Final Report

Integrated pest management of nematodes in sweetpotatoes

Project leader:

Sandra Dennien

Delivery partner:

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Integrated pest management of nematodes in sweetpotatoes (PW17001)

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Level 7
141 Walker Street
North Sydney NSW 2060

Telephone: (02) 8295 2300

www.horticulture.com.au

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Public summary

The Australian sweetpotato industry ($90M farm gate value) is heavily impacted by plant-parasitic nematodes, costing an estimated $20M per year in losses (ASPG pers. com.). Root-knot nematodes (RKN) are widely distributed throughout the sweetpotato-growing areas of Queensland and northern NSW. Feeding activity affects root initiation, causes stunting, skin damage and yield loss. At project commencement there was one registered chemical (S7 classification being removed from the market) and one minor use permit for RKN control. Thus, it was crucial to find alternative control methods through soil health improvement and Integrated nematode management.

The project completed the first comprehensive nematode species survey undertaken on sweetpotato producing soils in Australia, with 85 fields sampled in an initial survey. Growers now have a greater understanding of the plant-parasitic nematodes causing yield loss and damage. A new detection of reniform nematode was made outside of the previously known range. Following the detection of guava root-knot nematode into Australia a pest alert fact sheet was produced for the industry. Experiments provided new knowledge on the effects of nematode species on sweetpotato cultivars. Results suggested that *R. reniformis* damage occurs at root formation resulting in fewer roots, infection with RKN (*M. javanica*) reduced both the number and weight of roots, and the cultivar Bellevue is moderately susceptible to *M. javanica* (contrary to existing information)

Thirty-six varieties of cover crops were identified as resistant or highly resistant to two species of RKN and 6 rotation crops and one sweetpotato cultivar were identified as resistant to reniform nematode. Of the 24 sweetpotato cultivars screened for resistance to two species of RKN, 15 were identified as resistant or highly resistant.

Growers have increased awareness of the nematode host potential of weeds and the importance of weed management. Trials provided growers with new knowledge on herbicide efficacy for volunteer control and safe plant back periods. A review identified future chemistry options adaptable to Australian conditions.

Long term trials indicated that high rates of organic amendments have the potential for effective RKN suppression as well as improved yield and long-term soil health benefits. The addition of organic matter improved soil carbon and other desirable soil chemistry traits and supported an increase in beneficial soil organisms. Findings indicated a correlation trend between lower RKN and higher soil carbon.

The project was highly successful at providing extension of current knowledge on soil health and nematode management through the delivery of Sweetpotato Soil Health Masterclasses, a soil health/integrated nematode management handbook, fact sheets, Lucid key development identifying resistant cover crops and ongoing dissemination of new information, at field days and project updates.

Key achievements of this project include:

- knowledge of nematode species diversity and distribution in the industry
- increased selection of resistant cover cropping options
- knowledge of resistance status of commercial sweetpotato cultivars
- increased understanding of soil health, suppression of nematodes by organic amendments, and importance of managing weed hosts and volunteers. Growers now have better tools to manage nematode pests on their farms.

Keywords

Sweetpotato, Nematodes, RKN, Reniform; Integrated nematode management; Soil health, Carbon, Nematode resistance.

Introduction

Australian sweetpotato growers produce the world's highest yields of quality sweetpotatoes per hectare with a current farm gate value in excess of $90M (ASPG pers. com). Loss from root-knot nematodes (RKN) to the Australian Sweetpotato industry amounts to $20 M per year (ASPG pers. com.). RKN are widely distributed throughout the sweetpotato-growing areas of Queensland and northern NSW. They are suited to the volcanic soils around the major production areas of Bundaberg and Cudgen and multiply readily in sandy soils. Nematodes feed on the root, affecting root initiation, causing stunting and yield loss. Reniform nematode is also present in Queensland. Other potential nematode pests of sweetpotato include root-lesion (Pratylenchus) dagger (Xiphinema) and stubby root nematodes (Paratrichodorus). The combination of year-round production, a sub-tropical environment, susceptibility of popular varieties and difficult to control post-harvest volunteer growth provide ideal conditions for rapid multiplication of nematodes.

Sweetpotato production relies quite heavily on chemical control of nematodes. However, at project commencement there was one registered chemical (S7 classification, that was being withdrawn from the market) and one minor use permit. Hence, the need to explore alternative or integrated approaches. This program addresses that need and encompassed research across a range of management approaches aimed at reducing losses due to nematodes, optimising production and improving soil health.

Hay and Stirling (2014) and Stirling (2013) describe the value of integrated nematode management programs using crop rotations, organic amendments, minimum tillage and organic mulching farming systems. The effects of agricultural management on the soil biota are well-recognised, with practices that promote soil biological activity and diversity being intimately linked to soil health and long-term sustainability (Lehman et al. 2015; Stirling et al. 2016). Composts are widely used (Thoden et al., 2011) and materials such as poultry manure, sugarcane trash, sawdust and mill mud have been effective in sugarcane soils (Stirling et al., 2003) to improve soil suppressiveness to nematodes. While the benefits of these approaches are well documented, little work has been undertaken in the unique and complex sweetpotato farming systems. This project assessed the suitability of a range of integrated nematode management options to sweetpotato production.

Rotation/cover crops should be resistant to all pathogenic nematode species and produce large amounts of biomass and have a leguminous component to provide carbon and nitrogen inputs to the soil. While some forage sorghum cultivars are known to be highly resistant to RKN (e.g., Jumbo LPA), the resistance of other potentially useful rotation/cover crops is unknown (e.g., sunn hemp, oilseed radish, tillage radish, forage brassica, lucerne, soybean, millet and sunflower). With new varieties being released each year there is an ongoing need to screen potential cover crop options for nematode resistance. As the sweetpotato industry presently has few winter cover crop options, particular attention was given to these species.

This program of work encompassed six key focus areas relevant to sweetpotato integrated nematode management.

1. Extension of current knowledge on soil health and nematode management to update industry on available nematode knowledge, build capacity within the project team, understand industry practices and collate historical data.
2. Initial industry wide grower surveys to identify nematode species present in sweetpotato growing soils with more intensive surveys and follow up sampling to assess impact of variable management on nematodes and sweetpotato production.
3. Control of weeds and sweetpotato volunteers to identify nematode weed hosts and control options.
4. Cover crops and sweetpotato variety nematode resistance screening for susceptibility to RKN and reniform nematodes and the impact of these nematodes on skin quality of two sweetpotato varieties.
5. Nematicides and biofumigants - Two field trials to investigate the efficacy of currently available nematicides and biofumigant residues against RKN in sweetpotato systems.
6. Two long term field trials to assess potential integrated nematode management options (including soil amendments, cover crops, tillage and bed formations) for their applicability to, and impact on, sweetpotato production systems.

Methodology

The following outlines the approach and methodologies implemented to deliver the PW17001 program. Due to the volume and complexity of the work delivered, individual detailed reports can be found in Appendices 1-22.

Governance

This program was delivered in close consultation with the Australian Sweetpotato industry. A Project Reference Group was established at commencement of the project which comprised project team members, sweetpotato growers and representatives from the Australian Sweetpotato Growers organisation. Regular updates on project progress were made to this group with meetings every 6 months.

Collaborator agreements were established with additional organisations to deliver outputs and outcomes for PW17001. These included Biological Crop Protection, Australian Sweetpotato Growers and Central Queensland University.

Extension of current knowledge on soil health and nematode management

Key initial activities focused on understanding and extending existing knowledge on nematode management to sweetpotato growers, primarily based on learnings from vegetables (MT 09067 and VG09052), and building capacity within the project team.

Sweetpotato Soil health Masterclasses

A series of four Masterclasses were conducted in 2019 (Cudgen, Bundaberg x 2 and Atherton). The aim of these events was to extend existing knowledge on nematode management in vegetables to sweetpotato farmers, improve grower's understanding of RKN and encourage them to develop more effective strategies for managing the pest. Classes consisted of theory and group sessions (discussions on soil health, soil biology and implementation of sustainable integrated pest management) along with hands-on practical sessions. As part of the masterclasses, eleven fact sheets were developed to provide sweetpotato growers with information on the topics discussed in the classes.

Nematology skills transfer

In 2018 a series of nematology training workshops were conducted at the DAF Ecosciences precinct with additional practical exercises at Gatton Research Facility. Training sessions were delivered by Graham Stirling (Biological Crop Protection) and DAF nematology staff Jennifer Cobon and Wayne O'Neill and covered techniques such as collection of soil for nematode identification, sampling protocols, storage and transport of samples, preparation of galled-root inoculum for use in field trials and setting up of pot rials, inoculation and bioassays to assess a soil's suppressiveness to nematodes. The eight attendees included new DAF nematology staff (1), the DAF sweetpotato team (6), and one Central Queensland University technician.

A seminar was held at DAF Ecosciences precinct (ESP) in December 2018 where visiting nematologists from Louisiana State University, Prof. Charles Overstreet and Prof. Ed McGawley, presented on their extensive experience with reniform nematode (*Rotylenchulus reniformis)* and RKN. The project team facilitated field visits to a number of sweetpotato farms in the Cudgen (NSW) area and a soil health trial site (managed by BCP) from the 16th to the 18th of December 2018 to complement the seminar presentations.

Survey of current sweetpotato grower practices

A survey was designed to capture current sweetpotato grower practices in relation to sweet potato production, with a focus on nematode control, cover crops and soil health. The survey collected data on; Soil type, area and varieties of sweetpotatoes grown, planting density, row spacing, crop losses due to nematodes, time of year, nematicides applied, rates used, effectiveness, rotation crops, timing of rotations, machinery used, GPS, minimum till, volunteer control, chemicals used and use of nematode testing services pre plant. Over 40 on farm surveys were conducted from October 2019 to August 2019.

Collation of historical data

A key objective of this work program was to improve knowledge of which nematode species occur in Australian sweetpotato. Prior to commencing any sweetpotato nematode surveys under this project, historical results from samples collected between 2010 and 2013 (through VG09052 and VG13004) were collated to provide information on prior nematode species detections. This collection comprised 500 sweetpotato soil samples submitted between April 2010 and August 2013 to the DAF Nematology Diagnostic Laboratory.

Sweetpotato field surveys

The focus and scope of the work undertaken through PW17001 necessitated some initial survey work and baseline data collection to provide context and a benchmark of the current breadth and diversity in nematodes in sweetpotato systems. Detailed methods are contained in Appendix 2 and reports can be found in Appendices 3 to 7.

Initial survey of plant parasitic nematodes in sweetpotato production

Initial field surveys were necessary to understand region specific nematode species occurrences and identify any potential biosecurity issues. This represents the first comprehensive nematode species survey undertaken on sweetpotato producing soils in Australia. A total of 85 fields were sampled across these regions: 45 in Wide Bay, 17 in northern NSW, 12 in Central Qld, 6 in Southeast Qld, and 5 in North Qld. Plant-parasitic nematodes were identified and quantified from samples taken at 10-15 cm deep soil core (Table 1, Appendix 2). From this survey, 81 soils (43 from Wide Bay, 16 from northern NSW, 12 from Central Qld, 6 from southeast Qld and 4 from North Qld) were submitted to SARDI (South Australian Research and Development Institute) for molecular identification of the RKN species present.

Intensive surveys of plant parasitic nematodes in sweetpotato production

Ongoing sampling of selected fields (both high and low nematode numbers) continued throughout the project from 2018-2023 to gain a better understanding of plant-parasitic nematode dynamics under a variety of management systems. These included four sites in northern NSW, seven sites in Wide Bay and four sites in Central Qld. Growers were provided with the nematode identification results for all samples.

Diagnostic sample submissions and follow-up soil samples

As part of the project, growers experiencing nematode issues in their crops were encouraged to send in soil samples for diagnostics. During the project, 61 soil samples were received from sweetpotato growers with nematode problems. Soil samples were collected and processed to determine the number of plant-parasitic nematodes present and whether these nematodes could be impacting yield and marketable product. Damaged and mishappen sweetpotatoes and root material was also received to assist with diagnosing plant-parasitic nematode problems.

Of the 61 soil samples, a limited number were selected for ongoing follow-up activities. Four blocks in northern NSW and seven blocks in Central Qld were monitored. Case studies of individual growers where numbers of either RKN or reniform nematode had changed, are presented in Appendix 6.

Initial soil survey

At the commencement of this project, sixty soil samples were taken from commercial sweetpotato farms across east coast growing districts and sent to the Department of Environment and Science (DES), Chemistry Centre for analysis. Analyses undertaken (Appendix 5), were, pH, Electrical conductivity (EC), Chloride (Cl), Nitrate- Nitrogen (NO3- 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.

Control of weeds and volunteers

Detailed reports can be found in Appendices 8 to 11.

Weed Surveys of Bundaberg and Cudgen Sweetpotato Farms

Surveys of commonly occurring weeds in sweetpotato crops were made at intervals from November 2019 – September 2022 at both Cudgen and Bundaberg. The weeds were identified to species or genus level and the nematode-host database, Nemaplex, was used to determine if the most commonly occurring weeds identified, were root knot nematode hosts. As this is a large database with multiple entries for many species, some conflicting host status has been reported, no doubt due to genetic, edaphic and climatic factors affecting both plant and nematode. The methodology and results of this survey are reported in detail in Appendix 8.

Controlling weeds and volunteers with herbicides

During rotations nematode host weeds and sweetpotato volunteers must be effectively managed. Three herbicide pot trials were conducted. Two studied the residual effect of herbicides on sweetpotato growth and one the use of herbicides to control sweetpotato volunteers. The methodology and results of this survey are reported in detail in Appendix 9.

Trial 1 – to assess control of sweetpotato volunteers Two pre-emergent (metolachlor and pendimethalin), four pre- and post-emergent (imazethapyr, oxyfluorfen, prometryn and terbuthylazine) and six post-emergent (2,4-DB, glyphosate, dicamba, fluroxypyr, glusosinate ammonium and MCPA) herbicides were tested.

Trial 2 - to assess residual effect of pre-plant herbicides on sweetpotato cuttings Randomized block design with 13 treatments and four replicates. Herbicides registered for Ipomea sp weeds.

Trial 3 – to assess plant back effect of specific herbicides selected by sweetpotato growers Randomized block design with 3 herbicide treatments (halosulfuron-methyl, simazine and the mixture triclopyr, picloram and aminopyralid) plus a nil herbicide control and three planting periods replicated four times.

Cover crops and nematode resistance screening

Resistance screening of suitable cover crops and sweetpotato varieties

Host range studies in the glasshouse screened 103 cultivars from 33 plant species for resistance to two species of RKN (Meloidogyne incognita and *M. javanica*), reniform nematode, (7 cultivars screened from 7 plant species) and lesion nematode (*Pratylenchus zeae* - 10 cultivars from 2 plant species). Twenty-four cultivars of sweetpotato were screened for resistance to two species of RKN and six of the commonly grown cultivars of sweetpotato were screened for resistance to reniform nematode. Methodology is reported in detail in Appendix 3 and results in Appendix 12.

Biofumigant cover crop demonstration.

In some sectors of the vegetable industry, biofumigation is being promoted to reduce populations of nematodes and soilborne pathogens. A grower demonstration site was selected in Bundaberg and planted to eight different winter cover crops with a bare fallow used as a control. Cover crops were chosen based on seasonal suitability and seed availability. Cover crops in the demonstration trial included a mix of Terranova Radish and Saia Oats, Terranova Radish, Saia Oats, Genie Oats, Nemsol (Terranova radish and Nemat), Fungisol (Terranova radish and Ethiopian mustard), Bare Fallow, Caliente and White French millet. Prior to planting, a representative soil sample was taken from each treatment for nematode extraction. The block was planted on the 21st of May 2020. The soil was sampled at 13 weeks after planting and before and after biofumigant incorporation. A biomass assessment was conducted on the 2nd of September 2020, samples were placed into oven drying facilities at 60°C, ground then analysed for glucosinolates.

Effects of biofumigants on survival of Meloidogyne javanica in field soil

This study assessed the impact of biofumigants on nematode survival in a highly controlled setting. Red ferrosol soil from the Redlands Research Station, Brisbane, was treated with ground vegetative material from brassica cultivars Caliente (Indian mustard), Nemat (Rocket), Terranova radish (Radish) and Cappuccino (Ethiopian mustard) before incorporation. A ground oats treatment was added to the experiment to simulate organic matter treatment without a biofumigation effect. Pots were then inoculated with live juvenile RKN and the soil surface left sealed or unsealed for 72 hours after which live nematodes were extracted over four days.

Effects of rand RKN infection on sweetpotato - long term pot trials

To determine the effects of reniform nematode (*Rotylenchulus reniformis)* and RKN species (*M. javanica)* on storage roots, two individual long term pot trials were conducted in 2022 at the Bundaberg Research Facility plant house. Reports on each of these trials can be found in Appendix 19 & 20. Each trial was designed to investigate the damage to skin quality caused by reniform and RKN on the storage roots of two sweetpotato cultivars Beauregard and Bellevue. The trials comprised two treatments (inoculated and control) and six replicates. Plants were w inoculated with juvenile *R. reniformis* and *M. javanica* nematodes by applying 100g of infested roots mixed with 200ml of nematology sand mix. The pot trials were grown according to best sweetpotato practice to commercial harvest or 132 days.

Integrated nematode management, long term trials

Two long-term field trials were conducted at Bundaberg Research Facility from November 2018 to June 2023 to test the feasibility of using integrated management practices to minimise losses caused by RKN (and potentially other plant-parasitic nematodes), while improving soil biological health. Longer-term trials were required for these investigations as improvements in soil biological health may not be seen immediately.

A number of parameters were monitored throughout the life of the trial including populations of plant parasitic and free-living nematodes, microarthropods and nematode trapping fungi, as well as soil physical and chemical properties. Crop assessment parameters included yield, nematode damage and root defects. A summary of each trial with more comprehensive methodology and results provided in Appendices 15 to 18.

Intensive trial Integrated Nematode Management Long term trial

Followed conventional sweetpotato best practice with relatively high rates of organic amendments at bed formation. A forage sorghum rotation was utilised in all plots between sweetpotato crops. The trial comprised five replicates of five soil amendment/nematicide treatments. Randomised complete block design. Four harvests were completed in the five years of the trial.

Extensive trial – Sustainable Farming Systems long term trial

Incorporated minimum tillage (pre-formed beds) with organic amendments and crop rotations of grasses, legumes and brassicas. The trial comprised four replicates of 10 treatments made up as a factorial of two factors. The trial was laid out as a randomised complete block. Three harvests were completed in the five years of the trial.

Efficacy of currently registered nematicides

The sweetpotato industry has limited nematicides and fumigants available for nematode control. In response to industry priorities, two trials were designed to evaluate the efficacy of currently registered nematicides for RKN control over the long winter growing period. A detailed report on this trial can be found at Appendix 21. Trial one was conducted a sandy loam and Trial two on a red clay soil. Efficacy was assessed by monitoring nematode populations and crop yield assessments at commercial harvest.

Trials were designed as a randomised block with six (Trial1) or eight replicates (Trial 2). Treatments included Vydate, Metham Sodium, a Nimitz standard application, a Nimitz alternative application, a nil control treatment and in Trial 2 the addition of a bare fallow and a Salibro standard application and a Salibro alternate application.

Results and discussion

The following is a summary of the results and key findings generated from the PW17001 program. Due to the volume and complexity of the work delivered, individual reports on each component are detailed in Appendices 1-21.

Extension of current knowledge on soil health and nematode management

Detailed reports can be found in Appendix 1

Sweetpotato Soil health Masterclasses

51 growers and stakeholders attended Sweetpotato soil health Masterclasses held in Cudgen, Bundaberg and Atherton (Kairi). A 92-page handbook 'Sweetpotato Masterclass – Soil health and Integrated nematode management' and 11 fact sheets were developed for the workshop. In Cudgen a peer grower, actively involved in improving soil health on his farm, presented to the class. Feedback indicated that 80% rated the event as excellent quality, 20% rated it as good quality. 82% said the event was highly relevant to their business and 18% said the event was mostly relevant.

Nematology skills transfer

Four nematology training workshops were attended by new DAF, nematology staff, DAF sweetpotato team members and a technician from Central Queensland University (CQU). Attendees gained knowledge on soil sampling protocols, nematode lifecycles and the nematode extraction process. A seminar was held at DAF Ecosciences precinct (ESP) for visiting nematologists from Louisiana State University, Prof. Charles Overstreet and Prof. Ed McGawley, in December 2018. The project team facilitated visits to sweetpotato farms in the Cudgen (NSW) and a soil health trial site (managed by BCP).

Collation of historical results

Over 500 sweetpotato soil samples were received at the DAF Nematology Diagnostic Laboratory between April 2010 and August 2013 were collated. Reniform nematode was recovered from some blocks from the Central Queensland and the Bundaberg areas. Meloidogyne spp. (RKN) were present in samples received from Central Queensland, Bundaberg and Cudgen. Many field trials had been carried out at the Bundaberg Research Facility where there were high numbers of both reniform and RKN.

Survey of current grower practices

Over 40 individual on farm surveys were conducted from October 2018 to August 2019. Block rotation times varied between 6 months and 5 years, with an average of 2 years. Results are contained in Appendix 1.

Sweetpotato field surveys

Initial Survey of Plant parasitic nematodes in sweetpotato production.

A report on results is contained in Appendix 3. A total of 85 fields were sampled across the Wide Bay, northern NSW, Central Qld, Southeast Qld, and North Qld regions, with over 90 samples processed by the DAF nematology team. Eighty soil samples were sent to SARDI for molecular identification of RKN. Results show that RKN (primarily *Meloidogyne incognita* and *M. javanica*) is widespread across growing regions. A new detection of *R. reniformis* during the survey is believed to be the most southerly recording of this species in Australia to date thus extending the known geographic range of this species.

The regions with the most mixed populations were Wide Bay and northern NSW with mixes of M. javanica/*M. incognita* and *M. javanica*/*M. arenaria* in Wide Bay and *M. javanica*/*M. incognita*, *M. javanica*/*M. hapla* and *M. incognita*/*M. hapla* in northern NSW. *M. javanica*, *M. incognita* and *M. hapla* were all found as single species populations in the different regions, but *M. arenaria* was only found in a mixed population (with *M. javanica*) during this initial survey. Growers now have a greater understanding of the plant-parasitic nematodes in each of the growing regions and of the ones causing the impacts to crop yield and damage. Individual growers have been informed which nematode species are present on their farms.

Development of PreDicta SP, a nematode/soil biology diagnostic service

Comparison of the SARDI molecular results and DAF traditional techniques from the initial surveys showed a very poor correlation between manual counts and the molecular results for samples with relatively low root-knot populations. As a consequence of these results, consideration of costs and benefits and discussions with the Project reference group (PRG), a decision was made to utilize traditional manual counts for the duration of the project and not to pursue a PreDicta system for the sweetpotato industry at this point (Appendix 3).

Biosecurity issues

The initial survey identified reniform nematode in the Lockyer Valley, this detection is believed to be the most southerly recording of this species in Australia to date and indicates that reniform nematode appears to be extending its geographical range.

