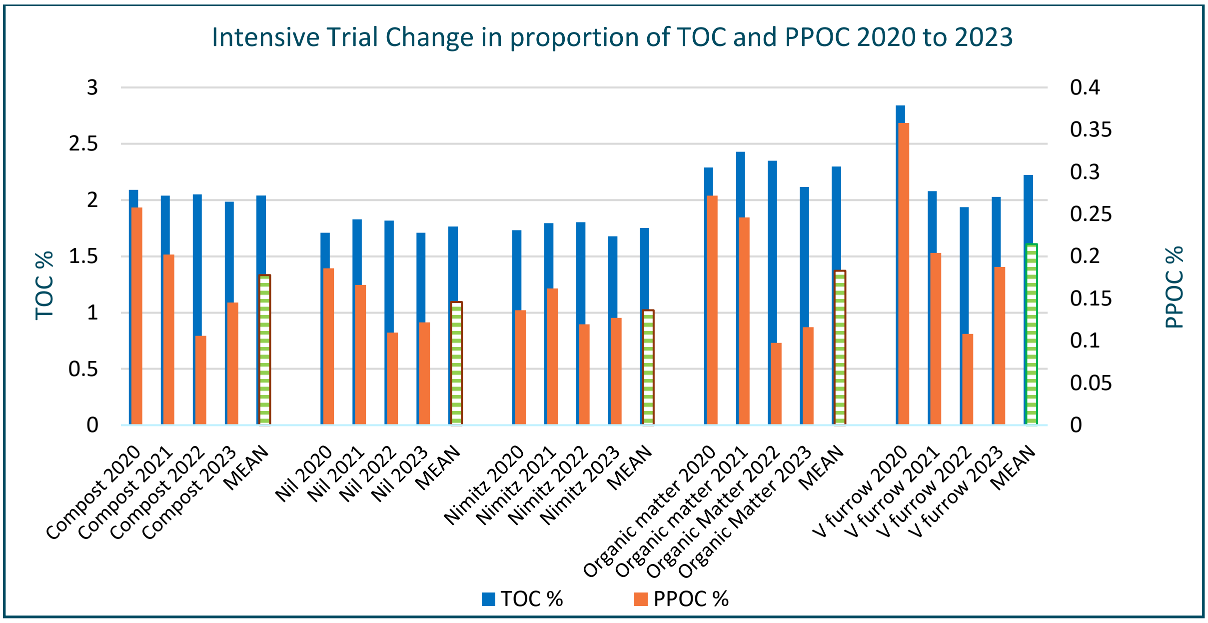

Figure 1 The relative proportion of PPOC to TOC at the four harvest sampling times. The PPOC scale is on the right hand side of the graph and is approximately 1/10 of the TOC scale.

pH

The ideal pH for growing sweetpotato is thought to be 5.5 – 6.5. Oklahoma State University extension material recommends optimum soil pH of 5.8 to 6.0 for high yields of marketable sweetpotatoes. Soils with a test result of 7.1 have been used for previous plantings at the Gatton Research Facility, where good yields of marketable sweetpotatoes were achieved. Further work, specific to sweetpotato, needs to be conducted under Australian farming conditions as most publications refer to ideal levels for English/Irish potato (Solanum tuberosum).

The effect of sampling time was significant, with the mean pH in June 2020 significantly higher than all other sampling times. As this sampling was early in the trial, the amendments had not had sufficient time to impact on soil chemistry.

The mean pH in May 2023 was significantly higher than the samplings in July 2021 and January 2022, which occurred during periods of heavy of rainfall. June 2022 had a significantly lower mean pH. In the 5 months before the sampling in June 2022, 851 mms of rainfall was recorded at BRF. Rainfall is often considered to be acidic, with surveys by Crockford et al recording rainfall pH between 4.6 and 5.8 at a Canberra location. Therefore, high rainfall events may acidify the soil and leach nutrients and breakdown compounds from the amendment material. Means in the tables below with a letter in common are not significantly different at the 0.05 level.

Table 7 Seasonal means showing the change in pH across all treatments over the four harvests.

Sample Date	June 2020	July 2021	January 2022	May 2023
Seasonal Mean	7.464 a	7.078 c	6.962 d	7.176 b

The mean pH was significantly lower in the organic matter treatment than all other treatments. The addition of sawdust and chicken manure has improved the soil pH and brought it closer to the ideal level of below 7.

Table 8 Mean pH by treatment over all harvest samplings

Treatment	Compost	Nil	Nimitz	Organic matter	V furrow
Treatment Mean	7.226 a	7.214 a	7.201 a	7.029 b	7.184 a

Electrical Conductivity (EC)

Electrical Conductivity is significantly higher in the Organic Matter treatment and as this consists of chicken manure and sawdust, a higher EC reading can be expected. The lower reading in June 2022 is consistent with the higher rainfall received.

Table 9 Seasonal means showing the change in EC across all treatments over the four harvests.

Date	June 2020	July 2021	June 2022	May 2023
Electrical Conductivity (dS/m)	0.1128 b	0.1416 a	0.0660 d	0.0820 c

Table 10 Mean EC by treatment over all harvest samplings

Treatment	EC dS/m
Compost	0.0965 b
Nil	0.0875 c
Nimitz	0.095 bc
Organic matter	0.1215 a
V furrow	0.1025 b

Colwell P (mg/kg)

Only three sampling events were analysed for Colwell P and PBI, with the June 2022 harvest not included. A significant main effect of sampling time ($p < 0.001$) and treatment ($p < 0.001$) was detected for Colwell P, but the interaction was not significant ($p = 0.754$). The mean Colwell P was significantly higher in July 2021 and May 2023. The overall mean Colwell P was significantly higher for organic matter compared to all other treatments. Nimitz had the lowest mean, but it was not significantly lower than compost and V furrow.