During the course of the project, Guava root-knot nematode (GRKN) was detected in Australia for the first time. The initial detection was in the Northern Territory in September 2022, and this was followed by a north Queensland detection in December 2022 and a further positive sample from the Wide Bay-Burnett region in January 2023. This pest is a risk to sustainable sweetpotato production in Australia and has already had a significant impact on the crop in the United States. Following the notification from the Northern Territory, a pest alert on GRKN and on farm biosecurity to stop the spread of any plant-parasitic nematodes was quickly drawn up and circulated via the ASPG executive officer (see Appendix 22).

Further nematode surveys

To gain a better understanding of plant-parasitic nematode dynamics under different management systems, Intensive sampling (Appendix 4). of selected fields was conducted. Many growers were able to reduce RKN numbers. But three of four sites had no reduction in reniform nematode, while one site saw an increase in RKN numbers. Results from follow up monitoring of fields affected by persistent nematode infections (Appendix 6), indicated that where there were high numbers of reniform nematodes (blocks in Qld), there were low numbers of RKN and vice versa. During the project, 61 plant and soil diagnostic samples were received from sweetpotato growers experiencing nematode problems in their blocks (Appendix7).

Results provide individual growers with information on nematode species in their blocks and changes over time, giving validation (or not) of on-farm management practices to control plant-parasitic nematodes. Diagnostic investigations increase the knowledge of nematode distribution for growers and researchers.

Initial Survey of sweetpotato producing soils

Results indicate that sweetpotato production occurs on a wide range of soil types. Particle size analysis showed that sixty soils had clay contents ranging from 1.2% to 72% and fine sand content ranging from 6% to 57% across all sites. The anticipated correlation between low numbers of nematodes and high clay content soils was not seen in this set of samples. Ferrosols are a favored soil for sweetpotato production in Australia, and though these have a clay content of over 50%, their open physical structure is very conducive to RKN survival and reproduction. Total Organic Carbon (TOC) in the two main growing areas ranged from 0.21% to 2.35% in Bundaberg and 2.00% to 3.72% in Cudgen, with this higher average, due in part to cooler temperatures and higher rainfall. Results were sent to individual growers along with a soil results interpretation guide, prepared by team members. See appendix 5.

A sample taken from remnant vine scrub soil, gave a result of 7.22% TOC. This area has not been disturbed since white settlement and should have the highest possible carbon storage potential for the area. A sample taken from the undisturbed tree line established at least 30 years ago, gave a result of 5.22% TOC and a sample taken from a best grower practice farm, gave a result of 1.85% TOC.

Control of volunteers and weeds

Weed Surveys of Bundaberg and Cudgen Sweetpotato Farms

Surveys of commonly occurring weeds in sweetpotato crops were made at intervals from November 2019 – September 2022 at both Cudgen and Bundaberg. A table has been produced identifying these weeds and their susceptibility to RKN (Appendix 8).

Ad hoc sampling of weeds in field trials and during grower visits revealed the presence of RKN on many common horticultural weeds and demonstrated the very wide host range of the pests. Even relatively poor hosts can allow RKN to persist in a field at elevated levels between sweetpotato crops, so control of weeds in a resistant cover crop or bare fallows and resistant rotations is essential. As RKN have a very wide host range all weeds should be considered hosts.

Controlling weeds and volunteers with herbicides

Trial 1 results indicated that that sweetpotato is sensitive to many herbicides, (Appendix 9). Thus growers must be aware of plant back periods, particularly when controlling weeds prior to planting. Glyphosate was the only post-emergent herbicide that showed no plant-back effect on sweetpotato. Other herbicides were destructive over all planting periods. Several pre-emergent herbicides, while not showing visual affects to the vines, affected early storage root development. This trial highlights the need to carefully consider herbicide use in pre- sweetpotato crop rotations or weed management near planting.

Trial 2 studied the residual effects of herbicide applications used in pre plant land management on sweetpotato cuttings (Appendix 10). Though Post-emergent herbicides did kill vines emerging from the sweetpotato roots, due to slow growth from cold weather the trial was not extended to look at vine regrowth. It is not expected that non-translocated herbicides such Glusosinate ammonium would control regrowth. Trial 3 looked at the plant back effect of herbicides recommended by the PRG - Halosulfuron-methyl, Simazine and the mixture Triclopyr, Picloram and Aminopyralid. Due to an early onset wet season the pots became waterlogged and no herbicide effects were observed.

A report '*Herbicides: a review of possible products for the Australian sweetpotato industry*' reviewed herbicide usage in global commercial sweetpotato production systems, (Appendix 11). The review found that whilst no single herbicide will control all problem weeds, some products could increase Mode of Action groups available to the Australian industry, reducing the potential for herbicide resistance.

Cover crops and nematode resistance screening

Resistance screening of cover crops

Additional information can be found in appendix 12 and in the Lucid key developed during this project.

Thirty-six varieties were resistant or highly resistant to M. incognita, M. javanica or both. This includes 2 brassicas, 13 legumes and 14 grasses resistant to M. incognita and 8 legumes and 14 grasses resistant to M. javanica. Cultivars of eight legumes (ground nut, sunn hemp and pigeon pea) two oats, three grasses and three forage sorghums were resistant to both M. incognita and M. javanica making these cultivars excellent rotation crops to reduce RKN numbers when the species is unknown.

Resistance screening of sweetpotato varieties

Twenty four sweetpotato cultivars were screened for resistance to RKN (*M. i and M. j*) and six commercial cultivars were screened for reniform nematode. Two sweetpotato cultivars were resistant to *M. incognita* while 13 were resistant to *M. javanica*. One sweetpotato cultivar of the six screened was resistant to *R. reniformis.*

Cover crop demonstration trial

While the different cover crop treatments (Terranova Radish and Saia Oats, Saia Oats, Genie Oats, Nemsol (Terranova radish and Nemat), Fungisol (Terranova radish and Ethiopian mustard), Bare Fallow, Caliente and White French millet) showed a reduction of RKN between sampling periods, the results must be looked at with caution. This was a non-replicated observation block, so cannot be interpreted by a statistician. There is a possibility that cooler winter temperatures and sampling variation (patchy distribution of RKN populations) could be a source of lower counts. The Brassica cover crop species attracted large populations of various insect pests and required more water than other rotation crops making them less attractive for some growers. Pot trials were undertaken (Appendix 14) determine the effect of each of the 5 glucosinolate compounds on RKN or whether total glucosinolate levels are effective for RKN control.

The effects of biofumigants on the survival of Meloidogyne javanica in field soil

Indian Mustard (cv. Caliente) showed significant potential in reducing RKN numbers. Further trials, especially in pot and field settings, are recommended to confirm the practical application of biofumigants in nematode management.

Integrated nematode management, long term trials

Nematode population monitoring

High rates of certain organic amendments have the potential for effective RKN control as well as improved yield and long-term soil health benefits. RKN control was achieved by treatments comprising high rates of banded organic amendments (applied just prior to planting at bed formation), combined with a resistant rotation crop. Ideally, these practices should be combined with other components - such as nematode monitoring, volunteer control and use of resistant sweetpotato cultivars. Vigilance in on-farm biosecurity is critical to avoid introduction of new nematode pests which may be more difficult to manage. Figure 2 below demonstrates the inverse relationship between root-knot nematode and free-living nematode numbers at the second sweetpotato harvest. The organic matter treatment has significantly less RKN and significantly more free-living nematodes than all other treatments.

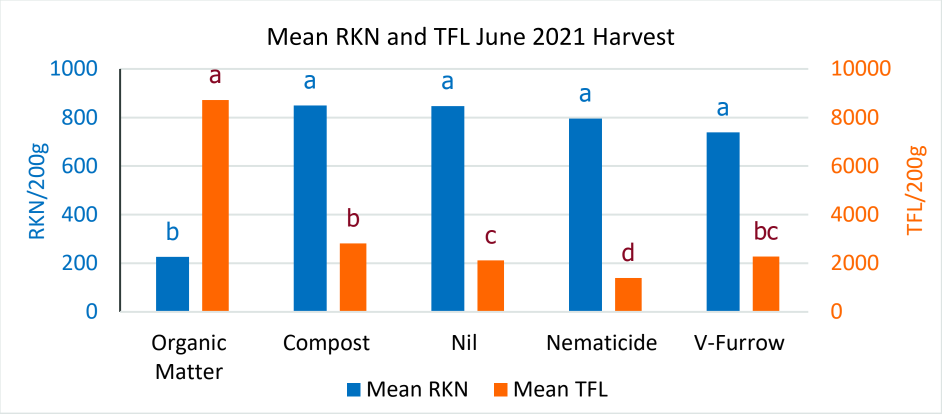

Figure 1 Mean root-knot and total free-living nematode counts (per 200g dry soil) at the second intensive trial harvest, June 2021.

Biological Suppression assays in the Intensive Trial.

Suppression assays investigated the nature of the apparent RKN suppression in some treatments in the intensive trial, following the addition of high rates of organic matter (Appendix 15).

Intact Core Assay: Analysis of the *P. zeae* counts showed no significant difference between the trial treatments, but all treatments had significantly less surviving *P. zeae* than the heat-treated soils. This indicates that biological factors are suppressing nematodes, as the heat treatment regime is sufficient to kill most organisms in the soil. Less *P. zeae* survived in field trial treatments with organic amendments (compared with the nil and nematicide treatments), but this trend was not statistically significant.

Pot Bioassays: Analysis of the RKN egg numbers recovered from the root systems of the bioassay plants showed no significant difference between the heat-treated soils and the non-heated soils, nor between any of the field trial treatments. However, there was significantly greater root galling in the plants grown in heat-treated soil. This finding supports a biological mechanism of RKN suppression at the trial site, but the assay was unable to demonstrate a difference between field trial treatments.

Soil monitoring as an indicator for soil health

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 (see Appendix 16). 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, NO_3N, TOC%, and PPOC%. Initial statistical analysis indicates this becomes increasingly uncertain as further modelling is done.

Biological monitoring

In the Intensive trial, microarthropod populations increased with buildup of organic matter from amendments and rotation crop (White French Millet/Jumbo Sorghum) prior to planting of first commercial sweetpotato crop (see Appendix 17 for full report). Increased presence of Nematode trapping fungi may be attributed to build-up of plant litter and organic matter in the soil. Presence of conidia (NTF fruiting body) was evident with buildup of organic matter in the soil. NTF traps nematodes, but only when their food source had been exhausted.

In the Extensive trial, mean microarthropod count increased in the double and incorporated amendment treatments. The increase can be attributed to build-up of plant litter and organic matter in the soil from application of amendments and cover crop Presence of NTF was high on first assessment due to the buildup of litter and cover crop and no tillage.

Crop yield and quality

Plants grown in the organic matter treatments had significantly lower incidences of nematode related defects and higher yields. However, roots grown in the amended treatments had significantly higher incidence wireworm damage in some years and significantly higher incidence or rots during wetter seasons.

Long term pot trials to determine the effects of reniform and RKN infection on two sweetpotato varieties.

Trial 1 Effects of reniform nematode

R. reniformis inoculated pots produced a lower number of roots compared to the uninoculated control plants, (Appendix 19). However, the overall mean weight of roots from inoculated pots was significantly higher than those grown in the uninoculated pots. This may suggest that damage occurs at root formation, supporting published findings that Reniform nematode feed on fibrous roots not storage roots with a diameter larger than 5 to 10mm. This could result in an increase in oversized roots leading to economic losses due to downgrading.

Trial 2 Effects of RKN (M. javanica)

Results are presented in Appendix 20. The mean *M. Javanica* count in pots from Beauregard plants was more than 3 times that of the pots containing Bellevue plants, indicating RKN reproduce more readily on Beauregard than Bellevue. Results indicated that, the higher the *M. javanica* population in the pot soil, the lower the number of premium roots and the higher the percentage of non-marketable roots.

Infection with *M. javanica* reduced both the number of roots produced and the overall weight of roots and was associated with reduced marketability, ultimately negatively impacting crop value.

Efficacy of registered Nematicides

Field trial 1 Sandy soil

Nematode monitoring

The site where this trial was located has a sandy loam soil which can be more conducive to rapid build-up of RKN populations than some other soil types. Although nematicidal effects had broken down by end of trial, nematicides appear to have given sufficient protection during the growth of the crop to allow increased marketable yield and reduction of some defects associated with nematode infection.

Biological monitoring

Data was collected on 5 occasions, see Appendix 21.

Microarthropods. The results from the combined analysis suggest there is a significant main effect of collection date ($p < 0.001$), but the main effect of treatment was not significant ($p = 0.334$), nor was the interaction of collection date and treatment ($p = 0.893$). Mean count of microarthropods increased significantly over time, with the last two assessments having significantly higher mean counts. Decline of microarthropods on 29-Jun-21 may be attributed to nematicide application. Nematicides, pesticides and fertilizers, have proven to reduce microarthropods population and or the soil microbiological community (Winter et al 1990, Seymour 2006, Stirling 2016).

NTF. A total of 600 plates were assessed for the five occasions of sampling. Only 16 plates out of 600 had trapping present: 3 Vydate, 3 Metham, 4 Nimitz, 2 Nil and 4 Nimitz trickle. No conidia were recorded.

Crop yield and quality

All treatments had a significantly lower mean percentage of blind pimples in large and medium sized roots than Nil plots. Analysis of yield data showed that all nematicide treatments had significantly higher marketable yield than the nil treatment. Metham Sodium and Vydate also had significantly higher total yield than other treatments. There were also significant differences for certain defects that can be associated with nematode damage. For example, all nematicide treatments also had significantly less barnacle lesions than the nil control. In the medium size category, all nematicide treatments also had significantly less blind pimple lesions compared with the nil treatment.

Field Trial 2 Red clay soil

Nematode monitoring

For RKN, the Nimitz alternative application provided the most consistent control for the duration of this trial. Vydate was very similar in performance, except for the August sampling where mean counts were not statistically different from the untreated control. Nimitz standard application, Salibro and the Salibro alternative application RKN counts were not significantly different from the nil control at any of the 4 sampling points. The alternative Nimitz application also provided the most consistent control for reniform nematode. Vydate and the alternative Salibro application provided significant reniform nematode control for much of the trial period. In the bare fallow treatment, the RKN population dropped to low levels without a susceptible host, as expected. Reniform nematode numbers also dropped in the bare fallow but were still at relatively high levels (around 200 per 200g dry soil) at the final sampling, possibly reflecting the differing life cycles and survival strategies of the two species. Free-living nematode populations were impacted by some of the nematicides in the mid-trial period, but at the final sampling there were no significant differences between treatments in total free-living nematode counts. Many free-living nematodes have a very short life cycle, so can rapidly recover their populations when chemical effects have dissipated. Free-living nematode counts in the bare fallow treatment were not significantly different from those in the nil control sweetpotato crop.

Biological monitoring

Microarthropod Counts. No significant treatment effect was detected at the first assessment on 7/3/2023 after Nimitz. However, there was a significant treatment effect at the second assessment on 28/8/2023. Microarthropod populations were higher in the first assessment mixed cover crop and a period of no tillage. However, the population dropped in the second assessment, which may be attributed to agronomic practices as all nematicide treatments are not significantly different to the nil treatment.

At the second assessment, Low counts of NTF and Conidia prevented valid statistical analysis of this aspect of the trial. Results from the analysis of the first assessment on 7/03/2023 found no significant difference between the treatments. Conidia were only observed on 4 plates from the 28/8/2023 sampling. These were 3 Vydate plates from the same plot and 1 Nil plate. A third assessment was completed at harvest. Based on the mean counts for all assessments, microarthropod populations started increasing for Nil treatment, Nimitz, Vydate and Salibro alternate by the last sampling date, (see Appendix 21).

Crop yield and quality

The Vydate and Metham treated plots produced a higher weight of total and medium sized roots, more roots. and a significantly lower incidence of nematode cracks and black pimples. Roots grown in the Nil and Nimitz treated plots were lower in weight and number than all other treatments except the Nimitz alternative treatment. Roots grown in the Metham treated plots had a significantly higher occurrence of wireworm damage.

Outputs

Table 1. Output summary

Output	Description	Detail
A program logic, monitoring and evaluation plan. A project risk register. A stakeholder engagement plan	A program logic with linkage to Hort Innovation and industry/fund objectives. A monitoring and evaluation plan, project risk register, stakeholder engagement plan were developed early in the project. Formation of a PRG - members: Matthew Prichard, Eric Coleman, Russell McCrystal, Rodney Wolfenden, Darren Zunker, Steve Paddon.	Reported in milestone 102. Six monthly milestone reports Milestones 102, 103, 104, 105, 106, 107, 108, 109 and 110 were all submitted throughout the project. on time and approved by Horticulture Innovation. 10 PRG meetings held over the life of the project
Sweetpotato nematode and soil health masterclass series and supporting documents	4 Masterclass events across key sweetpotato growing regions. 92-page handbook 'Sweetpotato Masterclass – Soil health and Integrated nematode management' for all participants 11 factsheets – Attachment 1 (covering nematode management, soil health and nematicides).	Four Masterclasses delivered (Cudgen, Bundaberg x 2 and Atherton) attended by 51 growers and stakeholders (report in Appendix 1). Handbook containing fact sheets in Attachment 1. Results reported in ASPG project newsletters (project PW21000) and project updates.
Increase in sweetpotato and nematology specific research capacity	Workshops for project team Seminars for project team	Four nematology training workshops were conducted in 2018 (Appendix 1).
Nematode survey program reports – type and distribution of pest nematodes in sweetpotato production regions.	Nematode survey protocols and soil sampling guide for project team Initial nematode species and distribution report for industry (Appendix 3). Intensive surveys, follow up and diagnostic sampling reports - farm specific and provided to individual growers (Appendices 4, 6 and 7).	Distributed to team members. Reports can be found at Appendices 3, 4, 6 and 7 and will be provided to ASPG for publication on the ASPG website.
	Biosecurity Qld notification of extension of range for *R. reniformis*.	Biosecurity Qld notification sent.
Grower practice surveys	Over 40 on farm surveys current grower practices conducted from October 2019 to August 2019, with a focus on nematode control, cover crops and soil health.	A report is contained within Appendix 1. Results were reported in ASPG project newsletters and project updates.
Soil surveys in sweetpotato fields.	65 Soil surveys of individual farms and undisturbed environments.	A report can be found at Appendix 5.
Field and pot experiment reports. Integrated nematode management systems for sweetpotato.	Reports - two long term pot trials completed in January 2023 Trial 1 *Effects of reniform nematode on two sweetpotato cultivars.* Trial 2 *Effects of RKN (M. javanica) on two sweetpotato cultivars.*	Trial 1 reported in Appendix 19. Trial 2 reported in Appendix 20. Reports provided to growers at field days and project updates, to the PRG and the ASPG executive officer for publication on the ASPG website and as part of industry newsletters.
	Report written on Identification of nematode resistance of summer and winter rotation/cover crops cover crops suitable for sweetpotato farming systems. Report written on nematode resistance screening of sweetpotato varieties.	Reports and tables in Appendix 12. Results/reports made available through milestone reports, provided to growers at field days and project updates, PRG. and in industry newsletters.
	Report on cover crop demonstration trial	Report on cover crop demonstration (Appendix 13) provided within milestone reports, and project updates and industry newsletter.
	On farm control of weeds and volunteers. Report: '*Controlling sweetpotato volunteers with herbicides'*. Report '*The effect of pre-plant herbicide application on growth of sweetpotato cuttings'*.	Report provided to the ASPG executive officer for publication on the ASPG website December 2020 (Appendix 9). Report provided to the ASPG executive officer for publication on the ASPG website June 2021 (Appendix 10).
	Herbicide review: '*Herbicides: a review of possible products for the Australian sweetpotato industry'*	Review can be found at Appendix 11.
	Report on survey of weeds in sweetpotato crops (Cudgen and Bundaberg 2019 to 2023).	Report can be found in Appendix 8. Distributed at grower meetings in November 2023
	Report on two long-term field trials were conducted at Bundaberg Research Facility November 2018 to June 2023. 1. The Intensive trial (Integrated Nematode Management) 2. The Extensive trial (Sustainable farming systems)	Reports on Intensive and Extensive trials are contained within in Appendices: 1. Appendix 15 - Nematode population monitoring and suppression assays (), 2. Appendix 16 - Soil physical and chemical properties (), 3. Appendix 17 - Biological monitoring (), 4. Appendix 18 - Yield and quality assessments (). All reports will be made available to growers, the PRG and the ASPG executive officer for publication on the ASPG website once the final report is accepted.
	Report on two nematicide trials	Report on nematicide trials can be found at Appendix 21. Preliminary results presented at a grower meeting in Bundaberg, November 2023.
Industry updates and field walks	Experimental results were reported to growers at field days and project updates. 2018 December 18th Cudgen, project update. 2019 March 5th Bundaberg, project update	Attended by 80% of industry. Reports were made available through milestone reports, provided to growers at field days and project updates, to the PRG and the

	2019 July 25th Cudgen growers visited Bundy trial site. 2019 August 14th Bundaberg field day 2020 June 11th Virtual project update and remote field walk. 2021 June 3rd Bundaberg project update, no field walk on station due to Covid. 2021 October 20th Bundaberg 2022 November 17th Bundaberg project update 2022 December 14th Cudgen project update. 2023 November 21st Cudgen project update. 2023 November 23rd Bundaberg project update.	ASPG executive officer for publication on the ASPG website and as part of industry newsletters.
Communication products factsheets, case studies, decision support tools	Eleven nematode fact sheets developed for the Masterclasses: *1. The life history of RKN* *2. Nematode population dynamics and damage thresholds* *3. Impact of environmental factors on nematode survival and multiplication* *4. Nematode monitoring as a management tool* *5. Soil organisms and the soil food web* *6. Beneficial organisms, bacteria, fungi and free-living nematodes* *7. Plant pathogenic nematode species* *8. The importance of carbon* *9. Sustainable farming systems for healthy soils* *10. Rotation crops, organic amendments and mulching* *11. Minimum tillage, control of volunteers and weeds* *12. Suppressive soils and early bed formation* *13. Resistant cultivars*	Provided to 51 Masterclass participants. Contained within Masterclass workbook.
	On line Lucid key development: Up to date information on crops and their resistance to plant-parasitic nematodes	On line key can be found here: Crop rotations and their resistance to plant-parasitic nematodes - Lucid4 Key Player (lucidcentral.org)
	Three herbicide fact sheets produced: 1. *Herbicides what are they?* 2. *Herbicide performance - environmental factors.* 3. *Herbicides - changes to modes of action*.	Facts sheets 1 and 2, provided to the ASPG executive officer for publication on the ASPG website, October 2020. Fact sheet 3, Provided to the ASPG executive officer for publication on the ASPG website, December 2021.
	One nematicide fact sheet produced: *1. Nematicides and sweetpotato*	Fact sheet 4, Provided to the ASPG executive officer for publication on the ASPG website, August 2022.
	Pest alert fact sheet developed for GRKN.	GRKN pest alert fact sheet made available to the ASPG and for distribution to growers November 2022.
	A tabulated list of weed species and their nematode host status.	Report and tabulated list of weed hosts can be found in Appendix 8. Distributed at grower meetings in November 2023
	Up to date tables of rotation crops and sweetpotato cultivars. Six case studies – Intensive nematode surveys	Provided as part of Appendix 12. Tables provided to and ASPG executive officer for publication on website in February 2021, April 2021, February 2022, July 2022 and April 2023 Provided as part of Appendix 4.
	A soil test results interpretation guide produced.	Report at Appendix 5.
Industry newsletter	8 project updates written for ASPG newsletter covering updates on current and ongoing project activities and experiments.	December 2018, June 2019, December 2019, December 2020, June 2022, November 2022, April 2023, September 2023.
Conference presentations	Conference presentations over the life of the project. ‘*Resistant rotation crops to reduce root-knot nematodes in sweetpotato production’*. Presented at the 21st Australasian Plant Pathology Society conference, Tasmania (online conference), November 2021. ‘*Plant -parasitic nematodes in sweetpotato production areas in Australia’*. Presented at the 11th Australasian Soilborne Disease Symposium, Cairns, August 2022. ‘*Glasshouse screening to identify rotation crops resistant to reniform nematode (Rotylenchulus reniformis) for the sweetpotato industry’. Presented at the* 11th Australasian Soilborne Disease Symposium, Cairns, August 2022. ‘*Integrated management of root-knot nematode in sweetpotato*’ Presented at the 11th Australasian Soilborne Disease Symposium, Cairns, August 2022. ‘*Suppression of Root-knot Nematode in Modified Commercial Sweetpotato Production Systems*’ Presented at the 24th Australasian Plant Pathology Society conference, Adelaide, November 2023.	Five conference presentations at: The 21st Australasian Plant Pathology Society conference, Tasmania (online conference), November 2021. The 11th Australasian Soilborne Disease Symposium, Cairns, August 2022. The 24th Australasian Plant Pathology Society conference, Adelaide, November 2023.

Outcomes

Table 2. Outcome summary

Outcome	Alignment to fund outcome, strategy and KPI	Description	Evidence
Sweetpotato producers will have increased knowledge on the benefit of healthy soils to manage nematode pests through masterclasses, masterclass workbook and factsheets.	**Outcome 2** Industry supply, productivity and sustainability. **Strategy 2** Support innovations in sweetpotato growing systems for sustainable production. **KPI:** Feasibility of new growing systems established and evaluated in collaboration with growers. **Strategy 3** Develop and optmise fit for purpose pest and disease management strategies. **KPI** Development of pest and disease management strategies that mitigate crop loss in collaboration with growers.	A series of Sweetpotato soil health masterclasses were conducted to extend current knowledge on nematode management in vegetable crops to sweetpotato farmers, improve grower's understanding of RKN and encourage the development of effective management strategies. Nematology workshops were conducted for project staff to extend knowledge on soil sampling protocols, nematode lifecycles and the nematode extraction process. A survey to capture current grower practices in relation to sweet potato production, with a focus on nematode control, cover crops and soil health. Collation of historical information on nematode species identified form sweetpotato blocks prior to 2018.	Growers and stakeholders have increased understanding of nematode pests and soil health through attendance at the Sweetpotato masterclasses – Integrated nematode management and soil health. Feedback indicated that 80% rated the event as excellent quality, 20% rated it as good quality. 84% said the event was highly relevant to their business and 18% said the event was mostly relevant. Nematology training workshops extended knowledge on nematode field sampling and extraction methods to the project team. Knowledge of grower practices in relation to on farm nematode control.
Increase in the number of farmers developing integrated nematode management systems adapted to their specific farm situation.	**Outcome 2** Industry supply, productivity and sustainability. **Strategy 2** Support innovations in sweetpotato growing systems for sustainable production. **KPI:** Feasibility of new growing systems established and evaluated in collaboration with growers. **Strategy 3** Develop and optmise fit for purpose pest and disease management strategies. **KPI** Development of pest and disease management strategies that mitigate crop loss in collaboration with growers.	Two long-term field trials were conducted at Bundaberg Research Facility November 2018 to June 2023. Trials investigated the applicability of using integrated management practices to minimise losses caused by plant-parasitic nematodes, while improving soil health. The Intensive trial (Integrated Nematode Management) followed conventional sweetpotato best practice with high rates of organic amendments and a RKN resistant forage sorghum rotation. with four commercial harvests in five years. The Extensive trial (Sustainable farming systems) incorporated minimum tillage (pre-formed beds) with high rates of organic amendments and alternate crop rotations with three harvests in five years. Nematicide trials to investigate the efficacy of currently registered nematicides to control nematodes in a long winter season sweetpotato crop in sandy soil (Trial 1) and red soil (Trial 2).	Field walks at the long-term field trials and project updates, (as listed in Outputs), provided growers with firsthand information on the development of integrated nematode management systems on their farms. Growers have increased knowledge on the efficacy of nematicide use during the winter cropping season.
New scientific knowledge generated on species and distribution of pest nematodes in sweetpotato production regions.	**Outcome 2** Industry supply, productivity and sustainability. **Strategy 3** Develop and optmise fit for purpose pest and disease management strategies. **KPI** Development of pest and disease management strategies that mitigate crop loss in collaboration with growers. **Strategy 4,** Improve industry preparedness and resilience to biosecurity threats. **KPI,** this is an additional KPI not listed in SIP.	The first comprehensive nematode survey undertaken in sweetpotato producing soils in Australia. 85 fields sampled: 45 in Wide Bay, 17 in northern NSW, 12 in Central Qld, 6 in Southeast Qld, and 5 in North Qld. 90 samples processed by the DAF nematology. 80 soil samples sent to SARDI (South Australian research and development Institute) molecular identification. Intensive and Follow up surveys along with grower submission of diagnostic samples were also processed by DAF nematology (Appendices 3, 4, 6 and 7.). New detection of *R. reniformis* during the survey in southeast Qld extends the known geographic range of this nematode species.	Individual growers have information on which nematode species are occurring in their blocks empowering them to implement appropriate management strategies. Growers have increased understanding of regional nematode distribution and population dynamics in relation to individual farming systems. Biosecurity Qld notified of extension of range for *R. reniformis.*

New knowledge and increased utilisation of summer and winter cover/rotation crop varieties resistant to the specific nematode pests in individual sweetpotato farming systems and strategies suitable for use in sweetpotato farming systems to manage the dominant pest nematode species in regions.	**Outcome 2** Industry supply, productivity and sustainability. **Strategy 3** Develop and optmise fit for purpose pest and disease management strategies. **KPI** Development of pest and disease management strategies that mitigate crop loss in collaboration with growers. **Strategy 1,** Identify and evaluate varieties that have superior agronomic performance and product quality attributes that meet consumer requirements. **KPI,** Availability of new knowledge on the performance of elite varieties form global programs under Australian conditions.	Glasshouse pot trials screened 103 potential cover crop cultivars from 33 plant species for resistance to two species of RKN (*M. i.* and *M. j.*), reniform and lesion nematode (*P. zeae).* New knowledge on suitability of biofumigants for use as rotation crops in sweetpotato farming systems. Twenty-four sweetpotato varieties screened for resistance to two species of RKN. Six common commercial varieties screened for resistance to reniform nematode.	Growers have up to date information on the resistance status of suitable cover crops and to ensure that rotation crops are effective in reducing plant parasitic nematode numbers. Growers have up to date information on the resistance status of current and newly imported sweetpotato varieties under Australian conditions. Growers have new information on nematode resistance status of commercial and newly imported varieties under Australian conditions.
Improved on-farm control of volunteers and weed nematode hosts.	**Outcome 2** Industry supply, productivity and sustainability. **Strategy 3** Develop and optmise fit for purpose pest and disease management strategies. **KPI** Development of pest and disease management strategies that mitigate crop loss in collaboration with growers.	Survey of commonly occurring weeds in sweetpotato crops in Cudgen and Bundaberg 2019 to 2023. The nematode host status of each weed researched on the Nemaplex website. Three investigations into herbicides to control weeds and volunteers at Appendix, 9 and 10 A review on herbicide usage in international sweetpotato production systems,	Growers have increased understanding of the nematode host potential of all weeds in their commercial crops and rotation blocks, either bare fallow or cover cropped. Growers understand that good weed management is essential to reduce nematode populations. Growers have new knowledge on the efficacy of herbicides to control weeds in sweetpotato crops and the appropriate plant back periods and volunteers in cover crop/fallow blocks. Growers have information on future herbicide options that could be adapted from international sweetpotato production systems.
Changes in growers' knowledge, awareness and attitudes, towards improving soil health and nematode control in sweetpotato production	**Outcome 2** Industry supply, productivity and sustainability. **Strategy 3** Develop and optmise fit for purpose pest and disease management strategies. **KPI** Development of pest and disease management strategies that mitigate crop loss in collaboration with growers.	Soil surveys of individual farms and undisturbed environments were conducted with samples analysed for a range of chemical and physical properties. Changes in soil chemistry were monitored in the long-term trials at BRF and correlated to nematode populations and key soil health indicators.	Growers understand the soil chemical and physical attributes of their farms. Growers have information on maximum achievable TOC levels related to their district. Growers and researchers have an increased understanding of the diverse range of soils supporting sweetpotato production.
		Reports - two long term pot trials completed in January 2023. *Effects of reniform nematode and RKN (M. javanica) on two sweetpotato cultivars*.	Growers and researchers have new knowledge on specific skin damage caused by two species of plant parasitic nematodes.
Increase capacity in sweetpotato and nematode specific research, with the ability to transfer this knowledge to on-farm situations for Industry benefit.	**Outcome 3.** Improved capability and an innovative culture in the Australian sweetpotato industry maximises investments in productivity and demand. **Strategy 1,** Deliver communication and extension capability to create positive change in the areas of sustainable production, pest and disease management, biosecurity, soil health and trade. **KPI,** Increased engagement, awareness and knowledge of RnD project outputs especially in relation to sustainable production, pest and disease management, biosecurity, soil health and trade.	This project has enabled the development of two temporary and casual staff and two scientific assistants to enable them to take on long term roles in DAF.	Enhanced sweetpotato specific research capacity, improved knowledge and experience for DAF to improve grower understanding/knowledge and benefit Industry. Enhanced nematology specific research capacity, improved knowledge and experience for DAF to improve grower understanding/knowledge and benefit Industry.

Monitoring and evaluation

Table 3. Key Evaluation Questions

Key Evaluation Question	**Project performance**	**Continuous improvement opportunities**
< Refer to the M&E Plan >	< Identify aspects of project performance that address the Key Evaluation Questions >	< List opportunities for improvement and future development >
Effectiveness 1. To what extent has the project achieved its expected outcomes?	Growers have increased knowledge on distribution of nematode species and strategies for Integrated nematode management to enhance soil health. Growers have increased knowledge on the efficacy of nematicides and suitable herbicides to control weed hosts and volunteers. New knowledge on resistance status of cover crop species and sweetpotato varieties has given growers the tools to make informed choices on farm.	Don't have up to date nutrient requirements of sweetpotato varieties under Australian conditions e.g., Potassium Phosphorus and high chloride levels. (note some of these may be addressed via PW21002). Findings from pathogenicity screening suggest that different strains of RKN may exist in Australia (to be addressed under PW2200).
Relevance2. How relevant was the project to the needs of intended beneficiaries?	The project has provided growers with new strategies and knowledge to better manage nematode pests on their farms.	Project PW22000 will provide future opportunities for improvement in nematode control strategies.
Process appropriateness 3. How well have intended beneficiaries been engaged in the project?	Eighty % of sweetpotato growers attended extension events, project updates or field walks in Bundaberg and Cudgen. All reports and fact sheets were made available to growers through delivered milestones, provided at field days and project updates, to the PRG and the ASPG executive officer for publication on the ASPG website and as part of industry newsletters. Some growers were engaged in on farm trials and all growers enjoyed the hands-on learning as part of the Sweetpotato masterclasses.	Whilst many growers have upskilled (Zoom and Teams meetings) over this project due to Covid-19 restrictions, future utilisation of social media platforms would make key project findings instantly accessible to growers. Continued on farm visits are crucial for continued engagement and cooperation between project teams and growers.
Efficiency 4. To what extent were engagement processes appropriate to the target audience/s of the project? How accessible were extension events to industry levy payers and did they incorporate their preferred learning style?	Extension events were delivered at local venues including pack sheds, on a suitable day and time most appropriate for busy growers. Information was delivered through power point presentation in an informal setting, followed by opportunity for grower to have one on one and group conversations with the project team. Regular PRG meetings were held to exchange project ideas and gain grower perspectives and technical advice.	Future accessibility through social media through recording of extension events. Project PW21001 would provide an efficient platform for dissemination of key project outputs into the future.
5. What efforts did the project make to improve efficiency?	Project updates and field walks were held in conjunction with ASPG events or concurrent with field work and trial site visits in Bundaberg and Cudgen.	Social media platforms could enhance exposure to key research findings to improve extension efficiencies.

Issues and risks

Whist COVID-19 disease remained a threat, project staff continued to follow recommended practices. Field days and other planned gatherings were replaced by webinars and teleconferences. Field activities were designed to follow recommended social distancing and hygiene protocols. Qld border closures posed restrictions on movement to/from NSW sampling sites. Alternative arrangements were developed including, enlisting local agribusiness staff to conduct soil sampling in the Cudgen area. Posting cover crop seed and trial plans to agribusiness staff to deliver to growers and assist with implementation of NSW grower demonstration sites and delivery of virtual project updates ensured that project work in Cudgen progressed to some degree.

Prolonged adverse weather events such as the drought in 2019 resulted in a decrease in nematode populations across the growing regions. This resulted in a delayed start to the first nematicide efficacy trial. Many blocks were surveyed in an effort to find a trial site with large enough RKN population. Eventually a block was located in conjunction with the PRG and after a rainfall event in 2021, RKN numbers were sufficiently high enough to commence the trial.

High rainfall events in 2022 led to delays in field trial harvests, assessments and incorporation of organic amendments. Planting of the second nematicide trial had to be postponed due to wet weather.

Although *Meloidogyne enterolobii* or Guava Root-knot nematode (GRKN) has not been detected in commercial sweetpotato production areas to date, the DAF sweetpotato research team raised the bar when it came to soil sampling and farm visits, as part of their prevention planning. Strategies included the use of disposable boot covers and gloves for each farm, additional cleaning and alcohol disinfestation of sampling equipment between blocks to remove all soil, using fresh sampling containers in between farms and parking vehicles on paved roadways.

Recommendations

RKN (primarily Meloidogyne incognita and M. javanica) is widespread across the industry and the Reniform nematode (Rotylenchulus reniformis) appears to be extending its geographical range. Pratylenchus zeae was found in 24 out of 85 sites across regions. Spiral nematodes and Rotylenchulus parvus (another reniform nematode) stubby, stunt, ring and dagger nematodes were common, but in low numbers suggesting sweetpotato is not a good host. Where root-knot and reniform nematode were plentiful, it appeared that where there were high numbers of reniform nematode in a block, there were low numbers of root-knot and vice versa.

As root knot nematode have a very wide host range, all weeds should be considered hosts. Control of weeds in a resistant cover crop or bare fallow is essential. Project work highlights the need to carefully consider herbicide use in crop rotations both to kill volunteers and used prior to planting a sweetpotato crop or weed management near planting.

RKN control as well as improved yield and long-term soil health benefits. was achieved by treatments comprising high rates of banded organic amendments (applied just prior to planting at bed formation), combined with a resistant rotation crop. Ideally, these practices should be combined with other components such as nematode monitoring, volunteer control and use of resistant sweetpotato cultivars where required into an integrated nematode management program to deliver consistent crop yield and quality. Vigilance in on-farm biosecurity is critical to avoid introduction of new nematode pests which may be more difficult to manage. However high levels of organic amendments are not recommended in high rainfall seasons due to the association with increased incidence of skin rots.

Reniform nematode became the dominant plant parasite in both of the long-term trials and there was no significant treatment effect at any assessment including those that suppressed RKN. This demonstrates that management strategies that may work for one nematode pest won’t necessarily control another. Compared with RKN, reniform nematode is more difficult to control as it becomes metabolically inactive in dry conditions (enabling it to survive for long periods of time) and can move very deep in the soil profile, avoiding the effects of nematicides and biological suppression. Pot trials however indicated that plant inoculated with R. r produced roots with few visual defects, however damage limited root development. Competitive interactions between reniform and RKN have been reported in the literature and reniform can be favoured in situations where RKN survival between crops is reduced by fallowing or resistant rotations.

The resistance screening expanded the range of suitable rotation options to help manage a range of plant-parasitic nematode pests. The project recommends the following cover/rotation crops be used in sweetpotato production systems: Forage sorghum spp. Jumbo and Sunn hemp found to be resistant or highly resistant to R. reniformis and two species of RKN, (M. incognita and M. javanica) and Swan Oats and Williams oats resistant or highly resistant to two species of RKN, (M. incognita and M. javanica) and Ground nut and soybean cultivars resistant to P.Zeae. Available varieties may frequently change, especially for crops such as forage sorghum.

The project recommends the following as possible future investigations:

- Long term pot trials to evaluate the effects of Australian *M. incognita* populations on Bellevue under Australian conditions including cultivar Beauregard as a control.
- Field trials to evaluate organic amendment treatments in combination with nematicides.
- Investigation into pathogenicity of Australian strains of M. incognita.
- The project notes that access to USA breeding program germplasm is vital for the Australian sweetpotato industry to secure improved varietal tolerances to major sweetpotato pests and diseases primary nematodes.

Refereed scientific publications

Conference presentations.

Cobon, J.A., O'Neill, W.T., Shuey, T., Langenbaker, R., Dennien, S., 2021, Resistant Rotation Crops to reduce root-knot nematodes in sweetpotato production. Oral presentation at the 21st Australasian Plant pathology Society Conference, Tasmania (online conference), November 2021.

Cobon, J.A., O'Neill, W.T., Shuey, T., Langenbaker, R., Dennien, S., 2022. Glasshouse screening to identify rotation crops resistant to reniform nematode (*Rotylenchulus reniformis*) for the sweetpotato industry. Oral presentation at the 11th Australasian Soilborne Disease Symposium, Cairns, August 2022.

Cobon, J.A., O'Neill, W.T., Shuey, T., Langenbaker, R., Dennien, S., 2022. Plant-parasitic nematodes in sweetpotato production areas in Australia. Oral presentation at the 11th Australasian Soilborne Disease Symposium, Cairns, August 2022.

O'Neill, W.T., Cobon, J.A., Shuey, T., Langenbaker, R., Dennien, S.E., 2022. Integrated management of Root-Knot nematode in sweetpotato. Oral presentation at the 11th Australasian Soilborne Disease Symposium, Cairns, August 2022.

Shuey, T., O'Neill, W.T., Cobon, J.A., Langenbaker, R., Day, B., Bobby, J., Firrell, M., Hughes M., Corner, R.D., Pattison, A.B. and Dennien S.E.,.2023 Suppression of Root-knot Nematode in Modified Commercial Sweetpotato Production Systems. Oral presentation at the 24th Australasian Plant pathology Society Conference, Adelaide, November 2023.

On line key development. This key contains all the information to date on crops and their resistance to several species of plant-parasitic nematodes Crop rotations and their resistance to plant-parasitic nematodes - Lucid4 Key Player (lucidcentral.org)

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Intellectual property

No project IP or commercialisation to report.

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Appendix

Glossary of terms and abbreviations

Appendix 1. Extension of current knowledge on soil health and nematode management

Appendix 2. General nematology methods

Appendix 3. Initial survey of plant-parasitic nematodes in sweetpotato production

Appendix 4. Intensive growers’ survey of plant-parasitic nematodes

Appendix 5. Initial Survey of sweetpotato producing soils

Appendix 6. Follow on nematode surveys.

Appendix 7. Diagnostic soil samples recieved

Appendix 8. Weed Surveys of Bundaberg and Cudgen Sweetpotato Farms

Appendix 9. The effect of pre-plant herbicide application on growth of sweetpotato cuttings.

Appendix 10. Controlling sweetpotato volunteers with herbicides

Appendix 11. Herbicides for the Australian sweetpotato industry: a review of possible products

Appendix 12. Nematode resistance screening

Appendix 13. Field evaluation of cover crops

Appendix 14. The effects of biofumigants on the survival of Meloidogyne javanica in field soil

Appendix 15. Sustainable farming systems trials – Nematode population monitoring

Appendix 16. Sustainable farming systems trials - Soil testing as an indicator of soil health improvement

Appendix 17. Sustainable farming systems trials - Biological monitoring

Appendix 18. Sustainable farming systems trials - Crop yield and quality

Appendix 19. The effects of Rotylenchulus reniformis on two sweetpotato cultivars

Appendix 20. The effects of Meloidogyne javanica on two sweetpotato cultivars

Appendix 21. Efficacy of current nematicides

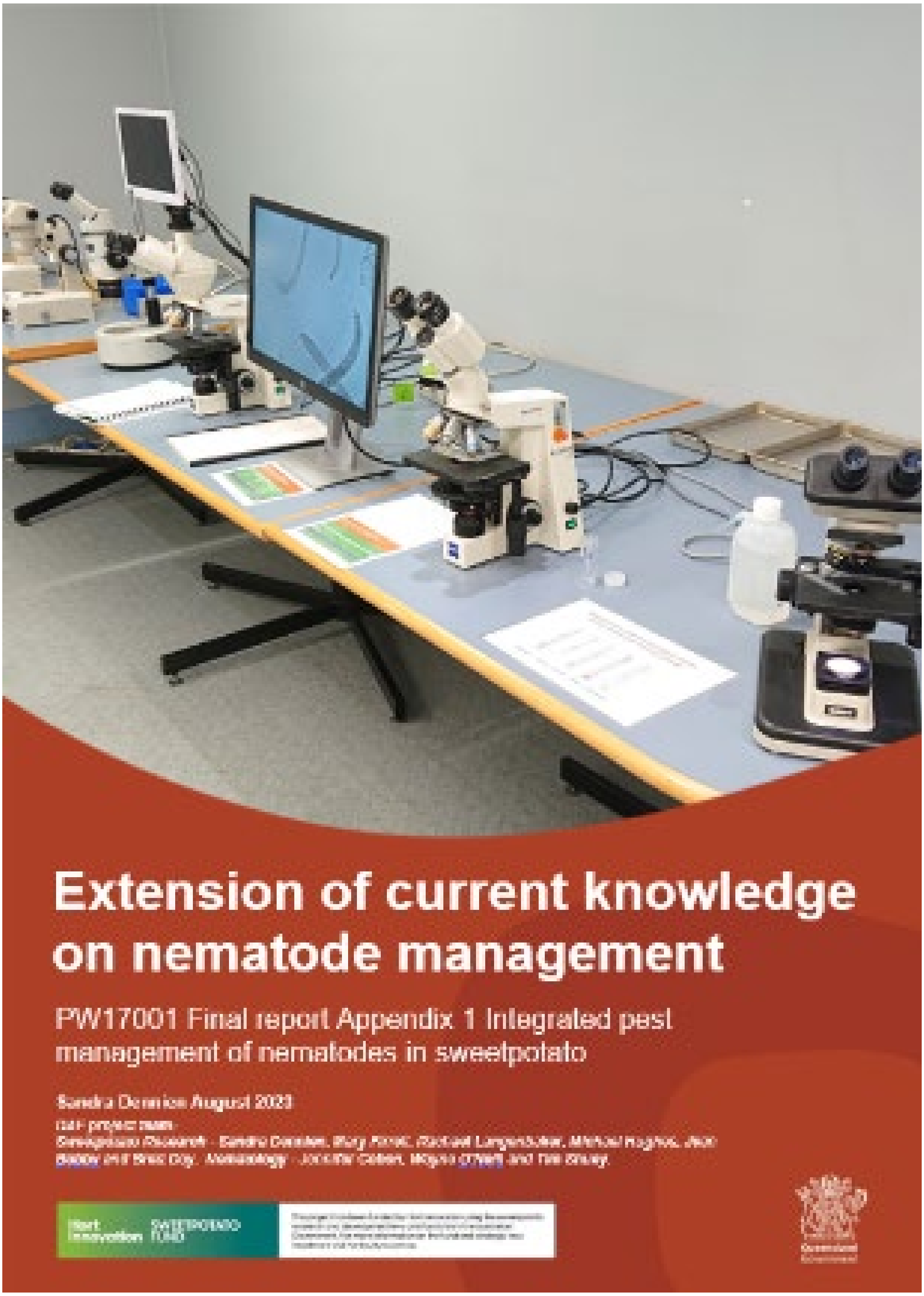
Appendix 22. Conference abstracts

Glossary of terms and abbreviations

ANOVA	Analysis of Variance
ASPG	Australian Sweetpotato Growers Inc.
BRF	Bundaberg Research Facility
Cl	Chloride
DAF	Department of Agriculture and Fisheries
DES	Department of Environment and Science
DLRS	Darkened lateral root scars
EC	Electrical Conductivity
GLM	Generalised Linear Model
GRF	Gatton Research Facility
GRKN	Guava Root-knot Nematode (*Meloidogyne enterolobii*)
HAL	Horticulture Australia Limited
lsd	Least Significant Difference
NO_3-N	Nitrate Nitrogen
NTF	Nematode Trapping Fungi
PBI_COL	Colwell Phosphorous (P) + phosphorus buffer index
POxC (PPOC)	Potassium Permangante Oxidisable Carbon
PRG	Project Reference Group
PSA	Particle Size Analysis
Reniform	Reniform nematode (*Rotylenchus spp*.)
RKN	Root-knot Nematode (*Meloidogyne spp.*)
SARDI	South Australian Research and Development Institute
TFL	Total Free Living (non-plant parasitic nematodes)
TOC	Total Organic Carbon
TN	Total Nitrogen

Appendix 1.