Table 11 Seasonal means showing the change in Phosphorous across all treatments over three harvests.

Sample Date	Colwell Phosphorous mg/kg)
June 2020	127.4 b
July 2021	149.3 a
May 2023	145 a

Table 12 Mean Phosphorous (Colwell) by treatment over all harvest samplings.

Treatment	Colwell Phosphorous (mg/kg)
Compost	133.9 bc
Nil	140.6b
Nimitz	128.1c
Organic matter	167.9a
V furrow	132.5 bc

Phosphorous Buffering index (PBI)

The overall mean PBI col was significantly higher for the nil and Nimitz treatments, and significantly lower for organic matter and V furrow. The higher numbers in the Nil and Nimitz treatments are an indication of the higher P binding capacity of these zero-amendment treatments thus making P less available to the plants. Organic Matter and Vfurrow amendment had significantly lower PBI thus allowing P to be more available for plant uptake.

Table 13 Mean Phosphorous Buffering Index by treatment over all harvest samplings.

Treatment	Mean PBI
Compost	267.5 b
Nil	282.3 a
Nimitz	281.8 a
Organic matter	250.3 c
V furrow	255.4 c

Extensive Trial

As there are multiple factors involved in the extensive trial i.e., an initial grass cover crop followed by either a brassica or legume cover crop followed by five individual treatments, there are two methods of statistical analysis and interpretation available. One approach is to analyse the data as ten individual treatments and the other is to use a factorial treatment structure. Either method is statistically valid. As there is no evidence of any effect due to crop, the results presented here are as ten individual treatments. Due to budget considerations, only TOC was analysed at the third harvest in April 2023.

Total Organic Carbon

Total Organic Carbon was measured at the 3 extensive trial harvests: June 2020, March 2022 and April 2023. A repeated measures ANOVA was applied to the data with a significant interaction of sampling date and treatment detected. There was no significant change in TOC% over time for grass/brassica and grass/legume with incorporated amendment, nematicide and nil. The result for nil and nematicide is unsurprising as no amendments were added over the life of the trial and this gives us a good measure of consistent sampling in a homogenous standard soil. The two double amendment treatments showed a significant decrease at the second sampling event but by the third sampling had returned to the first sampling levels and had significantly higher means than all other treatments.

Grass/brassica with V furrow had a significantly higher mean TOC% at the third sampling event, while grass/legume with V furrow decreased significantly after the first sampling event. This could in part be due to the nature of the amendment application, where a non-homogenous sawdust and chicken manure mixture is applied into a furrow at the top of the bed. In these circumstances, consistent sampling over a 3 year period is difficult to achieve.

There were no differences between the brassica and legume cover crops.

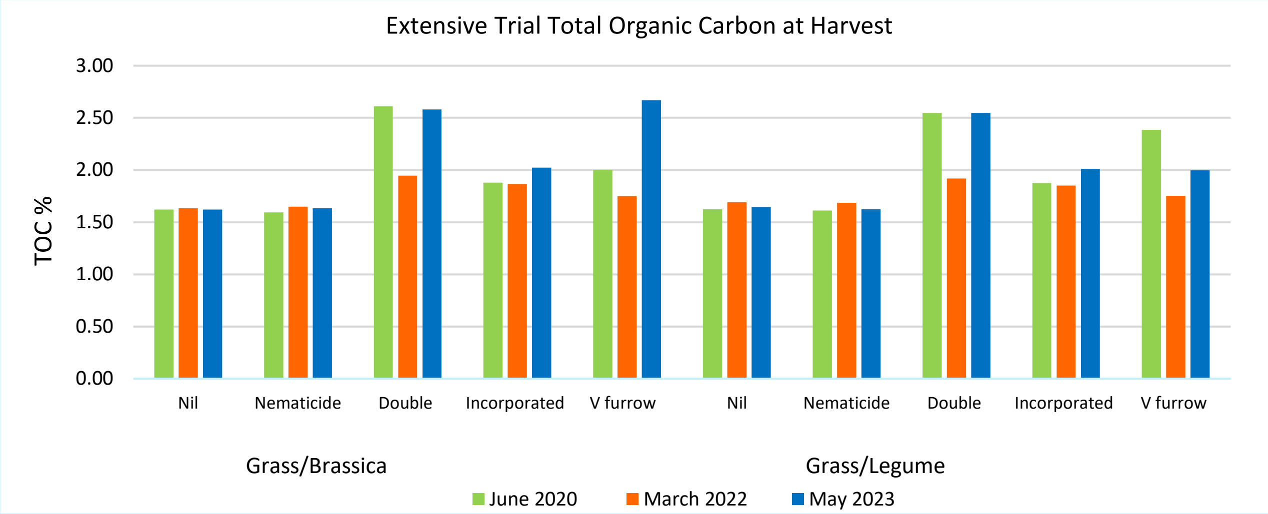

Figure 2 Comparison of TOC levels at the 3 harvest sampling events.