Extension of current knowledge on soil health and nematode management



Extension of current knowledge on nematode management

PW17001 Final report Appendix 1 Integrated pest management of nematodes in sweetpotato

Sandra Dennien August 2023

Introduction

Practices to reduce losses from RKN in vegetable crops are detailed in Hay and Stirling (2014) (Horticulture Australia Limited project MT09067). Little work on nematodes specific to the Australian sweetpotato cropping system had been conducted in the past. HAL project VG09052 conducted commercial scale observational trial comparing the efficacy of Vydate® L by chemigation and the soil incorporation of molasses in conjunction with best bet cover crop management strategies. The project also demonstrated Improved varietal tolerance levels to RKN under Australian conditions with two imported USA varieties, Evangeline and Bienville. (McCrystal, et al., 2014).

There was limited information on which nematode species were occurring in sweetpotato producing soils as no widescale surveys had been conducted. Information on nematode species identified as part of soil sampling within HAL project VG09052, mostly conducted at designated field trial sites would need to be collated. Limited information on nematode life cycles and population dynamics had been provided to sweetpotato growers in the past.

Sweetpotato Soil health Masterclasses

Introduction

A series of Masterclasses were conducted early in the project to extend current knowledge on nematode management in vegetable crops to sweetpotato farmers, improve grower's understanding of root-knot nematode and encourage them to develop more effective strategies for managing the pest. An important focal point of the masterclasses was to improve biological health of the soils used for sweetpotato production and to enhance natural biological mechanisms that regulate nematode populations for long term sustainability.

Methodology

The masterclasses were modelled on the successful sugar industry series which were designed to improve grower's understanding of root-knot nematode. Classes consisted of theory and group sessions along with hands-on practical sessions with a focus on interactivity, thus classes were limited to 15 to 20 participants A second focus was the introduction of existing farm practices to reduce losses from RKN in vegetable crops and detailed discussions on soil Health, soil biology and integrated pest management.

The masterclasses incorporated the below key topics:

- The life history of RKN
- Nematode population dynamics and damage thresholds
- Impact of environmental factors on nematode survival and multiplication
- Nematode monitoring as a management tool
- Soil organisms and the soil food web
- Beneficial organisms, bacteria, fungi and free-living nematodes
- Plant pathogenic nematode species
- The importance of carbon
- Sustainable farming systems for healthy soils
- Rotation crops, organic amendments and mulching
- Minimum tillage, control of volunteers and weeds
- Suppressive soils and early bed formation
- Resistant cultivars

Results and discussion

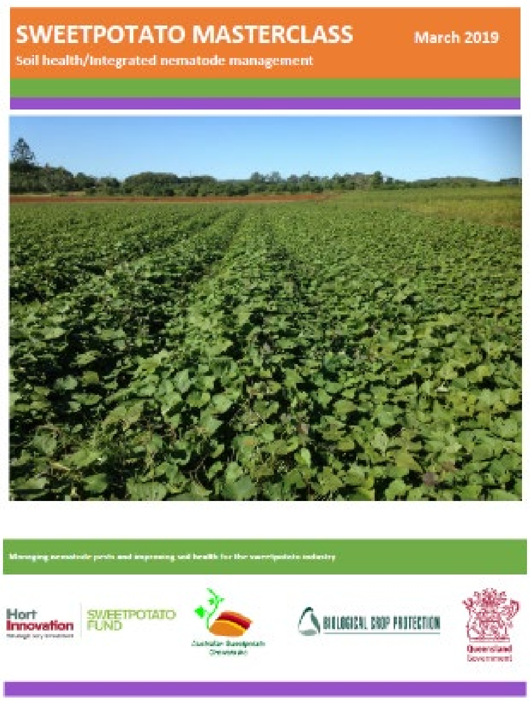
51 growers and stakeholders attended one of four initial masterclasses were held in Cudgen on the 4th of March 2019, in Bundaberg on the 6th and 7th of March 2019 and in Atherton (Kairi) on the 14th of March 2019. In Cudgen a peer grower, already involved in improving soil health, presented to the class. A second focus was the introduction of existing farm practices to reduce losses from RKN in vegetable crops. Open discussion sessions encouraged participants to exchange ideas on how various management practices could be integrated into their sweetpotato farming system. Feedback indicated that 80% rated the event as excellent quality, 20% rated it as good quality. 84% said the event was highly relevant to their business and 18% said the event was mostly relevant.

Masterclass handbook

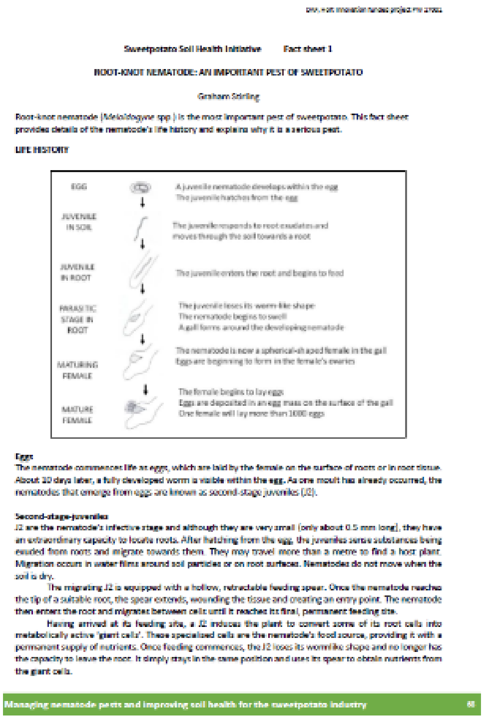
Attendees were presented with information on RKN management in vegetable crops and damage caused to sweetpotato and a 92 page handbook ‘Sweetpotato Masterclass – Soil health and Integrated nematode management’ developed for the workshop. This can be found as appendix 1.

As part of the masterclasses, and extension of current knowledge on nematodes, eleven fact sheets were developed to provide sweetpotato growers with information on the topics discussed in the classes. Titles are listed below. The factsheets are included in the Sweetpotato masterclass handbook in attachment 1. Root-knot nematode: An important pest of sweetpotato

- Ecology of root-knot nematode on sweetpotato
- Monitoring as a tool for managing root-knot nematode on sweetpotato
- Plant parasitic nematodes: An important pest of sweetpotato
- Integrated nematode management in sweetpotato
- Nematicides for use on sweetpotato
- Crop rotation, cover cropping and bare fallows to reduce nematode damage on sweetpotato
- Weed and volunteer control plays an important role in reducing losses from root-knot nematode on sweetpotato
- Organic inputs to improve soil health and reduce losses from nematode pests
- Management strategies to enhance a soil’s capacity to supress nematode pests
- Towards more sustainable sweetpotato farming systems


SWEETPOTATO MASTERCLASS
March 2019
Soil health/Integrated nematode management

Managing nematode pests and improving soil health for the sweetpotato industry


Sweetpotato Soil Health Initiative Fact sheet 1

ROOT-KNOT NEMATODE: AN IMPORTANT PEST OF SWEETPOTATO

Graham Stirling

Root-knot nematode (*Meloidogyne* spp.) is the most important pest of sweetpotato. This fact sheet provides details of the nematode’s life history and explains why it is a serious pest.

LIFE HISTORY

EGG – A juvenile nematode develops within the egg. The juvenile hatches from the egg
JUVENILE IN SOIL – The juvenile responds to root exudates and moves through the soil towards a root
JUVENILE IN ROOT – The juvenile enters the root and begins to feed
PARASITIC STAGE IN ROOT – The juvenile loses its worm-like shape. The nematode begins to swell. A gall forms around the developing nematode
MATURING FEMALE – The nematode is now a spherical-shaped female in the gall. Eggs are beginning to form in the female’s ovaries
MATURE FEMALE – The female begins to lay eggs. Eggs are deposited in an egg mass on the surface of the gall. One female will lay more than 1000 eggs

Eggs
The nematode commences life as eggs, which are laid by the female on the surface of roots or in root tissue. About 10 days later, a fully developed worm is visible within the egg. As one moult has already occurred, the nematodes that emerge from eggs are known as second-stage juveniles (J2).

Second-stage-juveniles
J2 are the nematode’s infective stage and although they are very small (only about 0.5 mm long), they have an extraordinary capacity to locate roots. After hatching from the egg, the juveniles sense substances being exuded from roots and migrate towards them. They may travel more than a metre to find a host plant. Migration occurs in water films around soil particles or on root surfaces. Nematodes do not move when the soil is dry.

The migrating J2 is equipped with a hollow, retractable feeding spear. Once the nematode reaches the tip of a suitable root, the spear extends, wounding the tissue and creating an entry point. The nematode then enters the root and migrates between cells until it reaches its final, permanent feeding site.

Having arrived at its feeding site, a J2 induces the plant to convert some of its root cells into metabolically active ‘giant cells’. These specialised cells are the nematode’s food source, providing it with a permanent supply of nutrients. Once feeding commences, the J2 loses its wormlike shape and no longer has the capacity to leave the root. It simply stays in the same position and uses its spear to obtain nutrients from the giant cells.

Managing nematode pests and improving soil health for the sweetpotato industry 48

Image 1: Left, Sweetpotato masterclass handbook (92 pages).Right Fact sheet 1, Root-Knot nematodes.

Image 2: Left, Growers view roots galls, nematodes under the microscope (centre) and discuss sustainable management options in Kairi (Right).

Image 3: Growers discuss the soil biome and microarthropods in Cudgen.

Image 4: Growers in Bundaberg are presented with information on organic amendments in Bundaberg by Dr Grahame Stirling.

Image 5: The Bundaberg workshops concluded with a field walk by John Duff (DAF) at Bundaberg Research Facility to view potential rotation crops.

Nematology skills transfer

Introduction

Early in the project, a nematology training workshop was conducted to extend knowledge and understanding within the project team. Of particular relevance to DAF sweetpotato researchers were techniques such as collection of soil for nematode identification, sampling protocols, storage and transport of samples, preparation of galled-root inoculum for use in field trials and setting up of pot rials, inoculation and bioassays to assess a soil's suppressiveness to nematodes.

Methodology

Training sessions were designed to encompass theoretical and practical aspects of the below topics:

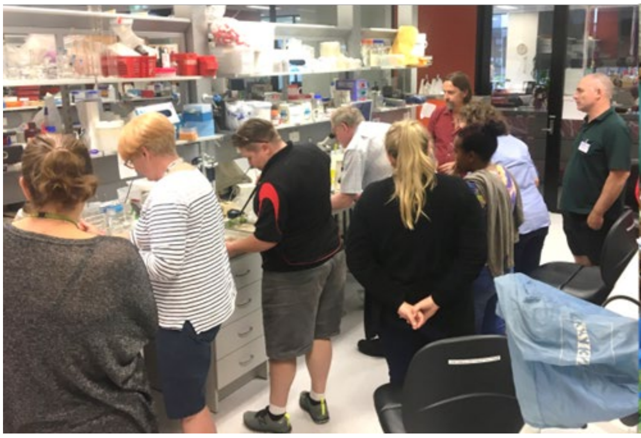
- Maintenance of RKN inoculum
- Preparation of suspensions containing known numbers of nematode eggs
- Extraction of nematode eggs from root galls, preparation of galled-root inoculum for use in field trials
- Culturing of reniform nematode, root-lesion nematode and other plant-parasitic nematodes
- Setting up bioassays to assess a soil's suppressiveness to nematodes
- Extraction nematodes using the Whitehead tray method
- Identification and counting of RKN in field samples
- Maintenance of pure cultures of 2 RKN species, M. incognita and M. javanica
- CO2 measurements using Solvita™
- Inoculation of pots with eggs or juveniles for pathogenicity bioassays
- Identification and culture of nematode trapping fungi and bacteria
- Extraction of microarthropods from soil samples

Results and discussion

Nematology training workshops were conducted at the Biological crop protection (BCP) laboratory, 26th and 27th of September and 10th of October 2018 and at DAF Ecoscineces precinct (ESP) 9th of October, 2018. An additional practical exercise was conducted at Gatton Research facility (GRF) on the 5th of October 2018. Training sessions were delivered by Graham Stirling (biological crop protection) and DAF nematology staff Jennifer Cobon and Wayne O'Neill. New DAF, nematology staff (1), the DAF sweetpotato team members (6), one Central Queensland University (CQU) technician gained knowledge on infield soil sampling protocols and an understanding of the nematode extraction process.

A seminar was held at DAF Ecosciences precinct (ESP) in December 2018 for visiting nematologists from Louisiana State University, Prof. Charles Overstreet and Prof. Ed McGawley, both of whom have extensive experience with Reniform and Root-Knot nematode. The project team facilitated farm visits to a number of sweetpotato farms in the Cudgen (NSW) area and a soil health trial site (managed by BCP) from the 16th to the 18th of December 2018.

Photos/images



Survey of current grower practices

Introduction

Running parallel with the initial nematode surveys, a second survey was conducted to collect information on current on farm production and pest control practices. These surveys were completed throughout the major sweetpotato cropping regions of Wide Bay, northern NSW, Central Queensland, Southeast Queensland and Far north Queensland.

Methodology

A survey was designed to capture current grower practices in relation to sweet potato production, with a focus on nematode control, cover crops and soil health. The survey collected data on; Soil type, area and varieties of sweetpotatoes grown, planting density, row spacing, crop losses due to nematodes, time of year, nematicides applied, rates used, effectiveness, rotation crops, timing of rotations, machinery used, GPS, minimum till, volunteer control, s chemicals used and use of nematode testing services pre plant?

Results and discussion

Over 40 on farm surveys were conducted from October 2019 to August 2019. Block rotation times varied between 6 months and 5 years, with an average of 2 years. When asked about the methods used to control volunteers, 31% said used chemical control, 14% physical control methods, 6% used cultural control methods and 50% of growers surveyed used a combination of methods on their farm.

Table 1 List Responses to survey questions (per cent of responses from total growers surveyed).

Question	Yes	Sometimes /occasionally	No	Unsure
Do nematodes cause losses on your farm?	58	24	18	
Are currently registered nematicides effective?	81	12	4	4
Would you conduct pre plant nematode tests if they were readily accessible and affordable?	71	11	18	
Do you use rotation crops?	89		11	
Do your rotation crops assist in nematode control?	88		12	
Do you remove volunteers?	92	3	5	
Do you use any organic amendments?	25		75	
Do you use GPS?	46		54	
Do you use chemicals to control volunteers?	31			

Current knowledge of nematode species occurring in sweetpotato production soils

Collation of historical data

Introduction

There was limited information on which nematode species were occurring in Australian sweetpotato producing soils as no widescale surveys had been previously undertaken. Information on nematode species identified as part HAL project VG09052 (McCrystal, et al., 2014), were mostly from samples collected at designated nematicide field trial sites and variety evaluation trials as part of HAL project VG13004 (Dennien et. Al., 2014). Prior to commencing the initial sweetpotato nematode surveys under this project, historical results from samples collected to 2013 were collated to provide information on which nematode species had been detected.

Methodology

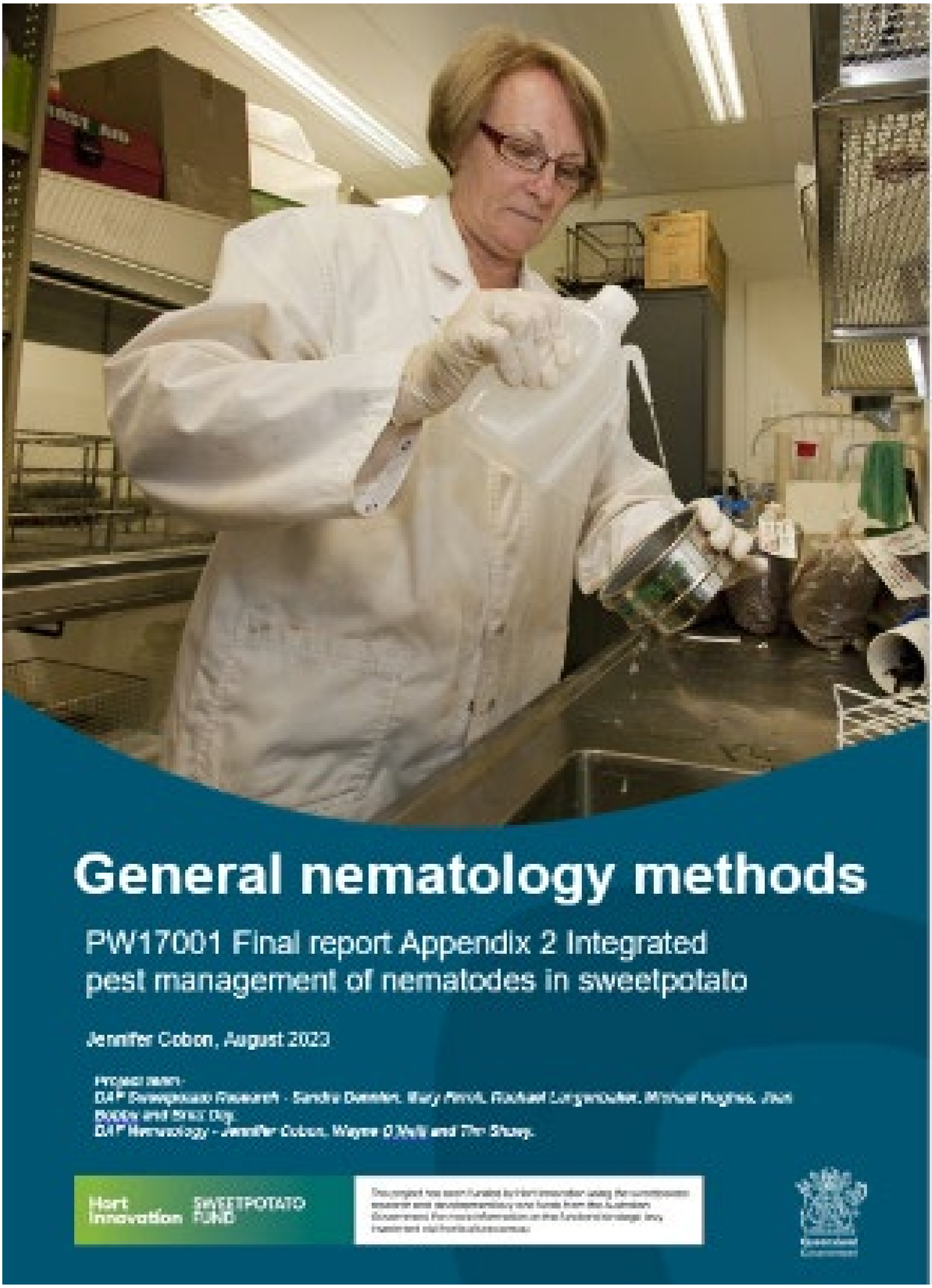
Between April 2010 and August 2013, 500 sweetpotato soil samples were received at the DAF Nematology Diagnostic Laboratory. Information on the location of where some of the samples were collected was not often provided to the laboratory. Many of these samples were field trial samples which meant that it was difficult for the nematologists to draw conclusions from this data.

Results and discussion

Where location information was available, it can be seen the Rotylenchulus reniformis (reniform nematode) was recovered from some blocks from the Central Queensland and the Bundaberg areas. Meloidogyne spp. (root-knot nematode) was present in samples received from Central Queensland, Bundaberg and Cudgen. No samples were received from sweetpotato growers from the Atherton Tablelands or South East Queensland during that timeframe. Many field trials had been carried out at the Bundaberg Research Facility where there were high numbers of both reniform nematode and root-knot nematode.

Appendix 2.

General nematology methods



General nematology methods

PW17001 Final report Appendix 2 Integrated pest management of nematodes in sweetpotato

Jennifer Cobon, August 2023

General methods

Soil sampling

Field sampling

A composite soil sample was taken from a block/field to a depth of 10-15 cm using a clean probe, corer or auger. At each individual soil sampling site, any surface organic matter or dry soil was pushed away. Approximately 40 samples, taken randomly across the block, were emptied into a clean bucket and mixed thoroughly. Approximately 600 mL of soil was divided off and placed in a well labelled sealed plastic bag for immediate transport to the nematology laboratory.

Field trials and in crop sampling

Soil sampled randomly along the row with a clean probe as above every two metres, was then emptied into a clean bucket and mixed thoroughly. Approximately 600 mL of soil was then divided off and placed in a well labelled sealed plastic bag for immediate transport to the nematology laboratory.

Nematode extraction and identification

Plant-parasitic nematodes were extracted, identified and quantified from all soil samples over four days using a Whitehead tray (Whitehead AG *et al.,* 1965) - a modified Baermann funnel technique - after which the solution was poured over a 38 µm sieve.

Two trays with approximately 230 grams of soil in each were set up for each sample. The results were standardised per 200 grams of dry weight equivalent soil. The major plant-parasitic nematodes recovered were identified using light microscopy and morphological characteristic according to the Commonwealth Institute of Parasitology (1972-1977) descriptions.

From this survey, soils were submitted to SARDI (South Australian Research and Development Institute) for molecular identification of the root-knot nematodes species present.

Nematode cultures used for resistance screening experiments

Meloidogyne spp.

Pure cultures of each root-knot nematode species (*M. incognita, M. javanica*) were maintained in a glasshouse on tomato (cv. Tiny Tim) plants. These were originally cultured from a field sourced single eggs mass, with the species identification confirmed by PCR (Stanton *et al*.,). Nematode eggs were obtained for use as inoculum by soaking roots in NaOCl (0.5% available chlorine) for five minutes, and then retrieving eggs on a 38 µm sieve by washing thoroughly with water. Nematode egg numbers were adjusted to achieve the required inoculum density.

Rotylenchulus reniformis

Pure cultures of *R. reniformis* were maintained in the glasshouse on tomato (cv. Tiny Tim) plants grown in an 80/20 mix of pasteurised nematology sand mix and a pasteurised red ferrosol soil. This was originally cultured from a field sourced single eggs mass, with the species identification confirmed by morphological identification. Nematode eggs were obtained for use as inoculum by soaking roots in NaOCl (0.5% available chlorine) for five minutes and retrieving eggs on a 38 µm sieve by washing thoroughly with water. Nematode egg numbers were adjusted to achieve the required inoculum density.

Pratylenchus zeae

Pure cultures of *P. zeae* were maintained as sterile monoxenic carrot cultures (Moody *et al*., 1973) which allows the *in vitro* rearing of large numbers of these nematodes as a pure source of inoculum. This was originally cultured from a field sourced single adult female nematode, with the species identification confirmed by morphological identification. To inoculate experiments, *P. zeae* was obtained by washing the nematodes from carrot cultures and retrieving the nematodes on a 38 µm sieve. Live nematode numbers were adjusted by dilution to achieve the required inoculum density.

Soil mixes for glasshouse experiments

Pasteurised sand mix for experiments with *Meloidogyne* spp. and *P. zeae*

This pasteurised sand mix consists of 150 L pit sand, 150 L bedding sand, 250 g superphosphate, 250 g blood and bone, 250 g Gypsum, 150 g Dolomite, 100 g Micromax, 50 g Potassium nitrate, 25 g Potassium sulphate.

Soil mix for experiments with R. reniformis

This mix was 80/20 mix of pasteurised sand mix and a pasteurised red ferrosol field soil obtained from Redlands Research Station. Previous work had shown R. reniformis reproduces well on plants grown in this mix and it was also easy to wash and strip the eggs from these roots for quantification.

Pot experiments

Resistance experiments

Seeds, runners or sweetpotato vines of each plant cultivar were sown directly into 1.3 -1.5 L pots of suitable soil mix. After germination, the plants were thinned so that several healthy plants remained in each pot. Plants were grown for two to four weeks before inoculation so that a healthy root system was available for the nematodes to infect.

Pots of each cultivar tested were inoculated with a known number of eggs for *Meloidogyne* spp. and *R. reniformis* or live nematodes for *P. zeae.* The nematode treatments were replicated five times for each species and maintained in a glasshouse with plants fertilised fortnightly with a liquid fertiliser (Aquasol®).

Tomato cv. Tiny Tim was grown and inoculated as the susceptible control for *Meloidogyne* spp. and *R. reniformis* experiments with maize cv. Messenger used as the susceptible control for the *P. zeae* experiments.

Harvest

Meloidogyne spp. experiments

Data obtained by monitoring temperatures with a data logger allowed the calculation of heat units for the *Meloidogyne* spp. experiments which were harvested approximately nine weeks after inoculation when it was calculated that at least 14,000 heat units (°C-hours) had been reached (sufficient for maximum egg production after inoculation). Heat hours accumulated during the experiments were calculated assuming minimum and maximum temperatures for *M. incognita* development of 10 °C and 28 °C respectively and for *M. javanica* development 13 °C and 32 °C respectively (Trudgill 1995). At harvest, the plant tops were cut at soil level and roots washed free of soil and the fresh root weights were recorded.

Pratylenchus zeae and R. reniformis experiments

At harvest, (13 weeks post inoculation for *P. zeae* and 16 - 23 weeks post inoculation for *R. reniformis* experiments), the plant tops were cut at soil level and roots washed free of soil and the fresh root weights were recorded.

Nematode extraction from glasshouse experiments

Meloidogyne spp. and R. reniformis experiments

Nematode eggs were recovered from the roots by soaking the roots system in NaOCl (1% available chlorine) for five minutes and then pouring the suspension over a 38 µm sieve. The egg/nematode suspension was diluted appropriately and counted at a magnification of 50X.

Pratylenchus zeae experiments

To extract nematodes, the roots were sliced lengthwise and placed in a misting chamber for seven days (Hooper 1986). Nematodes were then recovered from the filtrate on a 38 µm sieve. The nematode suspension was diluted appropriately and counted at a magnification of 50X.

Resistance levels

Levels of resistance or susceptibility were determined by inoculating plants with a known number of nematode eggs/live nematodes (initial population density Pi), measuring final population density (Pf) and then making the following calculation:

Reproduction Factor (RF) = Pf/Pi.

Meloidogyne spp.

Since not all eggs in *Meloidogyne* inoculum are capable of hatching and invading roots, a conservative figure of 1/10 of the Pi was used as Pi, i.e., 1,000 for both *M. incognita* and *M. javanica* if inoculated with 10,000 eggs.

For *Meloidogyne* experiments, susceptible crop varieties were further categorised as highly, moderately or slightly susceptible according to the reproduction factor (Table 1).

Table 1 Resistance categories

Reproduction Factor	Resistance Rating
> 100	Highly Susceptible (HS)
10 - 100	Moderately Susceptible (MS)
1 - < 10	Slightly Susceptible (SS)
0.1 - < 1	Resistant (R)
< 0.1	Highly Resistant (HR)

Rotylenchulus reniformis

Since not all eggs in inoculum are capable of hatching and invading roots, a conservative figure of 1/10 of the Pi was used.

Possible rotation crops can be distinguished into two groups. Susceptible crops that are capable of supporting the development of *R. reniformis* populations, with a reproduction factor greater than 1.

The reproductive factors of *R. reniformis* in roots of resistant crops were less than 1 indicating that the final populations densities of *R. reniformis* decreased (Marwoto, B. 2010).

Pratylenchus zeae

Live nematodes were used in inoculum, so no hatching was involved, and live nematodes are capable of invading roots. Pi was the actual number of live nematodes prepared in the inoculum.

Possible rotation crops could be distinguished into two groups. Susceptible crops that can support the development of *P. zeae* populations, with a reproduction factor greater than 1.

Resistant crops have significantly less *Pratylenchus* juveniles recovered from the roots compared with the susceptible control.

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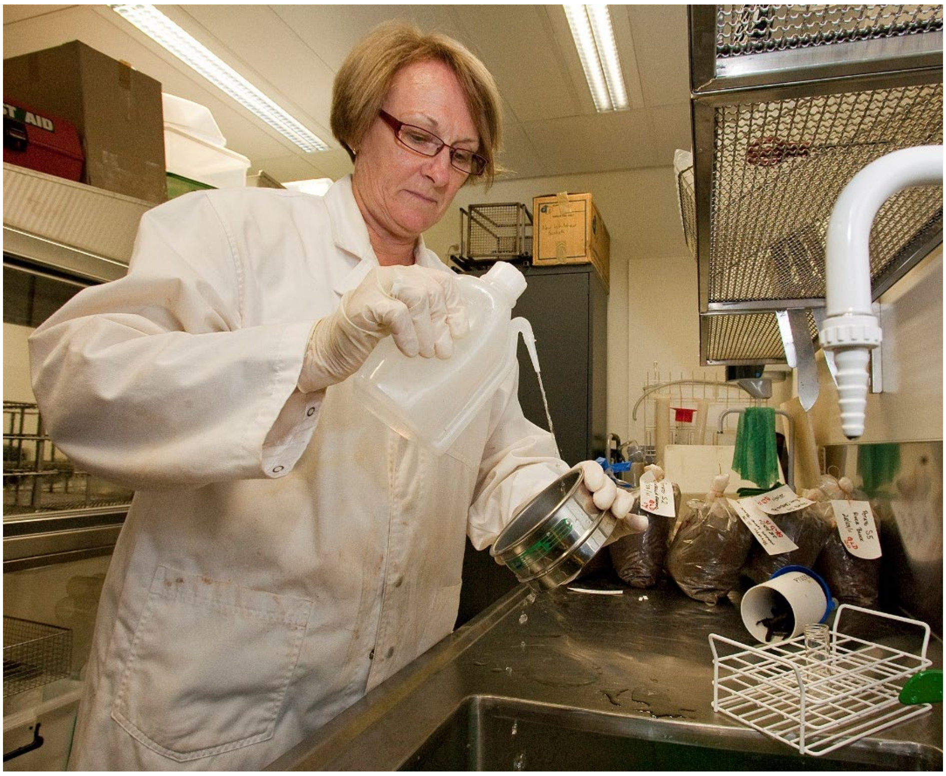


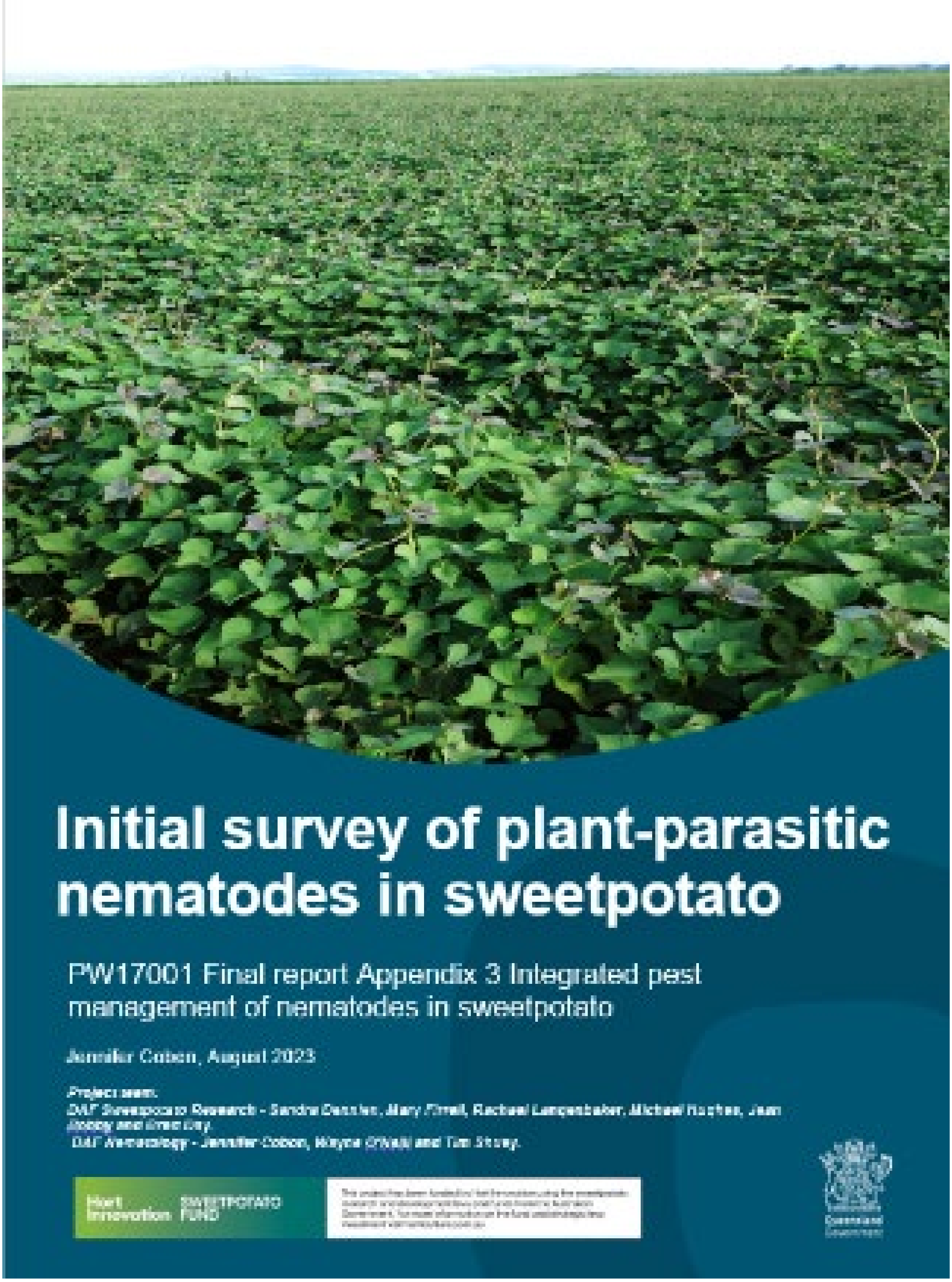
Image 1 Jennifer Cobon extracting nematode eggs on a 38 µm sieve.

Image 2 Left, Tim Shuey checking Whitehead trays used to extract nematodes from soil samples. Right, a juvenile root-knot nematode at 50X magnification.

Image 3 Wayne O’Neill identifying nematode species from collected soil samples.

Appendix 3.

Initial survey of plant-parasitic nematodes in sweetpotato production



Initial survey of plant-parasitic nematodes in sweetpotato

PW17001 Final report Appendix 3 Integrated pest management of nematodes in sweetpotato

Jennifer Cobon, August 2023

Project team:
DAF Sweetpotato Research - Sandra Dennien, Mary Firrell, Rachael Langenbaker, Michael Hughes, Jean Hobby and Brad Day.
DAF Nematology - Jennifer Cobon, Wayne O'Neill and Tim Shuey.

Summary

Field surveys to understand region specific nematode species occurrences and identify any potential biosecurity issues were undertaken throughout the major cropping regions. Initial surveys were conducted in the sweetpotato productions areas of Wide Bay, northern NSW, Central Queensland, southern Queensland, North Queensland. A total of 85 fields were sampled across these regions: 45 in Wide Bay, 17 in northern NSW, 12 in Central Qld, 6 in southern Qld, and 5 in North Qld. Plant-parasitic nematodes were identified and quantified from a soil sample taken at a depth of 10-15 cm.

From this survey, 81 soils (43 from Wide Bay, 16 from northern NSW, 12 from Central Qld, 6 from southern Qld and 4 from North Qld) were submitted to SARDI (South Australian Research and Development Institute) for molecular identification of the root-knot nematodes species present.

Outcomes

A new detection of *R. reniformis* during the survey in southern Qld extends the known geographic range of this nematode species. Growers have a greater understanding of the plant-parasitic nematodes in each of the growing regions and of the ones causing the impacts to crop yield and damage. Individual growers have been informed which nematode species are present on their farms.

Introduction

Initial survey

Initial surveys were conducted in the sweetpotato productions areas of Wide Bay, northern NSW, Central Qld, southern Qld, North Qld. A total of 85 fields were sampled across these regions: 45 in Wide Bay, 17 in northern NSW, 12 in Central Qld, 6 in southern Qld, and 5 in North Qld. Plant-parasitic nematodes were identified and quantified from a soil sample taken at a depth of the 10-15 cm (Table 1).

From this survey, 81 soils (43 from Wide Bay Qld, 16 in northern NSW, 12 in Central Qld, 6 in southern Qld and 4 in North Qld) were submitted to SARDI (South Australian Research and Development Institute) for molecular identification of the root-knot nematodes species present (Table 2).

Materials and methods

Plans for intensive surveys were developed to sample a representative group of fields, both pre-plant and post-harvest. Information on each field's soil type and previous cropping history has been collected and will be used to assess the impact of these factors on nematode occurrence and population density. Drought conditions especially during the latter half of 2019 and throughout 2020 prevented further surveys as dry soil does not give a true representation of nematode numbers. Recent rainfall events in Queensland and northern New South Wales and relaxation of Covid restrictions allowed surveys to re commence in October 2020.

Representative soil samples were taken from a block/field to a depth of 10-15 cm using a clean probe, corer or auger. Nematodes were extracted from the soil samples in a Whitehead tray over four days. Nematodes were retrieved on a 38 µm sieve and then examined under a compound microscope for identification and quantification of all plant-parasitic nematode species.

The major plant-parasitic nematodes recovered were identified using light microscopy and morphological characteristic according to the Commonwealth Institute of Parasitology (1972-1977) descriptions.

Split soil samples were received by SARDI (South Australian Research and Development Institute) for molecular identification of the root-knot nematodes species present. General methods are described in detail elsewhere in appendix 2.

Results and discussion

Eighty-five survey samples were collected and processed by the DAF nematology team. Eighty-one soil samples were sent to SARDI for molecular identification of root-knot nematode.

Initial results show that root-knot nematode (RKN), primarily *Meloidogyne incognita* and *M. javanica*, is widespread across the industry and reniform nematode appears to be extending its geographical range. A detection in the Lockyer valley is believed to be the most southerly recording of this species in Australia to date.

Morphological identification

The results of the initial survey (Table 1) determined that *Meloidogyne* spp., (root-knot nematode) was the most common nematode pest in sweetpotato. Root-knot nematode was present in 55 of 85 sites (65%) across all regions. In Wide Bay, 27 of 45 sites (60%) were found to have *Meloidogyne* spp., with 15 of 17 sites (88%) in northern NSW, 7 of 12 sites (58%) in Central Qld, 2 of 6 sites (33%) in southern Qld and 4 of 5 sites (80%) in North Qld all similarly infested with *Meloidogyne* spp.

Rotylenchulus reniformis (reniform nematode) which is a major pest in the USA was present at some sites, mainly in warmer areas with 3 of 45 sites (7%) in Wide Bay, 4 of 12 sites (33%) in Central Qld and 1 of 6 sites (25) in southern Qld having reniform nematode present. This new detection of *R. reniformis* in southern Qld extends the known geographic range of this nematode species previously known to occur in Queensland from Bundaberg north (Table 1).

Pratylenchus zeae was found from 24 sites (53%) in Wide Bay, 5 sites (29%) in northern NSW, 6 sites (50%) in Central Qld, 4 sites (67%) in southern Qld, 3 sites (60%) in North Qld (Table 1).

Spiral nematodes and *Rotylenchulus parvus* (another reniform nematode) were common, but in low numbers suggesting sweetpotato is not a good host to these species. Also in low populations were stubby, stunt, ring and dagger nematodes.

Molecular identification

Total production area

In total from sweetpotato soil samples (n=81), SARDI identified root-knot nematode DNA using their non-specific *M. javanica/incognita/arenaria* primers from 54 sites (67%) with no DNA identified from 27 sites (33%). In 33 of these 54 samples (61%), SARDI were further able identify the root-knot nematode to species level (using a specific assay), but in 21 samples the RKN species present was not able to be determined (Table 1.2).

Using specific primers

Twenty-three of 54 sites (43%) were identified with *M. javanica* as either single or mixed populations making it the most commonly identified species of RKN throughout the sweetpotato production area (Table 1.2). *Meloidogyne incognita* was identified in 10 of 54 sites (19%) as either single or mixed populations. *Meloidogyne arenaria* was identified at 1 of 54 sites (2%) as a mixed population with *M. javanica*. *M hapla* was identified at 7 of 54 sites (13%) as either single or mixed populations. *Meloidogyne hapla*, a cooler climate RKN, was only found at sites in southernQld and northern NSW, while *M. javanica*, a very tropical RKN, was most predominant in the Wide Bay region and in Central Qld. *Meloidogyne incognita* is a subtropical species and was identified mostly in northern NSW and Wide Bay.

Regional results

Regionally, with the Wide Bay samples (n=43) SARDI identified root-knot nematode DNA using their non-specific M. javanica/incognita/arenaria primers from 28 sites (65%) with no DNA from 15 sites (35%) (Table 2, 3)

Using specific primers

- 13 sites were identified with a single population of *M. javanica* (46%)
- 3 sites were identified as *M. incognita* (11%)
- 2 sites were mixed populations of *M. javanica* and *M. incognita* (7%)
- 1 site was a mixed populations of *M. javanica* and *M. arenaria* (4%)
- species identification of *Meloidogyne* was not successful from 9 sites (32%)

From the northern NSW samples (n=16) SARDI identified root-knot nematode DNA using their non-specific *M. javanica/incognita/arenaria* primers from 14 sites (88%).

Using specific primers

- 1 site was identified as *M. javanica* (7%)
- 3 sites were identified as *M. hapla* (22%)
- 1 site was identified as *M. incognita* (7%)
- 1 site was a mixed populations of *M. javanica* and *M. incognita* (7%)
- 1 site was a mixed populations of *M. javanica* and *M. hapla* (7%)
- 2 sites were mixed populations of *M. incognita* and *M. hapla* (14%)
- species identification of *Meloidogyne* was not successful for 5 sites (36%)

From the Central Qld samples (n=12) SARDI identified root-knot nematode DNA using their non-specific *M. javanica/incognita/arenaria* primers from 7 sites (58%).

Using specific primers

- 2 sites were identified as *M. javanica* (29%)
- species identification of *Meloidogyne* was not successful for 5 sites (71%)

From the southern Qld samples (n=6) SARDI identified root-knot nematode DNA using their non-specific *M. javanica/incognita/arenaria* primers from 4 sites (67%).

Using specific primers

- 1 site was identified as *M. javanica* (25%)
- 1 site was identified as *M. hapla* (25%)
- species identification of *Meloidogyne* was not successful for 2 sites (50%)

From the North Qld samples (n=4) SARDI identified root-knot nematode DNA using their non-specific *M. javanica/incognita/arenaria* primers from 2 sites (50%).

Using specific primers

- 1 site was identified as *M. javanica* (50%)
- 1 site was identified as *M. incognita* (50%)

Conclusion

The regions with the most mixed populations were Wide Bay and northern NSW with mixes of *M. javanica*/*M. incognita* and *M. javanica*/*M. arenaria* in Wide Bay and *M. javanica*/*M. incognita*, *M. javanica*/*M. hapla* and *M. incognita*/*M. hapla* in northern NSW.

Meloidogyne javanica, M. incognita and *M. hapla* were all found as single species populations in the different regions, but *M. arenaria* was only found in a mixed population (with *M. javanica*) during this initial survey.

SARDI identified eight sites with their non-specific assay from which DAF were unable to extract and identify root-knot nematode, however, DAF identified seven different sites with root-knot nematode where SARDI was unable to identify DNA using their non-specific assay.

Table 2 Morphological identification of plant-parasitic nematodes/200 g dry soil weight extracted over four days using the Whitehead tray method from soils surveyed during surveys conducted 2017.