Table 14 The mean TOC comparison between treatments in the Extensive trial and across all sampling dates. Means with a letter in common are considered not significantly different at the 0.05 level

	Means					
Treatments	2/06/2020		15/03/2022		17/04/2023	
Grass/brassica + Double amendment	2.612	a	1.947	bcd	2.580	a
Grass/brassica + Incorporated amendment	1.880	bcdef	1.867	bcdef	2.022	b
Grass/brassica + Nematicide	1.593	f	1.647	def	1.635	ef
Grass/brassica + Nil	1.622	ef	1.632	ef	1.622	ef
Grass/brassica + V furrow amendment	2.000	bc	1.750	bcdef	2.670	a
Grass/legume + Double amendment	2.547	a	1.920	bcde	2.547	a
Grass/legume + Incorporated amendment	1.875	bcdef	1.852	bcdef	2.010	b
Grass/legume + Nematicide	1.612	ef	1.685	def	1.625	ef
Grass/legume + Nil	1.625	ef	1.692	cdef	1.645	def
Grass/legume + V furrow amendment	2.385	a	1.752	bcdef	1.998	bc

Overall, it has been difficult to consistently improve TOC levels above an initial gain. The nil and nematicide treatments represent the base level soil C with no amendments and only cover cropping between sweetpotato crops. The double amendments initially showed dramatic increase in June 2020 but by May 2023 had not improved significantly beyond the initial level of 2.5 – 2.6%. The low second sampling result could perhaps be attributed to the excessive rainfall in the cropping period leading to harvest. This excessive rainfall can displace the applied amendments and remove them from the sampling zone.

Table 15 Rainfall in the 5 month period prior to harvest.

Harvest	Rainfall (Millimetres)
June 2020	525
March 2022	1228
April 2023	535

This level of 2.5% is good for a Bundaberg farming system, as losses of carbon through tillage practices and crop removal often result in much lower levels of TOC, as evidenced in our grower survey results where 2.35% was the absolute highest achieved by a best practice grower. Our survey of undisturbed vine scrub forest sites on a similar soil type gave a maximum of 7.22%. and a level of 1.85% was recorded for a grower using good cover cropping strategies. See appendix 5.

Potassium Permanganate Oxidisable Carbon (PPOC)

The mean PPOC (mg/g) decreased significantly from June 2020 to March 2022. The two double amendment treatments had the highest mean PPOC (mg/g) but they were not significantly different to grass/legume with V furrow.

Table 16 The mean PPOC comparison between treatments and across 2 sampling dates in the Extensive trial. Means with a letter in common are considered not significantly different at the 0.05 level.

	Potassium Permanganate Oxidisable Carbon (mg/g)			
Treatment	June 2020	March 2022	Mean	
Grass/brassica + Nil	1.225	0.885	1.055	e
Grass/brassica + Nematicide	1.225	0.897	1.061	e
Grass/brassica + Double amendment	2.55	1.208	1.879	a
Grass/brassica + Incorporated amendment	1.625	1.092	1.359	bcde
Grass/brassica + V furrow amendment	1.65	0.967	1.309	cde
Grass/legume + Nil	1.5	0.97	1.235	de
Grass/legume + Nematicide	1.725	0.917	1.321	cde
Grass/legume + Double amendment	2.125	1.165	1.645	ab
Grass/legume + Incorporated amendment	1.875	1.105	1.49	bcd
Grass/legume + V furrow amendment	2.125	0.995	1.56	abc

Other Soil Components

All other soil components were only measured at 2 sampling events (2/06/2020, 15/03/2022) to accommodate budget limitations.

pH

The overall mean pH decreased significantly from June 2020 to March 2022. Grass/brassica with nematicide had the highest mean pH and it was significantly higher than all other treatments except the two nil treatments. The addition of amendments to the other treatments has improved the soil pH and has brought it closer to the ideal level of below 7, perhaps attributable to the high amounts of rainfall.

Table 17 The mean pH comparison between treatments and across 2 sampling dates in the Extensive trial. Means with a letter in common are considered not significantly different at the 0.05 level.

Treatment	June 2020	March 2022	Mean	
Grass/brassica + Nil	7.498	7.225	7.361	ab
Grass/brassica + Nematicide	7.625	7.328	7.476	a
Grass/brassica + Double amendment	7.35	7.04	7.195	d
Grass/brassica + Incorporated amendment	7.605	7.05	7.328	bc
Grass/brassica + V furrow amendment	7.403	7.05	7.226	cd
Grass/legume + Nil	7.628	7.13	7.379	ab
Grass/legume + Nematicide	7.51	7.155	7.333	bc
Grass/legume + Double amendment	7.36	7.018	7.189	d
Grass/legume + Incorporated amendment	7.495	7.118	7.306	bcd
Grass/legume + V furrow amendment	7.468	7.128	7.298	bcd

Electrical Conductivity

The overall mean EC decreased significantly from June 2020 to March 2022. This finding supports the theory that sustained rainfall during crop growth in the previous 5 months has led to significant leaching of nutrients.

Grass/brassica with double amendment had the highest mean EC, but it was not significantly higher than grass/brassica with incorporated or V furrow amendment, or grass/legume with double amendment.

Table 18 The mean EC comparison between treatments and across 2 sampling dates. Means with a letter in common are considered not significantly different at the 0.05 level.