Species by Location	Positive sites	Mean nematode numbers	Range of nematode numbers
Wide Bay Queensland (n=45)			
Meloidogyne spp. (Root-knot nematode)	27 (60%)	255	(1-3413)
Rotylenchulus reniformis (Reniform nematode)	3 (7%)	21	(5-35)
Pratylenchus zeae (Lesion nematode)	24 (53%)	61	(1-220)
Helicotylenchus dihystera (Spiral nematode)	12 (27%)	503	(1-1611)
Rotylenchus brevicaudatus (Spiral nematode)	12 (27%)	207	(3-985)
Paratrichodorus sp. (Stubby root nematode)	16 (36%)	16	(1-94)
Rotylenchulus parvus (Reniform nematode)	17 (38%)	61	(1-638)
Tylenchorhynchus sp. (Stunt nematode)	8 (18%)	6	(2-14)
Xiphinema sp. (Dagger nematode)	5 (11%)	48	(1-187)
Criconemella sp. (Ring nematode)	7 (16%)	22	(2-53)
Total Free-living Nematodes	45	1607	(79-2495)
northern NSW (n=17)			
Meloidogyne spp. (Root-knot nematode)	15 (88%)	297	(1-1611)
Pratylenchus zeae (Lesion nematode)	5 (29%)	26	(1-88)
Helicotylenchus dihystera (Spiral nematode)	16 (94%)	127	(8-591)
Paratrichodorus sp. (Stubby root nematode)	5 (29%)	3	(1-6)
Rotylenchulus parvus (Reniform nematode)	2 (12%)	47	(12-18)
Xiphinema sp. (Dagger nematode)	2 (12%)	55	(5-104)
Criconemella sp. (Ring nematode)	4 (24%)	4	(1-9)
Total Free-living Nematodes	17	1577	(275-2870)
Central Queensland (n=12)			
Meloidogyne spp. (Root-knot nematode)	7 (58%)	98	(1-587)
Rotylenchulus reniformis (Reniform nematode)	4 (33%)	265	(15-799)
Pratylenchus zeae (Lesion nematode)	6 50%)	22	(1-57)
Helicotylenchus dihystera (Spiral nematode)	6 (50%)	26	(1-123)
Rotylenchus brevicaudatus (Spiral nematode)	2 (17%)	21	(18-24)
*Paratrichodorus sp. (*Stubby root nematode)	5 (42%)	4	(1-7)
Rotylenchulus parvus (Reniform nematode)	1 (8%)	130	
Tylenchorhynchus sp. (Stunt nematode)	1 (8%)	27	
Criconemella sp. (Ring nematode)	2 (17%)	201	(31-371)
Unknown	1 (8%)	14	

Total Free-living Nematodes	12	7552	(61-1129)
southeast Queensland (n=6)			
Meloidogyne spp. (Root-knot nematode)	2 (33%)	8	(3-13)
Rotylenchulus reniformis (Reniform nematode)	1 (2%)	53	
Pratylenchus zeae (Lesion nematode)	4 (67%)	28	(1-106)
Helicotylenchus dihystera (Spiral nematode)	5 (83%)	16	(1-34)
Rotylenchus brevicaudatus (Spiral nematode)	2 (33%)	26	(17-35)
Paratrichodorus sp. (Stubby root nematode)	4 (67%)	3	((1-4)
Rotylenchulus parvus (Reniform nematode)	4 (67%)	60	(1-210)
Total Free-living Nematodes	6	913	(371-1431)
North Queensland (n=5)			
Meloidogyne spp. (Root-knot nematode)	4 (80%)	1098	(1-2620)
Pratylenchus zeae (Lesion nematode)	3 (60%)	13	(1-25)
Rotylenchulus parvus (Reniform nematode)	2 40%)	3	(3-7)
Criconemella sp. (Ring nematode)	1 20%)	1	
Total Free-living Nematodes	5	3128	(1187-4051)

Table 3 Results of the molecular identification of Meloidogyne spp. (root-knot nematode) by SARDI from 81 sites using non-specific and specific primers from soils surveyed during initial surveys conducted 2017.

		Using non-specific primers	Further identification using specific primers			
DAF code	Region	*M. javanica/ incognita/ arenaria* *(pgDNA/g Sample)*	*M.hapla* *(pgDNA/g Sample)*	*M.javanica* *(pgDNA/g Sample)*	*M.incognita* *(pgDNA/g Sample)*	*M.arenaria* *(pgDNA/g Sample)*
RL01	Wide Bay Qld	5	0	0	0	0
RL02	Wide Bay Qld	241	0	372	0	0
RL03	Wide Bay Qld	512	0	558	0	0
RL04	Wide Bay Qld	175	0	60	0	0
RL05	Wide Bay Qld	56	0	58	309	0
RL06	Wide Bay Qld	0	0	0	0	0
RL07	Wide Bay Qld	222	0	259	0	0
RL08	Wide Bay Qld	27	0	0	0	0
RL09	Wide Bay Qld	346	0	407	0	0
RL10	Wide Bay Qld	106	0	41	0	410
RL26	Wide Bay Qld	0	0	0	0	0
RL28	Wide Bay Qld	157	0	142	0	0
RL29	Wide Bay Qld	320	0	224	0	0
RL30	Wide Bay Qld	0	0	0	0	0
RL31	Wide Bay Qld	4	0	0	0	0
RL32	Wide Bay Qld	0	0	0	0	0
RL33	Wide Bay Qld	16	0	0	244	0
RL34	Wide Bay Qld	32	0	39	0	0
RL35	Wide Bay Qld	0	0	0	0	0
RL36	Wide Bay Qld	0	0	0	0	0
RL37	Wide Bay Qld	261	0	234	0	0
RL38	Wide Bay Qld	0	0	0	0	0
RL39	Wide Bay Qld	64	0	0	0	0
RL40	Wide Bay Qld	4	0	0	0	0
RL41	Wide Bay Qld	32	0	49	0	0
RL48	Wide Bay Qld	0	0	0	0	0
RL49	Wide Bay Qld	51	0	26	0	0
RL50	Wide Bay Qld	0	0	0	0	0
RL51	Wide Bay Qld	9	0	0	0	0
RL54	Wide Bay Qld	4	0	0	107	0
RL60	Wide Bay Qld	0	0	0	0	0
GS01	Wide Bay Qld	52	0	56	131	0
GS02	Wide Bay Qld	0	0	0	0	0
GS03	Wide Bay Qld	0	0	0	0	0
GS04A	Wide Bay Qld	204	0	0	393	0
GS04B	Wide Bay Qld	7044	0	0	0	0
GS04C	Wide Bay Qld	0	0	0	0	0
GS05	Wide Bay Qld	148	0	219	0	0
GS06	Wide Bay Qld	19	0	0	0	0
GS07	Wide Bay Qld	0	0	0	0	0
GS08	Wide Bay Qld	257	0	88	0	0

GS09	Wide Bay Qld	76	0	0	0	0
GS10	Wide Bay Qld	0	0	0	0	0
RL18	northern NSW	319	0	25	828	0
RL19	northern NSW	250	3	173	0	0
RL20	northern NSW	4	4	0	0	0
RL21	northern NSW	5	0	0	0	0
RL22	northern NSW	9	2	0	0	0
RL23	northern NSW	0	0	0	0	0
RL24	northern NSW	4	0	0	0	0
RL25	northern NSW	10	0	0	0	0
RL45	northern NSW	66	2	0	110	0
RL46	northern NSW	1	0	0	0	0
RL47	northern NSW	118	0	162	0	0
RL53	northern NSW	11	0	0	0	0
EC02	northern NSW		0	0	0	0
EC04	northern NSW	314	0	0	548	0
EC05	northern NSW	4	2	0	0	0
EC06	northern NSW	24	2	0	68	0
RL11	Central Qld	0	0	0	0	0
RL12	Central Qld	12	0	0	0	0
RL13	Central Qld	568	0	732	0	0
RL14	Central Qld	6	0	0	0	0
RL15	Central Qld	8	0	0	0	0
RL16	Central Qld	10	0	0	0	0
RL17	Central Qld	131	0	188	0	0
RL55	Central Qld	0	0	0	0	0
RL56	Central Qld	0	0	0	0	0
RL57	Central Qld	12	0	0	0	0
RL58	Central Qld	0	0	0	0	0
RL59	Central Qld	0	0	0	0	0
RL42	southeast Qld	0	0	0	0	0
RL43	southeast Qld	0	0	50	0	0
RL44	southeast Qld	8	0	0	0	0
EC07	southeast Qld	0	0	0	0	0
EC08	southeast Qld	17	0	0	0	0
EC09	southeast Qld	19	4	0	0	0
MH01	North Qld	0	0	0	0	0
MH003	North Qld	0	0	0	0	0
MH004	North Qld	512	0	697	0	0
MH005	North Qld	442	0	0	939	0

Table 4 Results of the SARDI molecular identification of *Meloidogyne* spp. (root-knot nematode) summarised into sweetpotato growing regions from soils surveyed during initial surveys conducted.

Species	Sweetpotato growing regions				
Meloidogyne spp. ID	Wide Bay (n=43)	northern NSW (n=16)	Central QLD (n=12)	southeast Qld (n=6)	North Qld (n=4)
DNA positive sites	28	14	7	4	2
M. javanica	13 (46%)	1 (7%)	2 (29%)	1 (25%)	1 (50%)
M. incognita	3 (11%)	1 (7%)	N/A	N/A	1 (50%)
M. arenaria	N/A	N/A	N/A	N/A	N/A
M. hapla	N/A	3 (22%)	N/A	1 (25%)	N/A
M. javanica, M. incognita	2 (7%)	1 (7%)	N/A	N/A	N/A
M. javanica, M. arenaria	1 (4%)	N/A	N/A	N/A	N/A
M. javanica, M. hapla	N/A	1 (7%)	N/A	N/A	N/A
M. incognita, M. hapla	N/A	2 (14%)	N/A	N/A	N/A
No identification	9 (32%)	5 (36%)	5 (71%)	2 (50%)	0 (0%)

Conference presentation

Cobon, J.A., O'Neill, W.T., Shuey, T., Langenbaker, R., Dennien, S., 2022. Plant-parasitic nematodes in sweetpotato production areas in Australia. Oral presentation at the 11th Australasian Soilborne Disease Symposium, Cairns, August 2022.

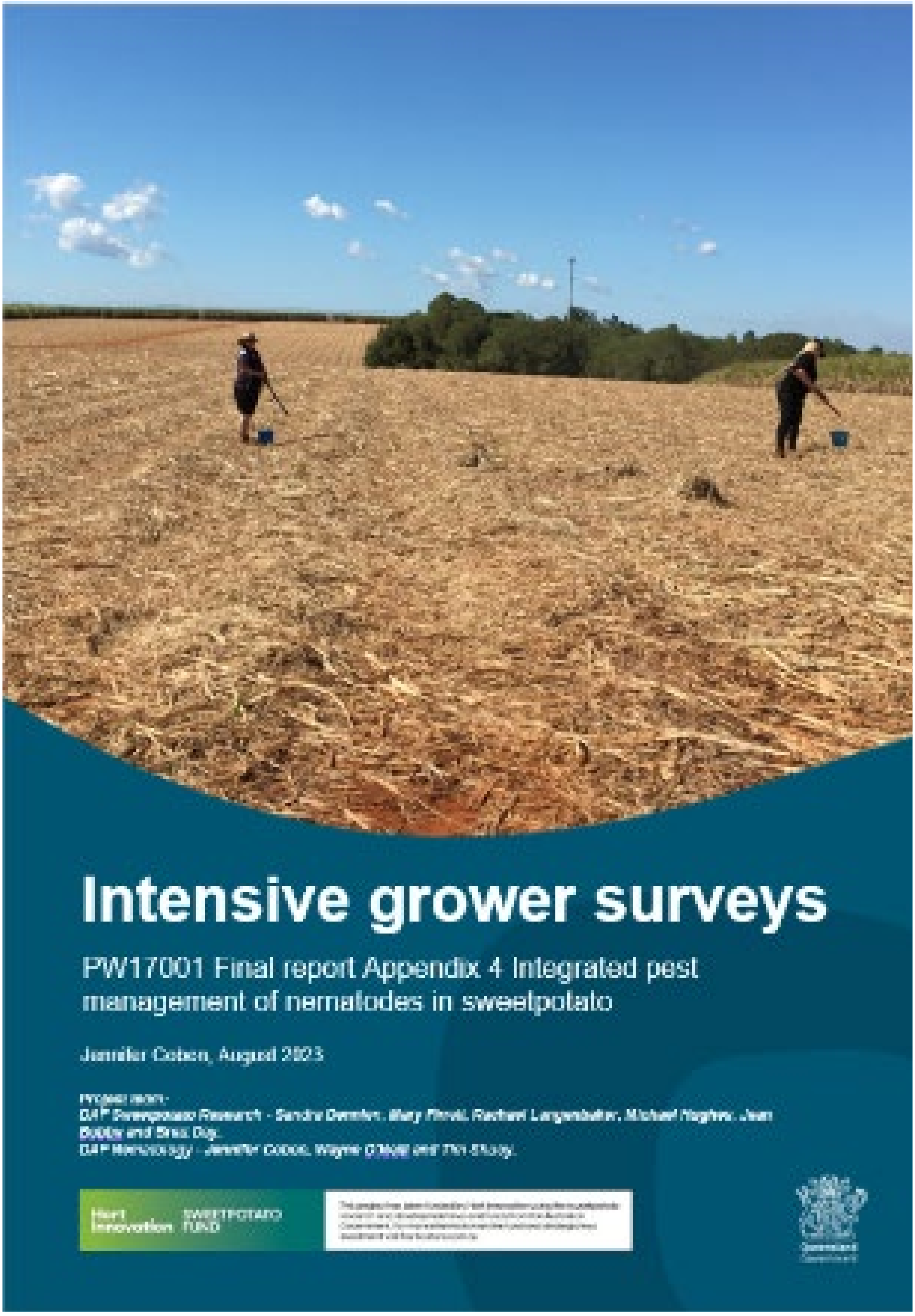
Image 1 Left, Blocks were sampled at the end of cover crop rotations. Right Blocks were sampled post-harvest.

Image 2 Left, Block sampled some weeks after-harvesting showing potential volunteer roots.Right, this block was sampled prior to bed forming.

Image 4 Left Some blocks were sampled prior to planting. Right, or after a rotation crop.

Appendix 4.

Intensive growers' survey of plant-parasitic nematodes in Australian sweetpotato production



Intensive grower surveys

PW17001 Final report Appendix 4 Integrated pest management of nematodes in sweetpotato

Jennifer Cobon, August 2023

Project team:
DAF Sweetpotato Research - Sandra Dennien, [illegible], Rachael Langenbaker, Michael Hughes, [illegible] and [illegible].
DAF Nematology - Jennifer Cobon, Wayne O'Neill and Tim Shuey.

Summary

At the beginning of the project in 2018, field surveys were conducted throughout the major cropping regions to gain an understanding of region-specific nematode species occurrences and identify any potential biosecurity issues. Over 85 survey samples were processed with plant-parasitic nematode identification and quantification being the focus. Free-living nematodes were also identified to give an overall indication of the soil's biological status.

Further sampling of selected growers' fields across the different growing regions took place in 2020, 2021, 2022 and in some cases 2023 to gain a better understanding of plant-parasitic nematode dynamics under the different management systems undertaken by the growers.

Intensive surveys of growers' fields have been undertaken in the three growing regions. Four sites in northern NSW, seven sites in Wide Bay and four sites in Central Qld have been resampled for the intensive grower surveys from 2018 - 2021. Growers participating in the intensive grower survey have been provided with the nematode identification results for all years of sampling for their consideration and so they can make comparisons.

In the Wide Bay region where root-knot nematodes (RKN) were the major nematode problem, many growers had no great spikes in nematode numbers, but some growers were able to reduce the numbers of RKN (RL03, RL04, RL06, RL09).

Three of four sites intensively surveyed in Central Qld, had no reduction in reniform nematode numbers with current practices, while RL13 saw an increase in RKN numbers. Reniform nematode was present in relatively high numbers at all blocks surveyed in Central Qld with only RL13 with having low numbers of reniform nematode.

Two growers in northern NSW were able to reduce root-knot nematode numbers (EC04, RL21). A new detection of *R. reniformis* during the intensive grower surveys of 2021 (RL21) in northern NSW extends the known geographic range of this nematode species previously known to occur only in Queensland from Bundaberg north. In the initial survey of this project, this species was found in southern Qld., then the most southerly distribution of this nematode species. It is vital that this nematode is not spread to other blocks.

Although *Meloidogyne enterolobii* or Guava Root-knot nematode (GRKN) has not been detected in commercial sweetpotato production areas to date, the DAF sweetpotato research team took extra precautions when surveying and conducting farm visits, as part of their prevention planning. Strategies include using disposable boot covers and gloves for each farm, additional cleaning and alcohol disinfestation of sampling equipment between blocks to remove all soil, using fresh sampling containers in between farms and parking vehicles on paved roadways.

Outcomes

New detection of R. reniformis during the intensive survey in northern NSW extends the known geographic range of this nematode species. Growers have a greater understanding of the plant-parasitic nematodes in fields and of the species causing the impacts to crop yield and damage. Individual growers have been informed of all nematode species in their blocks and changes over time. This survey provides growers with validation (or not) of their on-farm management practices to control plant-parasitic nematodes.

Introduction

At the beginning of the project in 2018, field surveys were conducted throughout the major cropping regions to gain an understanding of region-specific nematode species occurrences and identify any potential biosecurity issues.

Further sampling of selected growers’ fields across the different growing regions took place in 2020, 2021, 2022 and in some cases 2023 to gain a better understanding of plant-parasitic nematode dynamics under the different management systems undertaken by the growers.

Intensive surveys of growers’ fields were undertaken in the three growing regions. Four sites in northern NSW, seven sites in Wide Bay and four sites in Central Qld have been resampled for the intensive grower surveys from 2018 to 2023. Growers participating in the intensive grower survey have been provided with the nematode identification results for all years of sampling for their consideration and so they can make comparisons.

Materials and methods

General methods are described in detail in appendix 2.

Representative soil samples were taken from a block/field to a depth of 10-15 cm using a clean probe, corer or auger. Nematodes were extracted from the soil samples in a Whitehead tray over four days. Nematodes were retrieved on a 38 µm sieve and then examined under a compound microscope for identification and quantification of all plant-parasitic species.

The major plant-parasitic nematodes recovered were identified using light microscopy and morphological characteristic according to the Commonwealth Institute of Parasitology (1972-1977) descriptions.

Results and Discussion

A table of results showing numbers of the three most important plant-parasitic nematodes together with all other plant-parasitic nematodes identified in sweetpotato production appears at Table 1. Total free-living nematode numbers are included in the table as an indication of the biological status of the soils, with high numbers indicating more biologically active soil.

In the Wide Bay region where root-knot nematodes (RKN) were the major nematode problem, many growers had no great spikes in nematode numbers, but some growers were able to reduce the numbers of RKN (RL03, RL04, RL06, RL09).

Three of four sites intensively surveyed in Central QLD, had no reduction in reniform nematode numbers with current practices, while RL13 saw an increase in RKN numbers. Reniform nematode was present in relatively high numbers at all blocks surveyed in Central Qld with only RL13 with having low numbers of reniform nematode.

Two growers in northern NSW were able to reduce root-knot nematode numbers (EC04, Rl21). A new detection of *R. reniformis* during the intensive grower surveys of 2021 (RL21) in northern NSW further extends the known geographic range of this nematode species previously known to occur only in Queensland from Bundaberg north. In the initial survey of this project, this species was found in southern Qld., which at that time was the most southerly distribution of this nematode species. It is vital that the spread of this nematode is restricted.

Table 5 Plant-parasitic nematodes in sweetpotato production from intensive growers' surveys conducted in 2018, 2020, 2021, 2022 and 2023

Plant-parasitic nematodes/200 g DW soil														
Sample ID	Year	Region	Root-knot *Meloidogyne* spp.	Reniform *Rotylenchulus reniformis*	Lesion *Pratylenchus* sp.	Reniform *Rotylenchulus parvus*	Spiral *Helicotylenchus dihystera*	Spiral *Rotylenchus brevicaudatus*	Stubby *Paratrichodorus* sp.	Dagger *Xiphinema* sp.	Stunt *Tylenchorhynchus* sp.	Ring *Criconemella* sp.	Pin *Paratylenchus* sp.	Total Free-living Nematodes
RL02	2018	Wide Bay Qld	394	0	0	0	43	0	0	0	0	0	0	390
RL02	2020	Wide Bay Qld	63	0	240	260	4	0	0	0	0	0	0	4496
RL02	2021	Wide Bay Qld	3	0	8	1	4	0	0	0	0	0	0	2443
RL02	2022	Wide Bay Qld	0	0	11	5	0	0	3	0	0	0	0	698
RL02	2022	Wide Bay Qld	125	5	25	15	0	0	1	0	0	0	0	2257
RL03	2018	Wide Bay Qld	264	23	0	0	273	0	0	0	0	20	0	904
RL03	2020	Wide Bay Qld	592	0	0	0	0	0	0	0	0	6	0	3032
RL03	2021	Wide Bay Qld	3	0	1	0	31	0	0	0	0	0	0	1157
RL03	2021	Wide Bay Qld	0	0	88	7	13	0	10	0	0	0	0	3899
RL03	2022	Wide Bay Qld	0	5	0	1	0	25	0	0	0	6	0	2846
RL03	2022	Wide Bay Qld	0	0	1	0	0	6	0	0	0	0	0	1976
RL04	2018	Wide Bay Qld	453	0	0	0	0	603	0	0	0	5	0	254
RL04	2020	Wide Bay Qld	2133	0	0	0	0	612	0	0	0	0	0	225
RL04	2021	Wide Bay Qld	100	0	0	0	0	596	0	0	0	0	0	1182
RL04	2022	Wide Bay Qld	183	0	0	0	0	457	0	0	0	0	0	489
RL04	2022	Wide Bay Qld	0	0	0	3	0	1	0	0	0	0	0	605
RL06	2018	Wide Bay Qld	0	35	68	0	54	0	82	0	8	22	0	549
RL06	2020	Wide Bay Qld	20	2	4	0	2	6	1	0	5	1	0	120
RL06	2021	Wide Bay Qld	1220	8135	0	0	0	0	0	0	0	0	0	794
RL06	2022	Wide Bay Qld	0	0	95	0	9	0	47	0	0	493	0	996
RL06	2022	Wide Bay Qld	0	0	0	0	0	0	0	0	0	0	0	10
RL09	2018	Wide Bay Qld	506	0	0	0	1611	0	0	0	0	0	0	413
RL09	2020	Wide Bay Qld	40	0	45	21	75	0	1	0	0	1	0	1351
RL09	2021	Wide Bay Qld	530	0	25	20	1035	0	15	0	0	0	0	1767
RL09	2022	Wide Bay Qld	102	98	68	0	386	0	22	0	0	0	0	980