	Electrical Conductivity			
Treatment	June 2020	March 2022	Mean	
Grass/brassica + Nil	0.1125	0.045	0.0787	bc
Grass/brassica + Nematicide	0.1075	0.055	0.0812	bc
Grass/brassica + Double amendment	0.1425	0.06	0.1012	a
Grass/brassica + Incorporated amendment	0.1175	0.06	0.0887	ab
Grass/brassica + V furrow amendment	0.1275	0.0575	0.0925	ab
Grass/legume + Nil	0.1075	0.04	0.0737	c

Grass/legume + Nematicide	0.125	0.045	0.085	bc
Grass/legume + Double amendment	0.135	0.0475	0.0912	ab
Grass/legume + Incorporated amendment	0.11	0.0525	0.0812	bc
Grass/legume + V furrow amendment	0.125	0.0475	0.0862	bc

Phosphorous (P)

Phosphorus was analysed using the Colwell P method.

The mean Colwell P increased significantly from June 2020 to March 2022. While there seemed to be a leaching effect of other soil elements from high rainfall, P increased.

Soils high in iron, such as ferrosol soils at the trial site, can adsorb phosphorous and fix it close to the surface. In the table below it's interesting to note the decrease in P from June 2020 to March 2022 in both the double amendment and the grass/legume+v furrow plots. When looked at in conjunction with PBI, the decrease in P corresponds to an increase in PBI, as this higher PBI value is an indication of the extent to which P is bound in the soil.

The addition of amendments such as Chicken manure can add significant amounts of P to the soil. The question is how much is too much ?. Discussions with leading growers indicate that different sweetpotato varieties have different P requirements but as a rule of thumb, growers shouldn't apply more than 30 units of P and no P fertiliser if using compost. Researchers in the USA have worked on nutrient addition and often use 100 units of P but they have different practices to Australian growers so it is difficult to extrapolate their findings to Australian requirements. More research needs to be conducted on nutrient requirements under Australian conditions.

Table 19 The mean Phosphorous comparison between treatments and across 2 sampling dates. Means with a letter in common are considered not significantly different at the 0.05 level.

	Phosphorous			
Treatment	June 2020	March 2022	Mean	
Grass/brassica + Nil	124.8	136.8	130.8	de
Grass/brassica + Nematicide	125.2	159.2	142.2	bcde
Grass/brassica + Double amendment	169.2	154.2	161.8	ab
Grass/brassica + Incorporated amendment	146.2	192	169.1	a
Grass/brassica + V furrow amendment	148.5	161.5	155	abc
Grass/legume + Nil	129.8	141.8	135.8	cde
Grass/legume + Nematicide	122.2	131	126.6	e
Grass/legume + Double amendment	168.5	155.8	162.1	ab
Grass/legume + Incorporated amendment	146.5	174.8	160.6	ab
Grass/legume + V furrow amendment	152.8	148.5	150.6	abcd

PBI col

The interaction of treatment and sampling date was significant for PBI col ($p = 0.034$). A significant decrease in mean PBI col from June 2020 to March 2022 was found for grass/brassica with incorporated and nematicide. All other treatments had no significant change over time.

Table 20: The mean PBI comparison between treatments and across 2 sampling dates. Means with a letter in common are considered not significantly different at the 0.05 level.

	Means			
Treatments	2/06/2020		15/03/2022	
Grass/brassica + Double amendment	221.8	i	233.5	fghi
Grass/brassica + Incorporated amendment	241.5	efg	224.8	hi
Grass/brassica + Nematicide	276.0	a	258.5	bcd
Grass/brassica + Nil	265.2	abc	260.5	bcd
Grass/brassica + V furrow amendment	248.5	def	234.8	fghi
Grass/legume + Double amendment	230.2	ghi	233.8	fghi
Grass/legume + Incorporated amendment	242.8	efg	233.0	ghi
Grass/legume + Nematicide	269.0	ab	264.8	abc
Grass/legume + Nil	263.5	abcd	258.8	bcd
Grass/legume + V furrow amendment	239.2	efgh	252.5	cde

TN%

The interaction of treatment and sampling date was significant for TN% ($p = 0.002$). A significant decrease in mean TN% from June 2020 to March 2022 was found for the two double amendment treatments and both V furrow treatments. All other treatments had no significant change over time.

Table 21 The mean Total Nitrogen comparison between treatments and across 2 sampling dates. Means with a letter in common are considered not significantly different at the 0.05 level.

Treatments	Means 2/06/2020		15/03/2022	
Grass/brassica + Double amendment	0.2175	a	0.1750	cd
Grass/brassica + Incorporated amendment	0.1825	bc	0.1725	cde
Grass/brassica + Nematicide	0.1525	f	0.1525	f
Grass/brassica + Nil	0.1550	f	0.1525	f
Grass/brassica + V furrow amendment	0.1825	bc	0.1575	ef
Grass/legume + Double amendment	0.2100	a	0.1750	cd
Grass/legume + Incorporated amendment	0.1775	bc	0.1675	cdef
Grass/legume + Nematicide	0.1525	f	0.1550	f
Grass/legume + Nil	0.1550	f	0.1550	f
Grass/legume + V furrow amendment	0.1925	b	0.1600	def

NO_3N (mg/kg)

No significant change over time was detected for the two incorporated amendment and nil treatments and grass/legume with nematicide. All other treatments had a significant increase in mean NO_3N over time.

At the first sampling event, the two incorporated treatments had significantly higher means than all other treatments except grass/legume with nil. At the second assessment, the only significant differences were grass/brassica with V furrow had a significantly higher mean than grass/brassica with nil and grass/legume with nematicide.

Table 22 The mean Nitrate-Nitrogen comparison between treatments and across 2 sampling dates. These means are back transformed after being analysed on a log10 scale. Means with a letter in common are considered not significantly different at the 0.05 level.