RL09	2022	Wide Bay Qld	2	0	0	0	2	0	0	0	0	0	0	1486
RL35	2018	Wide Bay Qld	0	0	2	2	39	0	1	0	0	0	0	962
RL35	2020	Wide Bay Qld	0	0	1	1	1	0	0	0	3	0	0	437
RL35	2021	Wide Bay Qld	0	0	0	0	0	24	0	0	0	0	0	3939
RL35	2022	Wide Bay Qld	0	0	0	0	0	51	0	0	0	0	0	908
RL35	2022	Wide Bay Qld	0	0	0	0	112	0	0	0	0	0	0	496
RL39	2018	Wide Bay Qld	162	0	2	221	199	0	18	0	0	0	0	1197
RL39	2020	Wide Bay Qld	0	0	0	0	1	0	0	0	0	0	0	1084
RL39	2021	Wide Bay Qld	17	0	3	0	0	0	0	0	0	0	0	2374
RL39	2021	Wide Bay Qld	15	0	0	0	18	0	2	0	0	0	0	2431
RL39	2022	Wide Bay Qld	0	0	1	105	0	0	20	0	0	0	0	3855
RL39	2022	Wide Bay Qld	0	0	0	69	0	0	0	0	0	0	0	1361
EC01	2018	northern NSW	20	0	0	0	218	0	7	0	0	0	0	736
EC01	2020	northern NSW	157	0	0	13	5	25	2	0	0	0	0	4051
EC01	2021	northern NSW	28	0	0	0	24	131	11	0	0	1	0	3728
EC01	2022	northern NSW	6	0	0	0	1	0	0	0	0	0	0	1464
EC01	2022	northern NSW	3	0	0	1	2	0	2	0	0	1	0	945
EC04	2018	northern NSW	1611	0	0	0	320	0	0	0	0	0	0	379
EC04	2020	northern NSW	388	0	0	0	59	7	0	0	0	0	0	1983
EC04	2021	northern NSW	57	0	0	0	127	0	5	0	0	0	0	2311
EC04	2022	northern NSW	33	0	0	0	83	0	0	0	0	0	0	2065
EC04	2022	northern NSW	126	0	0	0	198	0	2	0	0	0	0	1221
RL21	2018	northern NSW	14	0	0	0	163	0	0	0	0	0	0	515
RL21	2020	northern NSW	44	0	1	0	8	0	1	0	0	0	0	1562
RL21	2021	northern NSW	1848	365	0	0	146	12	0	0	0	12	0	1471
RL21	2022	northern NSW	0	0	0	0	24	0	1	0	0	0	0	549
RL24	2018	northern NSW	1	0	88	0	93	0	2	0	0	0	0	870
RL24	2021	northern NSW	0	0	0	0	11	0	0	0	0	0	0	431
RL24	2022	northern NSW	13	0	824	0	178	0	33	0	0	0	0	1319
RL24	2022	northern NSW	4	0	209	0	22	0	12	0	0	0	0	709
RL11	2018	Central Qld	0	15	25	0	11	24	0	0	0	0	0	308
RL11	2020	Central Qld	2	2156	4	0	0	1	0	0	0	0	0	1396
RL11	2021	Central Qld	0	1573	0	0	0	0	0	0	0	0	0	1633
RL11	2022	Central Qld	0	3091	0	0	0	152	0	0	0	0	0	93
RL11	2022	Central Qld	0	187	0	0	0	0	0	0	0	0	0	3085

RL11	2023	Central Qld	0	2058	0	0	0	0	0	0	0	0	0	1920
RL13	2018	Central Qld	587	0	5	0	0	0	5	0	0	31	0	914
RL13	2021	Central Qld	0	2	0	0	1	0	2	0	1	3	0	1839
RL13	2022	Central Qld	0	0	20	0	0	0	140	0	2	2	0	2293
RL13	2022	Central Qld	43	5	1	0	0	0	6	0	0	1	0	1024
RL13	2023	Central Qld	2679	0	0	0	0	0	10	0	0	19	19	2024
RL15	2018	Central Qld	4	19	57	0	13	0	0	0	0	0	0	1129
RL15	2020	Central Qld	4	125	7	0	0	0	0	0	0	0	0	3285
RL15	2021	Central Qld	411	411	0	0	0	4	0	0	0	0	0	451
RL15	2022	Central Qld	0	20	6	0	19	0	0	0	0	0	0	2406
RL15	2022	Central Qld	0	121	0	0	0	0	2	0	0	26	0	1785
RL16	2018	Central Qld	6	799	0	0	123	0	0	0	0	0	0	870
RL16	2020	Central Qld	2	147	0	0	5	0	0	0	0	0	0	2564
RL16	2021	Central Qld	3	9	0	0	0	0	0	0	0	0	0	2825
RL16	2022	Central Qld	0	227	35	0	0	0	0	0	0	0	0	2137
RL16	2022	Central Qld	0	103	0	0	31	0	3	0	0	25	0	2248

Selected case studies

RL03 Wide Bay

Had reduced the RKN population to undetectable levels by 2022. Has been growing Jumbo sorghum during 2021 and 2020. This is an excellent non-host rotation crop for both *M. javanica* and *M. incognita*.

RL04 Wide Bay

RKN numbers peaked in 2020 but have been falling since then. Triticale which is a good host of RKN was planted in 2019 so that may have contributed to the high numbers thereafter. Bare fallow in 2021 and 2022 reduced numbers. Used Metham in 2022 and numbers of RKN are now at undetectable levels.

RL06 Wide Bay

Numbers of RKN and reniform nematode peaked dramatically after a crop of Orleans and Bellevue in 2021. Bare fallow, Jumbo sorghum after that crop in 2021 more sorghum in 2022 and numbers of RKN and reniform nematode then undetectable in early 2022. Metham applied and numbers still undetectable.

RL09 Wide Bay

RKN after Saia oat rotation, then fallow and numbers dropped, then followed by crop of Orleans, Beauregard and Eclipse. Numbers peaked again, then followed by fallow, another crop and then fallows. RKN down but reniform nematode detected. Metham in 2022, RKN very low and reniform nematode undetectable.

RL21 northern NSW

Low numbers of RKKN in 2018 and 2020. Numbers of RKN and reniform nematode (first detection) peaked in 2021. Jumbo sorghum planted, the bare fallow followed by more Jumbo sorghum. Sweetpotato sampled mid-crop in 2022 and numbers of RKN and reniform nematode undetectable.

RL11 Central Qld

Reniform nematode numbers peaked in 2020 after pigs, Algerian Oats rotation, bare fallow and Nimitz. Bare fallow followed from Sept 2021- April 2022 when both RKN and reniform nematode were undetectable. Few pumpkins, Swan oats and weeds sampled in October and numbers of reniform nematode beginning to climb up again. Planted sweetpotatoes (Orleans and mixed) with Nimitz, harvested smooth spuds with no sign of nematode damage. Sampled in June 2022, still no RKN, but reniform nematode high again.

RL15 Central Qld

RKN and reniform nematode numbers peaked in 2021 after a sweetpotato crop of Bellevue. Planted forage sorghum which seems to have reduced RKN to undetectable levels, but reniform nematode numbers are creeping up again. Reniform nematode numbers are hard to reduce once it has been found in a field.

Image 1 Left, Measurements and GPS coordinates were used to identify sampled areas within production blocks. Right, Project staff collecting soil samples wearing disposable boot covers.

Appendix 5

Initial Survey of sweetpotato producing soils

Sweetpotato soil surveys

PW17001 Final report Appendix 5 Integrated pest management of nematodes in sweetpotato

Mary Firrell August 2023

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

Hort Innovation SWEETPOTATO FUND

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Queensland Government

Sweetpotato soil surveys

Summary

Part A: Summary grower surveys

At the commencement of this project, sixty soil samples were taken from commercial sweetpotato farms across east coast growing districts and sent to the Department of Environment and Science (DES), Chemistry Centre for analysis.

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.

Results indicate there is a wide range of soil types that support sweetpotato production. Particle size analysis showed these sixty soils had clay contents ranging from a low of 1.2% to 72% and fine sand content ranging from 6% to 57% across all sites. The anticipated correlation between low numbers of nematodes and high clay content soils hasn't been encountered in this set of samples. Ferrosols are a favored soil for sweetpotato production in Australia, and though these have a clay content of over 50%, they have an open physical structure which is conducive to root-knot nematode survival and reproduction.

Total Organic Carbon (TOC) in the two main growing areas ranged from 0.21% to 2.35% in Bundaberg and 2.00% to 3.72% in Cudgen. Results were sent to individual growers along with a soil results interpretation guide, prepared by team members. See appendix 5.

Key Points

- A wide range of soil types support sweetpotato production in Australia.
- The average TOC % is higher in Cudgen, due in part to cooler temperatures and higher rainfall.
- TOC results vary widely between farms due to the stage of the crop cycle when sampling occurred, and to variations in grower management practices.

Part B: Summary baseline Carbon surveys

As part of this project, the team established a long term trial at Bundaberg Research Facility to investigate the use of organic amendments and composts to improve soil health and suppress root knot nematodes. Total Organic Carbon (TOC) results in this long term trial initially improved, however plateaued in the early stages of the trial. As a comparison between maximum TOC levels in the long-term trial, samples were taken from nearby undisturbed areas.

Soil samples were taken to a depth of 10cm, as this reflects the sampling depth for the long term trial and analysed for TOC at DES. Samples were taken from protected remnant vine scrub and an undisturbed tree line at BRF and from a best practice growers farm < 10 km from BRF.

The sample taken from the protected remnant vine scrub, gave a result of 7.22% TOC. This area has not been disturbed since white settlement and should have the highest possible carbon storage potential for the area. The sample taken from the undisturbed tree line established at least 30 years ago, gave a result of 5.22% TOC and a sample taken from a best grower practice farm, gave a result of 1.85% TOC. This compares to levels ranging from 1.86 – 2.43% in the amended treatments of the long term trial.

Part A: Summary grower surveys

Introduction

At the commencement of this project, sixty soil samples were taken from commercial farms across east coast growing districts and sent to the Chemistry Centre at the Department of Environment and Science for physical and chemical analysis.

Results were compared to nematode counts within the project, and a copy of the soil test specific to each farm was sent to that grower along with an interpretation guide (see example below)

In 2021, samples were also taken from undisturbed sites close to the Bundaberg Research Facility as a comparison with the long-term trial at BRF.

Image 4 Survey soil samples. Sweetpotatoes are grown on a range of soil types.

Methodology

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

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 (NO_3- N)
- Total Organic Carbon (TOC)
- Potassium Permanganate Oxidisable Carbon (POxC), (PPOC)
- Total nitrogen (TN)
- Colwell Phosphorous (P) + phosphorus buffer index (PBI_COL)
- Particle size analysis (PSA)

Each sample was also tested using the Solvita®CO2 Burst method for determining soil microbe respiration as an indication of microbial population levels. This burst test simulates a rain event (drying – wetting) by activating soil microbes which then respire and produce a burst of CO_2. Test results were sent to growers, however this test method wasn't continued past the initial stage of the project.

Part B: Summary baseline Carbon surveys

As a comparison between maximum TOC levels in the long-term trial, samples were taken from nearby undisturbed areas and sent to the Chemistry Centre for TOC analysis. A sample was taken from an area of protected remnant vine scrub, at the Bundaberg Research Facility, another sample taken from an undisturbed tree line established at least 30 years ago and another from a nearby good practice grower farm.

Image 5: Vine scrub sampling site at BRF, TOC =7.22%

Image 6 Undisturbed tree line at BRF with a TOC result of 5.22%

Image 7 Grower rotation cropping with a nematode resistant sorghum crop

Results and discussion

Soils analyzed, indicate that there is a wide range of soil types that support sweetpotato production, with clay content ranging from a low of 1.2% to 72% and fine sand content ranging from 6% to 57% across all sites. The anticipated correlation between low numbers of nematodes and high clay content of soils hasn't been encountered in this set of samples. Ferrosols are a favored soil for sweetpotato production in Australia, and though these have a clay content of over 50%, they have an open physical structure which is conducive to root-knot nematode survival and reproduction.

An extensive range of soil properties and chemistry was reported for the survey of grower soils. The samples were taken from different farms at varying times in the cropping cycle and under varied management regimes so the large variation in values is to be expected.

Table 6 Range of soil chemistry values from grower soil surveys

Range of values for grower soils			
	Lowest	Highest	Mean
pH	5.02	7.85	6.48
EC (dS/m)	0.02	0.42	0.11
P (mg/kg)	4	276	104
Cl (mg/kg)	21	362	70
NO3-N (mg/kg)	1	87	11
TOC (%)	0.21	3.7	1.64
Total N (%)	0.016	0.632	0.15

Total Organic Carbon (TOC) in the two main growing areas ranged from 0.21% to 1.93% in Bundaberg and 2.00% to 3.72% in Cudgen. The higher result for Cudgen soils can be due to cooler temperatures and higher average rainfall than that in Bundaberg.

Table 7 Total Organic Carbon values in grower's soils

Range of TOC values for grower survey soils (%)				
	Lowest	Highest	Mean	n
Cudgen	2.00	3.72	2.68	16
SEQ	0.28	1.78	0.99	6
Bundaberg	0.21	1.93	1.31	38
CQ	1.04	1.84	1.32	7
NQ	1.65	2.27	1.96	2
Pasture Cudgen		7.71		1
Pasture Bundaberg	2.18	4.13	3.16	2

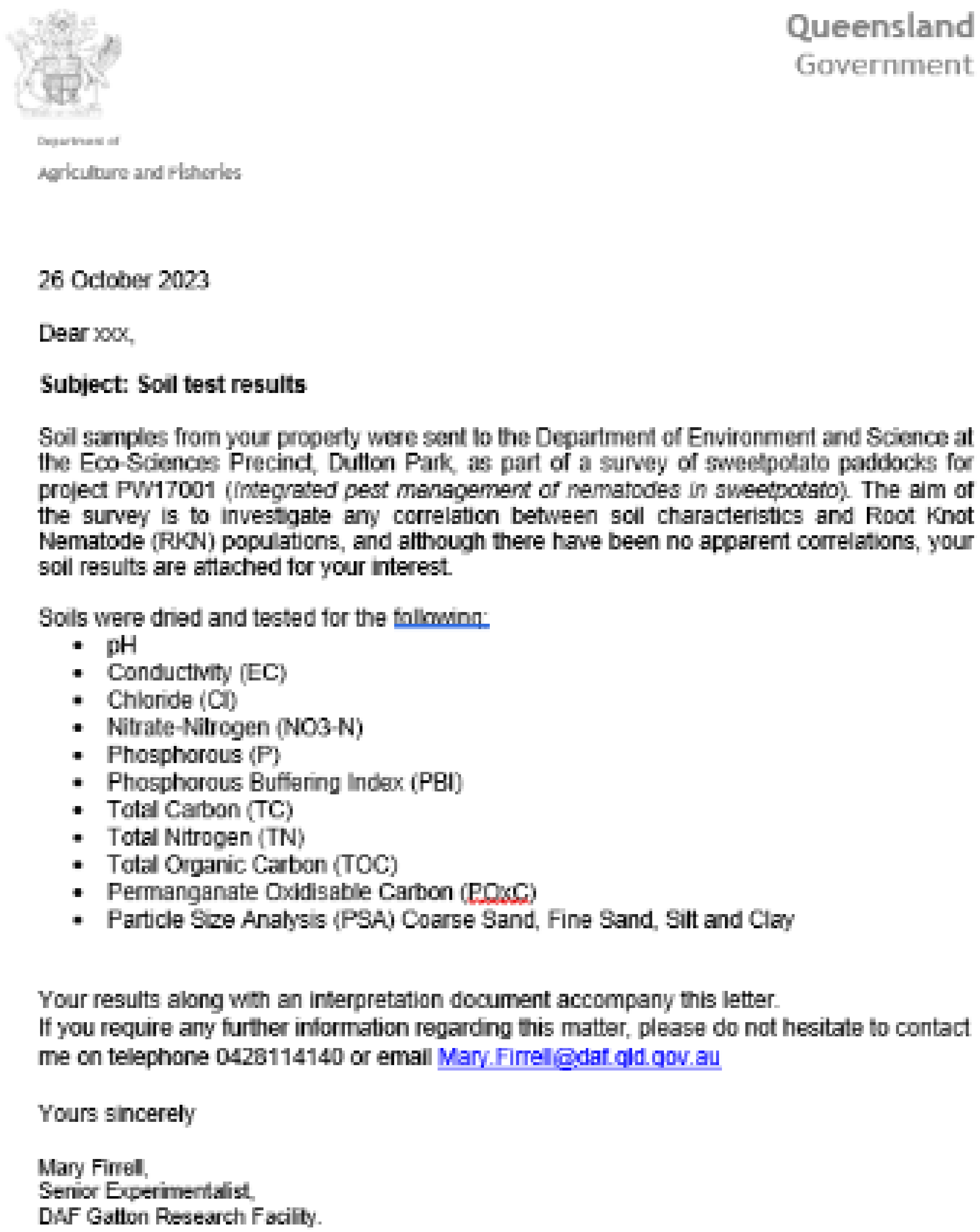
Results of the TOC survey of undisturbed sites reported 7.22% TOC for the area of protected remnant vine scrub. This area has not been disturbed since white settlement and should have the highest possible carbon storage potential for the area.

A sample taken from an undisturbed tree line established at least 30 years ago, gave a result of 5.22% TOC. This tree line had a large amount of dry leaf litter on the surface of the soil which is generally left untouched although the area is exposed to strong sunlight.

A sample taken from a nearby, best grower practice, commercial sweetpotato farm gave a result of 1.85% TOC. A nematode resistant sorghum cover crop had been grown and rotary hoed into the paddock with a considerable amount of stubble incorporated into the soil.

The levels of 1.86 – 2.43% TOC in the amended treatments of the Intensive Trial compare well to these results, with the trial amendments giving higher results than good grower practice but obviously not achieving the levels of undisturbed soil.

Soil test results example letter sent to sweetpotato growers



Queensland
Government

Department of
Agriculture and Fisheries

26 October 2023

Dear xxx,

Subject: Soil test results

Soil samples from your property were sent to the Department of Environment and Science at the Eco-Sciences Precinct, Dutton Park, as part of a survey of sweetpotato paddocks for project PW17001 (*Integrated pest management of nematodes in sweetpotato*). The aim of the survey is to investigate any correlation between soil characteristics and Root Knot Nematode (RKN) populations, and although there have been no apparent correlations, your soil results are attached for your interest.

Soils were dried and tested for the following:

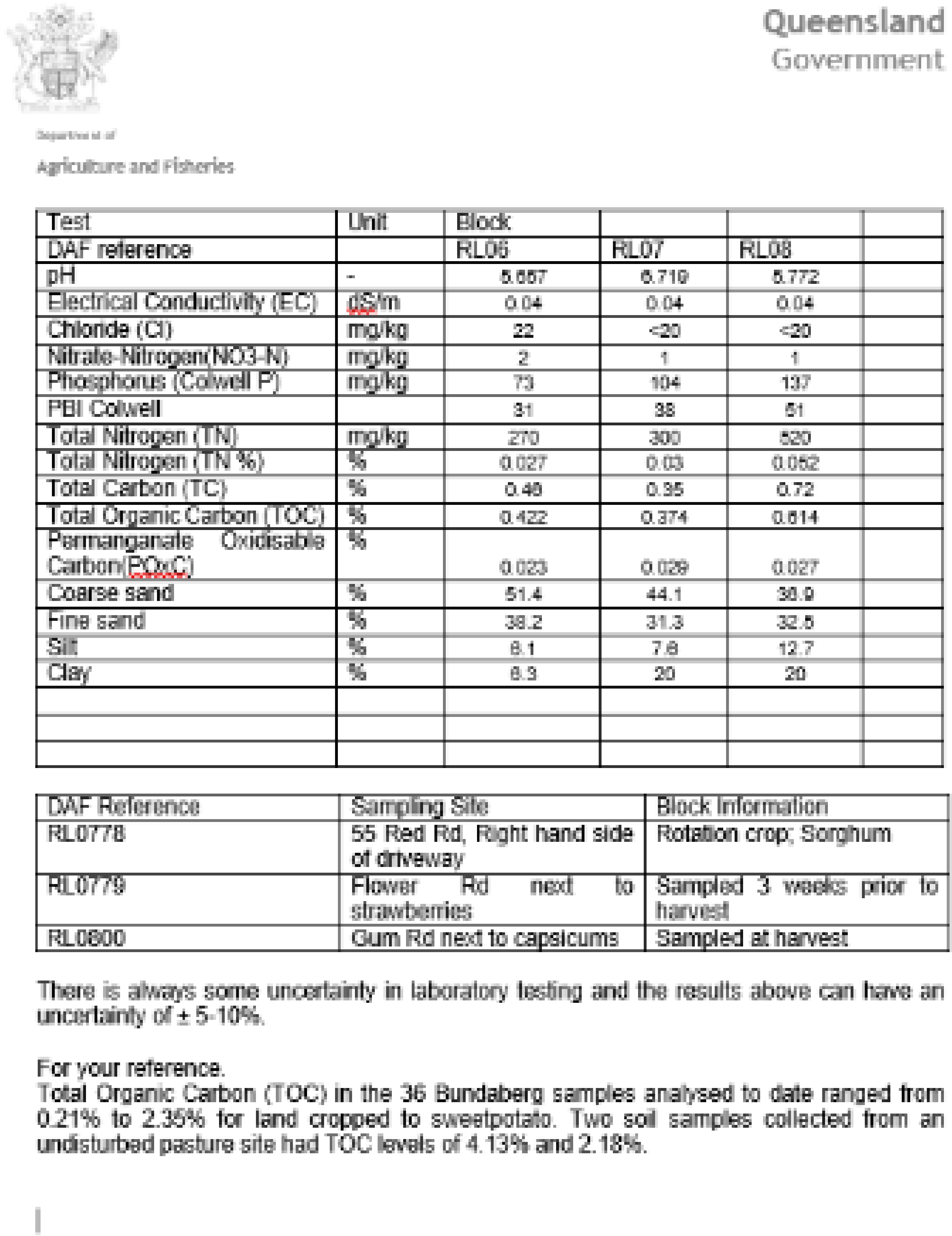
- pH
- Conductivity (EC)
- Chloride (Cl)
- Nitrate-Nitrogen (NO3-N)
- Phosphorous (P)
- Phosphorous Buffering Index (PBI)
- Total Carbon (TC)
- Total Nitrogen (TN)
- Total Organic Carbon (TOC)
- Permanganate Oxidisable Carbon (POxC)
- Particle Size Analysis (PSA) Coarse Sand, Fine Sand, Silt and Clay

Your results along with an interpretation document accompany this letter.
If you require any further information regarding this matter, please do not hesitate to contact me on telephone 0428114140 or email Mary.Firrell@daf.qld.gov.au

Yours sincerely

Mary Firrell,
Senior Experimentalist,
DAF Gatton Research Facility.

Image 8. Example letter soil test results.



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Test	Unit	Block			
DAF reference		RL06	RL07	RL08	
pH	-	5.657	5.719	5.772	
Electrical Conductivity (EC)	dS/m	0.04	0.04	0.04	
Chloride (Cl)	mg/kg	22	<20	<20	
Nitrate-Nitrogen(NO3-N)	mg/kg	2	1	1	
Phosphorus (Colwell P)	mg/kg	73	104	137	
PBI Colwell		31	38	51	
Total Nitrogen (TN)	mg/kg	270	300	520	
Total Nitrogen (TN %)	%	0.027	0.03	0.052	
Total Carbon (TC)	%	0.46	0.35	0.72	
Total Organic Carbon (TOC)	%	0.422	0.374	0.614	
Permanganate Oxidisable Carbon(POxC)	%	0.023	0.029	0.027	
Coarse sand	%	51.4	44.1	38.9	
Fine sand	%	38.2	31.3	32.5	
Silt	%	8.1	7.6	12.7	
Clay	%	6.3	20	20	

DAF Reference	Sampling Site	Block Information
RL0778	55 Red Rd, Right hand side of driveway	Rotation crop; Sorghum
RL0779	Flower Rd next to strawberries	Sampled 3 weeks prior to harvest
RL0800	Gum Rd next to capsicums	Sampled at harvest

There is always some uncertainty in laboratory testing and the results above can have an uncertainty of ± 5-10%.