Treatments	June 2020		March 2022	
Grass/brassica + Double	2.3	defg	6.62	ab
Grass/brassica + Incorporated	5.584	abc	6.402	ab
Grass/brassica + Nematicide	1.732	fgh	5.958	abc
Grass/brassica + Nil	2	efg	3.31	bcdef
Grass/brassica + V furrow	1.189	gh	7.364	a
Grass/legume + Double	1.934	efg	4.229	abcd
Grass/legume + Incorporated	4.899	abc	5.318	abc
Grass/legume + Nematicide	2.213	defg	3.224	bcdef
Grass/legume + Nil	2.913	cdef	3.663	abcde
Grass/legume + V furrow	0.841	h	3.984	abcde

Intensive Trial: The relationship between soil parameters and nematode populations

The relationship between soil parameters and nematode populations was an interesting finding in the Intensive trial.

After the first harvest in 2020, a trend was emerging between low numbers of Meloidogyne spp (RKN) and higher numbers of Total Free Living (TFL) nematodes with higher Organic Carbon. The graphs below represent this relationship with two graphs presented for each harvest. The first graph shows the relationship between TOC and RKN only, while the second presents the figures for both groups of nematodes and is shown on a different scale to capture the higher TFL counts. The scale on the second axis (left hand side of the graph) is the nematode counts, standardised for 200grams of dry soil.

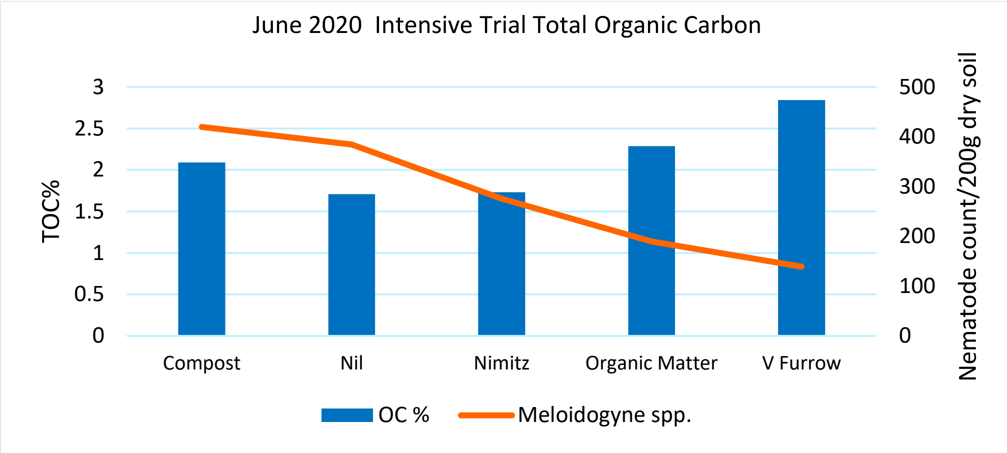

Figure 3 Comparison of TOC levels at the 3 harvest sampling events.

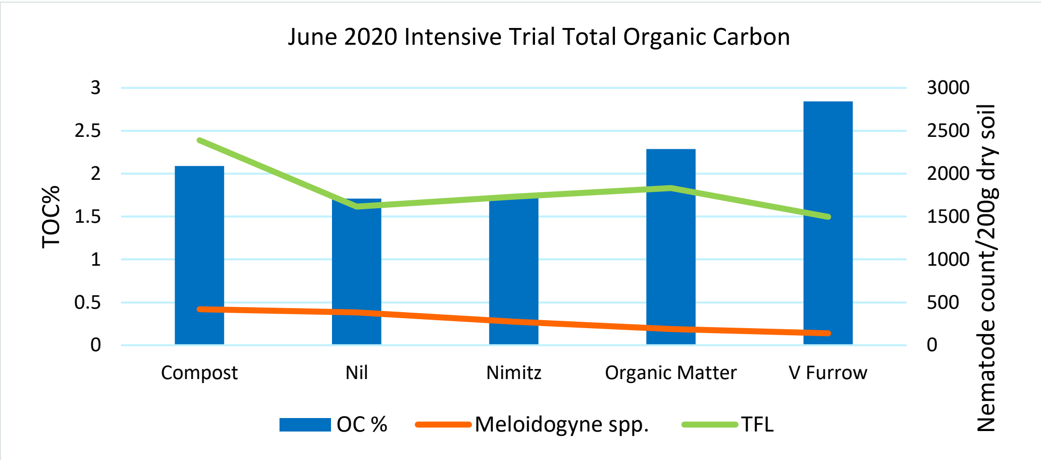

Figure 4 The relationship between Total Organic Carbon, Total Free Living nematodes and Root Knot Nematode counts

Harvest 2021

By the second harvest in July 2021, the trend was becoming more apparent, with the Organic Matter treatment supporting lower populations of RKN and increased TFL, the beneficial nematodes that are widely believed to predate upon plant parasitic nematodes.

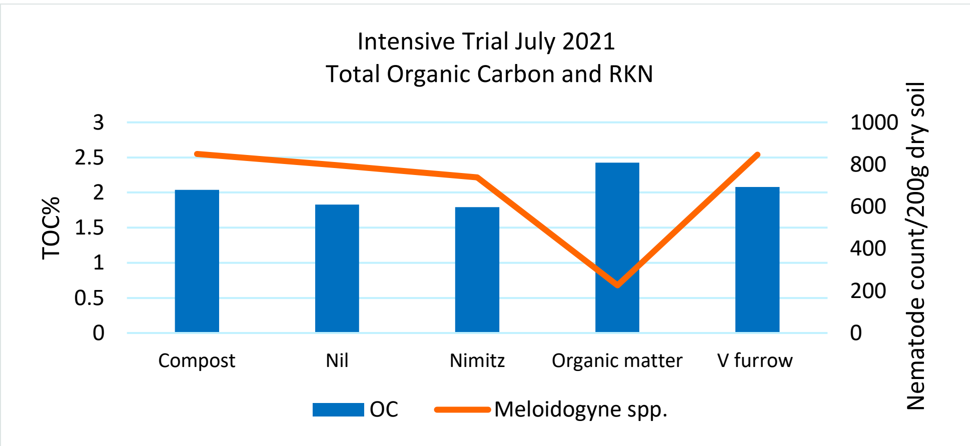

Figure 5 The relationship between Total Organic Carbon and RKN counts in July 2021

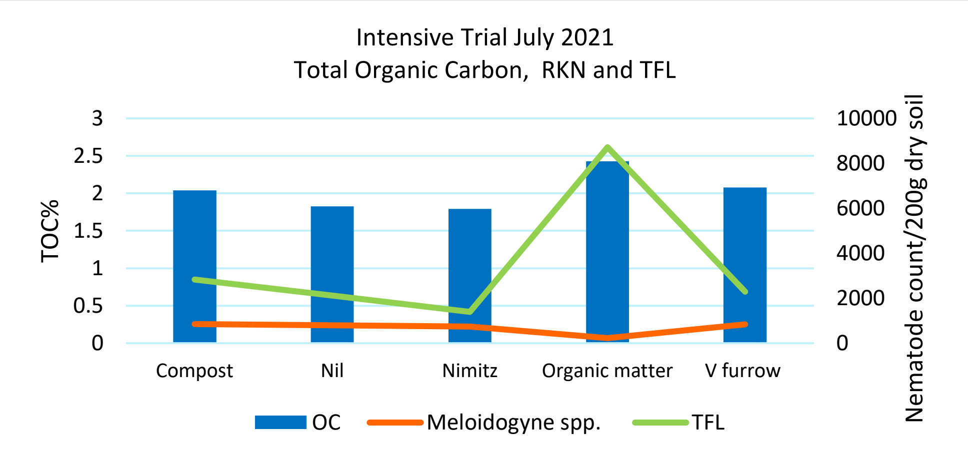

Figure 6 The relationship between Total Organic Carbon, Total Free Living nematodes and Root Knot Nematode counts in July 2021

Harvest 2022

The third harvest in June 2022 repeated the findings of 2021 and also showed an inverse relationship between the Organic Matter treatment and RKN and a direct relationship of TOC to TFL.

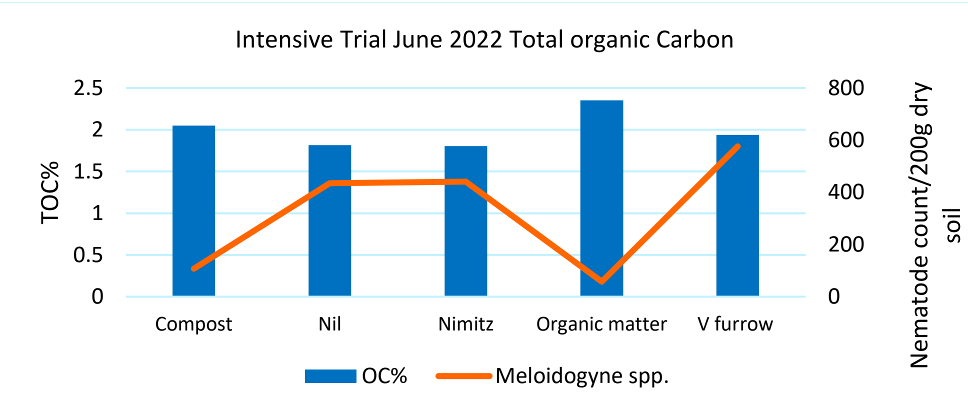

Figure 7 The relationship between Total Organic Carbon and Root Knot Nematode counts in June 2022.

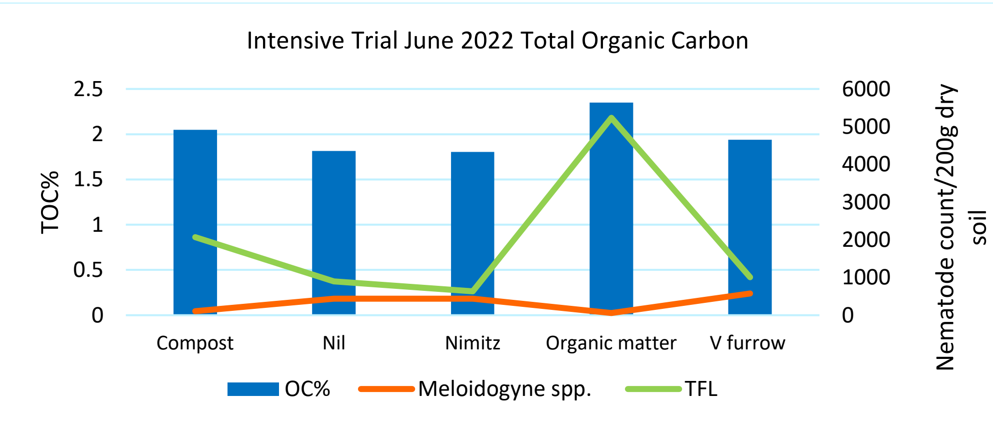

Figure 8 The relationship between Total Organic Carbon, Total Free Living nematodes and Root Knot Nematode counts in June 2022.

Harvest 2023

By 2023, the population of Meloidogyne had all but disappeared from the trial block and has made it difficult to be confident in drawing any conclusions for that sampling period. Although the counts for TFL were also markedly reduced, it is still adequate to show low populations in the Nil and Nimitz and higher in the Organic Matter.

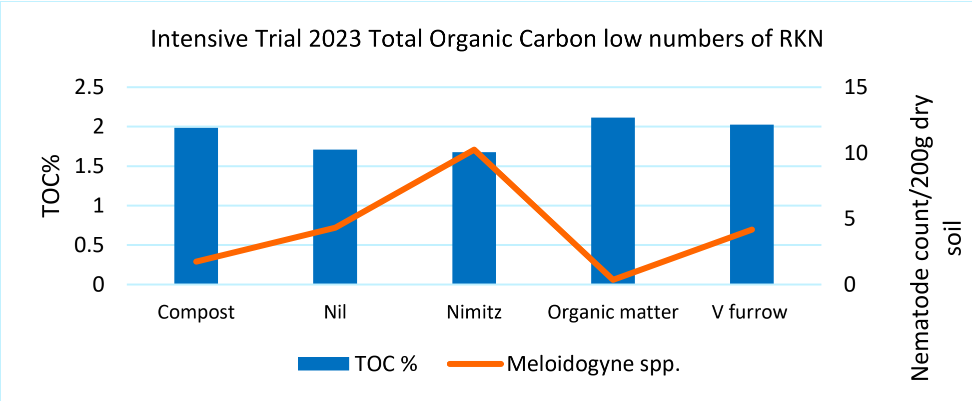

Figure 9 The relationship between Total Organic Carbon and Root Knot Nematode counts in May 2023. Note the very low counts of RKN.

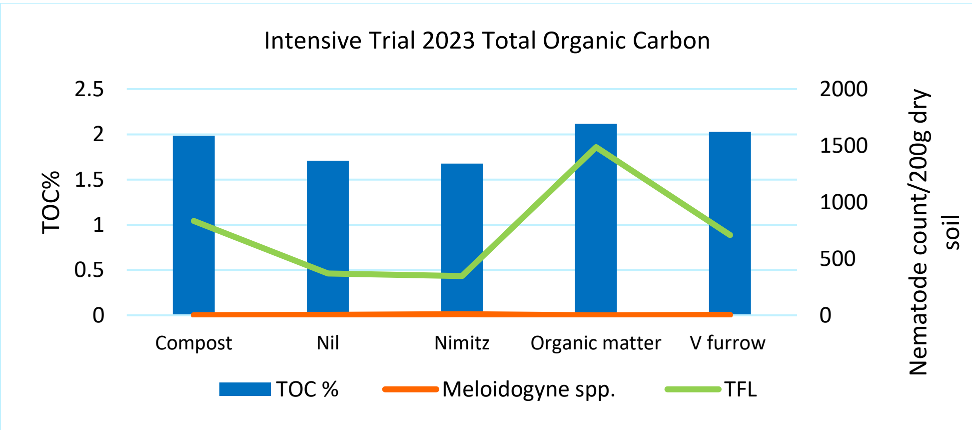

Figure 10 The relationship between Total Organic Carbon, Total Free Living nematodes and Root Knot Nematode counts. Note the very low counts of RKN.

It is not possible to say that TOC is the sole contributor to the change in populations as there are many other components in the soil amendments that may contribute to this relationship.

Statistical Analysis of the relationship of soil components and nematodes.

The data was analysed by the DAF statistician to investigate whether these observations had any statistical basis. Correlations between the soil components and the nematodes counts were calculated for data collected from 2020 to May 2023. These correlations assume no causal relationship and only provide an indication of the strength of a linear relationship. No correlations between the nematode species, Helicotylenchus dihystera with the soil components were significant and relationships are not strong or consistent for Rotylenchulus reniformis.

For Meliodogyne, negative correlations were found in each year that data was collected for EC, NO3N, TC%, TOC%, and PPOC%. This suggests that the count of Meliodogyne decreases as these soil components increase. Numerous significant correlations were detected for total free living (TFL) nematodes. Positive correlations were detected with EC in each year. Negative correlations were detected from 2021-2023 with TOC, pH and PBI.

Assuming there is a causal relationship between the soil components and the nematodes, linear and non-linear regression models were fitted. The following table shows the adjusted R2 which represents the percentage of variance explained by the model. The higher the adjusted R2, the better the model fit. In general, the percentage of variance explained is low, suggesting that the models would not be able to predict the nematode counts well. An exception to this is the relationships between TFL and Colwell P and TOC% in 2021, and with TC% and TOC% in 2022. These relationships have adjusted R2 values greater than 70%. The fitted models for relationships with an adjusted R2 above 50% are shown below the tables.

Table 23 Table of adjusted R^2 values for regression models for total free living nematodes (TFL) and soil parameters. Values under 70% indicate poor model fit.

Linear Model Adj R2 (%)	TFL			
	2020	2021	2022	2023
H	*	28.35	19.62	*
EC_dS_m	*	51.37	46.04	20.00
Cl_mg_kg	*	28.34	*	*
NO3_N_mg_kg	*	*	19.91	19.04
Colwell_P_mg_kg	*	73.16		13.06
TC%	*		70.18	
TN%	*		31.39	
PBI_col	*	36.57		30.56
PBI_unadj		50.46		
TOC_%		72.98	70.42	35.90
PPOC_mg_g			*	*
PPOC_%	*	65.75		*
Coarse_sand_%	*	*		
Fine_sand_%	*	*		
Silt_%	*	*		
Clay_%	*	24.86		

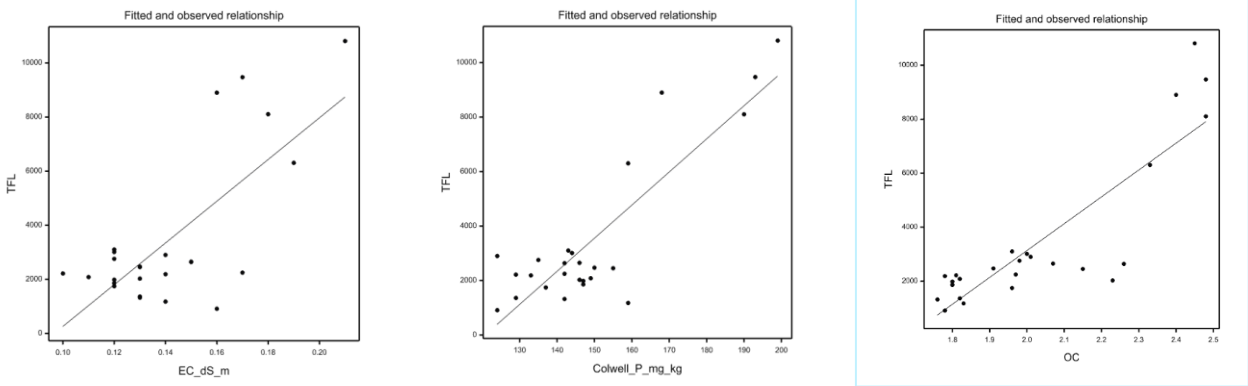

Figure 11 The fitted models for relationships with an adjusted R2 above 50%

It is possible that some of the relationships may be better explained by a non-linear model, such as an exponential model. Adjusted R^2 for exponential model fits suggest there is an improvement for TFL with TOC (%) and PPOC in 2021. The adjusted R^2 for these models are 86.94% and 74.53% respectively.

Multiple linear regressions (MLR) were also fitted where the best subset of soil components were selected that explained the nematode counts. Meloidogyne showed a marginal improvement in model fit in 2021, 2022 and 2023 when 2 soil components were fitted.

The relationship of soil components and nematodes in the Extensive Trial.

A relationship between soil carbon and nematode populations was also noted in the extensive trial, with higher counts of TFL associated with higher TOC levels and lower RKN counts. As noted in the Intensive Trial, this can't be attributed solely to Carbon as there are other components in the amendments.

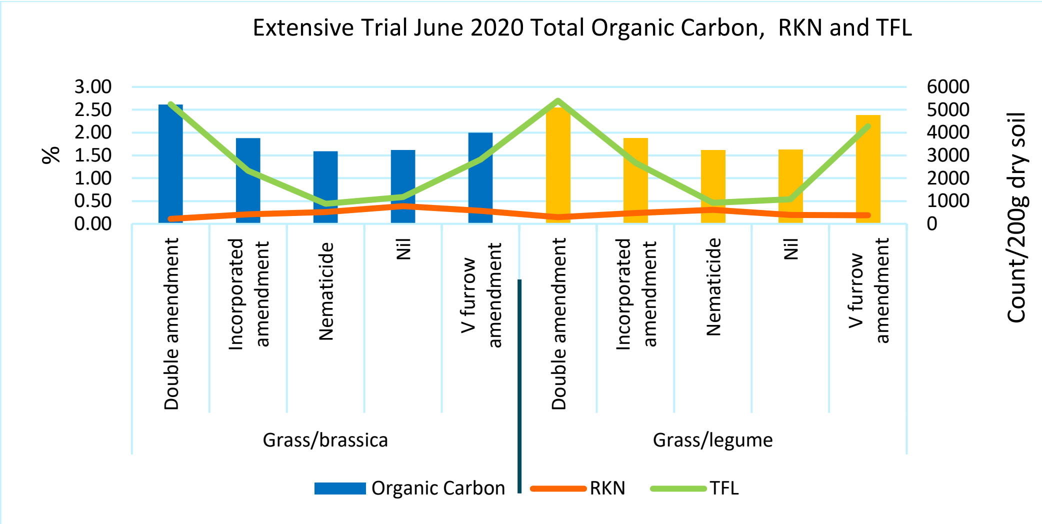

Figure 12 The relationship between Total Organic Carbon, Total Free Living nematodes and Root Knot Nematode counts in June 2020.

Conclusion

In the Intensive trial, plots treated with organic amendments had a significantly higher mean TOC % over all the samplings than the nil and nematicide treatments, with organic matter and v furrow being significantly better than compost.

Other soil chemistry parameters such as pH, P and PBI were significantly improved in the organic matter treatment of the Intensive trial. There is a possible correlation between lower root knot nematode and increased EC, NO3N, TOC%, and PPOC% in the Intensive trial. Initial statistical analysis indicates this, however it becomes increasingly uncertain as further modelling is done and the variances are less well explained. There does seem to be a relationship though between TFL and Colwell P and TOC in 2021, and with TOC in 2022. These relationships have a good model fit. This relationship trend was also seen in the Extensive trial results.

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