For your reference.
Total Organic Carbon (TOC) in the 36 Bundaberg samples analysed to date ranged from 0.21% to 2.35% for land cropped to sweetpotato. Two soil samples collected from an undisturbed pasture site had TOC levels of 4.13% and 2.18%.

Image 9. Example letter soil test results.

Soil Test Information Guide sent to growers.

The below soil test interpretation guide was provided to growers with their soil test results.

Soil test interpretation guide

The following information is a brief background on the tests conducted on your soil.

Through the soil surveys and testing conducted for this project we hope to understand any correlations between soil characteristics and nematode populations.

pH

This is a measure of the acidity or alkalinity of the soil and influences the availability of nutrients to the plants.

- pH <7 = acidic
- pH 7 = neutral
- pH > 7 = alkaline
- A pH range from 5.5 to 7.0 is suitable for most vegetable crops
- A pH of 5- 7.5 is acceptable for sweet potatoes with an optimal range of 5.5 to 6.5

Electrical Conductivity (EC).

This is a measure of the salts (or salinity) in the soil and is usually reported as deciSeimens/metre (dS/m)

In sweet potato production, yields can decline rapidly as salt levels rise. Below are the ranges at which yield is reduced.

Table 8. Electrical conductivity readings.

EC reading	Yield Impact
≤ 1.5 dS/m	satisfactory
1.5-2.4 dS/m	0-10% yield reduction
2.4-3.8 dS/m	10-25% yield reduction
3.8-6.1 dS/m	25-50% yield reduction

Chloride (Cl)

Chloride is an important nutrient for plant growth and health however it can also cause damage if levels are too high. Fertiliser and irrigation water quality are the usual inputs that affect soil chloride levels. Sweet potato specific information is difficult to find however in general discussion with an agronomist, it seems that levels < 250mg/Kg are considered harmless.

Nitrate- Nitrogen (NO3-N)

This is a measure of nitrogen that is in the easiest form for plants to use. Nitrogen can be present in other forms (e.g. Organic N) that are not immediately available to the plant. The advice from an experienced sweet potato agronomist is that an optimum level in sweet potatoes is <20 mg/Kg

Phosphorus

Colwell P (Phosphorus). This is a direct measure of the phosphorus in the soil in mg/kg but this alone doesn't indicate the availability of P to plants and must be interpreted in conjunction with PBI.

Phosphorus Buffering Index (PBI). Phosphorus Buffering Index (PBI) is an indication of a soils ability to bind and release P. Soils with a high PBI will bind P and make it unavailable for plant uptake and soils with a low PBI will bind only small amounts of P.

Total Nitrogen (TN)

This is a measure of all forms of Nitrogen (N) in the soil sample and is made up of Organic N, often in the form of crop residues which aren't immediately available to plants, Ammonium forms of Nitrogen and Nitrate-Nitrogen (NO3-N)

Total Carbon

Total carbon(TC) Is the sum of all the carbon forms and is made up of; Total Organic Carbon (TOC) + Total Inorganic Carbon (minerals e.g. Calcium carbonate) + Elemental Carbon (e.g. graphite or charcoal).

Total Organic Carbon (TOC).

Total organic carbon is a measure of the Carbon(C) contained within the soils organic matter and is made from plant, animal and microbial residues. It consists of different fractions of C, one which is very stable and doesn't change much over time, this is often referred to as Recalcitrant/Resistant Organic C (ROC) but the other two fractions can be influenced by farming practices such as cover cropping and reduced tillage. These other 2 labile fractions are often referred to as Humus Organic Carbon (HOC) and Particulate Organic Carbon (POC)

Total Organic Carbon = Recalcitrant Organic Carbon (ROC) fraction which has a turnover time of 2500 years + slower fraction (HOC) with a turnover time of 20–40 years + labile fraction (POC) that has a turnover time of 2–3 years

Permanganate Oxidizable Carbon or (POxC)

Labile carbon is also made up of different fractions one of which is termed Permanganate Oxidizable Carbon or POxC. It has been correlated with microbial biomass and is a potential indicator of microbial activity.

Particle Size Analysis (PSA)

This is a measure of soil texture and categorises the soil as Coarse Sand, Fine Sand, Silt and Clay. A soil texture triangle is a tool that can be used to classify your soil based on particle size distribution.

Using the soil texture triangle

The soil texture triangle, below, is used to convert particle size distribution into a recognised texture class for a soil based on the relative amounts of sand, silt and clay as a percentage.

Example A: – Sand 50% + Silt 30% + Clay 20% = SILTY LOAM

The grid on the triangle allows you to move to the left or the right of your position running parallel with either side of the triangle. It is best to start at the base with the sand. Position your finger along the base line at the 50% mark. Move your finger up the line running parallel with the right side of the triangle. Simultaneously use another finger to trace a line from the 30% silt mark until the two meet. Your two fingers will always meet at clay for the remaining percentage, in this case 20%. This is always the case that the first two sizes chosen will lead you to the third.

Example B – Sand 80% + Silt 5% + Clay 15% = SANDY LOAM

Trace your finger along the 80% sand line while simultaneously tracing another finger along the 5% silt line until the two meet. This should be where clay is 15%.

Ref:(Katharine Brown (The University of Western Australia) and Andrew Wherrett (Department of Agriculture and Food, Western Australia).http://soilquality.org.au/

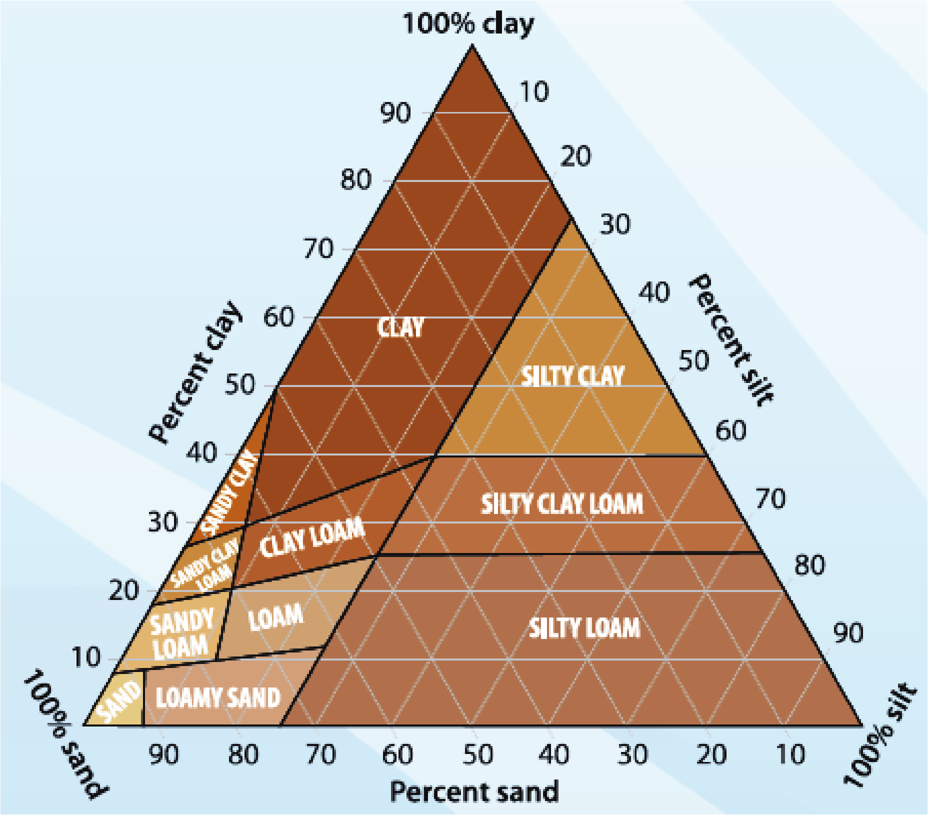

Figure 2 The soil texture triangle *Image adapted from Hunt and Gilkes (1992).* http://soilquality.org.au/

Further Reading.

The following references are general Australian soil references and although not specific to sweetpotato provide background information about soil characteristics and testing. The Nitrogen Book was written as a resource for grain growers but may be of interest.

Soil health for vegetable production in Australia—Part 4: Measuring soil health
https://www.daf.qld.gov.au/__data/assets/pdf_file/0011/77519/Soil-health-vegetable-production-Part_3a.pdf

The Soil Quality Website http://soilquality.org.au/

https://www.hort360.com.au/wordpress/uploads/Nutrient/Decision/Soil_Test_Interpretation_Guide_1.pdf

The Nitrogen Book. Principles of soil nitrogen fertility management in central Queensland farming systems.

https://www.daf.qld.gov.au/business-priorities/agriculture/plants/crops-pastures/broadacre-field-crops/cropping-efficiency/nitrogen-books

Hazelton P. and Murphy B. (2013) “Interpreting soil test results. What do the numbers mean?” CSIRO Publishing: Collingwood, Vic., Australia

Katharine Brown (The University of Western Australia) and Andrew Wherrett (Department of Agriculture and Food, Western Australia).http://soilquality.org.au/

Carbon Dioxide (CO_2) and Carbon (C) Test Result.

Carbon Dioxide (CO_2) as measured in the soil samples collected from your farm is an indication of biological activity within your soil.

We have used a test called the Solvita CO_2- Burst test where we have taken a subsample of your soil, warm dried it, added a measured quantity of water, a CO_2 probe and then incubated it for 24 hours. At the end of the 24-hour period we have read the colour change of the probe in ppm CO_2.

This burst test simulates a rain event (drying – wetting) by activating soil microbes which then respire and produce a burst of CO_2.

The following is a guide to interpreting the test result you have received for your soil.
Table 9. Carbon dioxide interpretation giude.

Level of CO_2-C as ppm	**Calibration to Suggested Soil Biological Fertility Classes and Soil Condition**
165 - 400	Unusual High-Biology Soil, High N-min Potential
70 - 165	Typical High Biology Soil, Strong N-min Potential
30 - 70	Medium Biology Soil, Some N-min Potential
12 - 30	Medium-Low, Low N-min Potential
5 - 12	Typical Low Biology Soil, Very Low N-min Potential
<5	Soil Very Low in Microbes, No N-min Potential

Adapted from Solvita Soil CO2-Burst Official Solvita Instructions Version 2016/1

The supplier of the Solvita test states:

“The quantity of CO2 evolved is proportional to microbial biomass. This burst of soil CO2 has been associated with positive nutrient fluxes and rapid availability to plants from mineralization”. (Woods End Laboratories)

Carbon

A sample of your soil was sent to the Lismore laboratories of Southern Cross University.

The following table may be used as a guide to interpreting your test result.

Table 10 Range of Proposed rating levels for soil carbon to assess soil health or soil condition. *will depend on texture, soil sodicity and presence of free iron.

Level of Organic carbon (%) (g/100g)	Rating	Band	Interpretation*
<0.40	Extremely low	1	Subsoils or severely eroded, highly degraded surface soils
0.40-0.59	Very low	2	Very poor structural condition, very low structural stability.
0.60-0.79	Low L1	3	Poor to moderate structural condition, low to moderate structural stability.
0.80-0.99	Low L2	4	
1.00-1.19	Moderate M1	5	The following improve with increasing soil carbon levels: structural stability, pH buffering capacity, soil nutrient levels (especially nitrogen), water holding capacity
1.20-1.39	Moderate M2	6	
1.40-1.59	Moderate M3	7	
1.60-1.79	High H1	8	Good structural condition, high structural stability, pH buffering capacity, soil nutrient levels (especially nitrogen), water holding capacity
1.80- 1.99	High H2	9	
2.00-2.19	Very high VH1	10	Soils with very good soil structure and high buffering capacity with sufficient organic matter to decrease bulk density and improve water holding capacity
2.20-2.39	Very high VH2	11	
2.40-2.59	Very high VH3	12	
2.60-2.99	Very high VH4	13	

3.00-8.70	Extremely high	14	Soils obviously have high levels of organic matter (dark coloured, greasy to touch and large amount of organic material in the soil). Usually associated with undisturbed woodlands and forested areas.
>8.70	Organic soil material	15	Highly organic soil including peat.

References

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Culman, S.W., Snapp, S.S., Freeman, M.A., Schipanski, M.E., Beniston, J., Lal, R., Drinkwater, L.E., Franzluebbers, A.J., Glover, J.D., Grandy, A.S., Lee, J., Six, J., Maul, J.E., Mirsky, S.B., Spargo, J.T. and Wander, M.M. (2012), Permanganate Oxidizable Carbon Reflects a Processed Soil Fraction that is Sensitive to Management. Soil Science Society of America Journal, 76: Issue 12

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Hong S, Gan P, Chen A. (2019) Environmental controls on soil pH in planted forest and its response to nitrogen deposition. Environmental Research 2019;172:159–165.

Soil health for vegetable production in Australia—Part 4: Measuring soil health https://www.daf.qld.gov.au/__data/assets/pdf_file/0011/77519/Soil-health-vegetable-production-Part_3a.pdf

The Soil Quality Website http://soilquality.org.au/

The Nitrogen Book. Principles of soil nitrogen fertility management in central Queensland farming systems.

https://www.daf.qld.gov.au/business-priorities/agriculture/plants/crops-pastures/broadacre-field-crops/cropping-efficiency/nitrogen-books

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Katharine Brown (The University of Western Australia) and **Andrew Wherrett** (Department of Agriculture and Food, Western Australia).http://soilquality.org.au/

Appendix 6

Follow on nematode surveys.

Follow on surveys

PW17001 Final report Appendix 6 Integrated pest management of nematodes in sweetpotato

Jennifer Cobon, August 2023

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

Hort Innovation SWEETPOTATO FUND

This project has been funded by Hort Innovation using the sweetpotato research and development levy and funds from the Australian Government. For more information on the fund and strategic levy investment visit horticulture.com.au

Queensland Government

Introduction

Monitoring of fields was carried out during the length of the project at blocks where growers were concerned crops were being affected by persistent nematode infections. Blocks were resampled and soil samples were processed to determine the number of plant-parasitic nematodes present and whether these nematode species could be impacting yield and marketable product.

Materials and Methods

General methods are described in detail in appendix 2.

Results and discussion

Four blocks in northern NSW and seven blocks in Central Qld were monitored. The major nematode species in northern NSW were root-knot nematode (RKN) and lesion nematode. In Central Qld the blocks were infested with very high numbers of root-knot nematode (D50, 10,599/200 g dry weight soil) or high numbers of reniform nematode (D36 and D37) (Table 1). In Central Qld, where root-knot and reniform nematodes are plentiful, it appeared that the two species were not in high numbers in the same block. Where there were high numbers of reniform nematodes in a block, there were low numbers of root-knot nematode and vice versa.

Analysis of these samples has led to increased knowledge on nematode distribution for growers and researchers. Growers have a greater understanding of the plant-parasitic nematodes in their fields and of those species impacting crop yields and damage. Individual growers have been informed of all nematode species in their blocks and population changes over time.

Table 11 Plant-parasitic nematode extracted from 'follow up' soil samples received during the course of the project.

			Plant-parasitic nematodes/200 g DW soil										
Sample ID	Sample ID	Region	Root-knot *Meloidogyne* spp.	Reniform *Rotylenchulus reniformis*	Lesion *Pratylenchus* sp.	Reniform *Rotylenchulus parvus*	Spiral *Helicotylenchus dihystera*	Spiral *Rotylenchus brevicaudatus*	Stubby *Paratrichodorus* sp.	Dagger *Xiphinema* sp.	Stunt *Tylenchorhynchus* sp.	Ring *Criconemella* sp.	Total Free-living Nematodes
EC05	2018	northern NSW	46	0	0	0	8	0	0	0	0	0	2282
EC05	2020	northern NSW	0	0	0	0	9	0	0	0	0	1	1232
EC05	2021	northern NSW	217	0	0	0	123	8	6	0	0	0	979
EC05	2022	northern NSW	37	0	12	0	128	0	92	0	0	44	917
EC05	2022	northern NSW	6	0	0	0	85	0	21	0	0	1	913
RL24 A	2020	northern NSW	1	0	9	2	8	0	0	0	0	0	889
RL24 B	2020	northern NSW	30	0	10	24	35	0	0	0	0	0	819
RL24 C	2020	northern NSW	140	0	0	0	39	0	0	0	0	0	1662
RL20	2018	northern NSW	34	0	4	0	120	0	1	0	0	0	1119
RL20	2022	northern NSW	2	0	0	0	54	7	3	0	0	0	310
RL25	2018	northern NSW	4	0	0	0	25	0	1	0	0	1	1084
RL25	2022	northern NSW	92	0	0	0	17	0	2	0	0	0	260
RL65A	2020	Central Qld	2	176	6	0	0	0	0	0	0	0	3777
RL65B	2020	Central Qld	1	37	22	0	0	0	0	0	0	0	2217
RL65B	2022	Central Qld	0	122	5	0	0	0	0	0	0	0	1260
D36	2020	Central Qld	1	0	0	0	0	42	0	0	0	0	624
D36	2021	Central Qld	39	4213	0	0	0	39	0	0	0	0	1482
D36	2022	Central Qld	0	0	0	0	0	1	0	0	0	0	267
D36	2022	Central Qld	0	180	0	0	0	0	0	0	0	0	343
D36	2023	Central Qld	0	742	0	0	0	0	0	0	0	0	1819

D37	2020	Central Qld	0	57	0	0	0	1	0	0	0	0	541
D37	2021	Central Qld	0	804	0	0	0	0	0	0	0	10	3916
D37	2022	Central Qld	0	0	0	0	0	18	0	0	0	0	742
D37	2022	Central Qld	0	91	0	0	0	0	0	0	0	0	181
D37	2023	Central Qld	0	3371	0	0	0	0	0	0	0	0	3339
D38	2020	Central Qld	0	42	0	0	0	0	1	0	8	5	612
D38	2021	Central Qld	0	0	0	2	0	0	0	0	1	2	509
D38	2022	Central Qld	0	0	3	0	0	0	12	0	0	0	992
D38	2022	Central Qld	103	3	0	0	0	0	4	0	5	0	1715
D38	2023	Central Qld	550	0	0	0	0	0	0	0	0	5	243
D50	2021	Central Qld	10599	0	0	0	0	0	0	0	0	89	1191
D50	2022	Central Qld	797	0	0	0	0	0	0	0	0	0	564
D50	2022	Central Qld	23	0	0	0	0	0	0	0	0	15	1721
D50	2023	Central Qld	2974	0	0	0	0	0	0	0	0	28	333
RL12	2018	Central Qld	1	0	44	0	2	0	1	0	0	0	895
RL12	2021	Central Qld	0	0	0	0	0	0	0	0	0	1	387
RL12 C	2022	Central Qld	0	0	2	0	0	0	0	0	0	3	622
RL12 T	2022	Central Qld	326	0	0	0	0	0	16	0	0	32	538
RL12 V	2022	Central Qld	9	0	0	0	0	0	0	0	1	3	368
RL12	2022	Central Qld	47	0	16	0	0	0	1	0	10	1	1304
RL12	2023	Central Qld	0	2	2	0	0	0	0	0	0	2	259
RL64	2020	Central Qld	0	0	25	0	28	0	0	1	0	0	1173
RL64	2021	Central Qld	0	1	0	0	2	19	0	0	0	0	991
RL64	2022	Central Qld	0	20	0	0	0	2	0	0	0	0	1525
RL64	2022	Central Qld	0	0	0	0	0	210	0	35	0	17	2639
RL64	2023	Central Qld	0	2	0	0	0	3	0	0	0	0	1096

Selected case studies

EC05 northern NSW

Root-knot nematode numbers relatively low, highest in 2021 (217/200 g dry weight soil) when sampled post-harvest. This had been a “wonderful crop” of Orleans. Used rotations of Jumbo sorghum. Numbers of RKN low post-harvest 2022 (6/200 g dry weight soil).

RL24 northern NSW

A rows 1-10, treated with Nimitz and Vydate after planting, 1 RKN, 9 lesion nematode.B rows 11-15, Nimitz 30 RKN, 10 lesion nematodes.C rows 35-45, Metham, 140 RKN, zero lesion nematode.

D50 hot spot area Central QLD

First sampled in 2021 just after harvest of Golds with visible pimples on spuds (RKN 10,599/200 g dry weight soil). Sprayed to kill the nightshade and Mexican poppy, both very good hosts of RKN. Bare fallow in 2022 and resampled, RKN 797/200g dry weight soil. Fumigated with methane and numbers reduced RKN to 23/200 g dry weight soil. Planted Orleans, Vydate applied to label, soil sampled at harvest, 2,974/200 g dry weight soil. Still RKN pressure (black eyes and pimpling), but not as severe as at 2021.

D36 hot spot area A Central Qld

Sampled after Nimitz 2020, 1 RKN and zero reniform nematode/200 g dry weight soil. Pigs to remove volunteers in Sept 2021 when sampled. Thirty-nine RKN and reniform nematode 4213/200 g dry weight soil. Used heavy black clay and bare fallowed, zero RKN and zero reniform nematode. Bare fallow, roundup, Nimitz, zero RKN and 180 reniform nematode/200g dry weight soil in Oct 2022. Applied Vydate and planted 4 varieties, no signs of nematode damage. Sampled after short fallow, zero RKN and 742 reniform nematode/200g dry weight soil. Reniform nematode hard to control once the field is infested.

D37 hot spot area A Central Qld

Sampled after previous crop of Lush sorghum. Zero RKN and 57 reniform nematode/200 g dry weight soil. Pigs to remove volunteers in Sept 2021 when sampled – zero RKN and 804 reniform nematode/200 g dry weight soil. Used heavy black clay and bare fallowed and Jumbo, zero RKN and zero reniform nematode. October 2022, zero RKN and 91 reniform nematode/200 g dry weight soil. Four sweetpotato varieties, no signs of nematode damage, fallow, pigs in block, June 2023 – zero RKN and 3,371 reniform nematode. Reniform nematode hard to control once the field is infested.

Image 1 A block sampled post-harvest in response to high crop damage levels.

Appendix 7

Diagnostic soil samples

Diagnostic samples

PW17001 Final report Appendix 7 Integrated pest management of nematodes in sweetpotato

Jennifer Cobon, August 2023

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

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Summary

During the project, 61 soil samples were received from sweetpotato growers experiencing nematode problems in their blocks. Soil samples were processed to determine the number of plant-parasitic nematodes present and whether these nematodes could be impacting yield and marketable product. Damaged and mishappen sweetpotatoes and root material was also received to assist with diagnosing plant-parasitic nematode problems.

Outputs

Grower field days presentations

PRG meeting presentations

Outcomes

Diagnostic samples assist growers and researchers to improve knowledge of nematode distribution for

Growers have a greater understanding of the plant-parasitic nematodes in fields and of the ones causing the impacts to crop yield and damage.

Individual growers have been informed of all nematode species in their blocks and changes over time.

Introduction

During the project, 61 soil samples were received from sweetpotato growers experiencing nematode problems in their blocks. Soil samples were processed to determine the number of plant-parasitic nematodes present and whether these nematodes could be impacting yield and marketable product. Damaged and mishappen sweetpotatoes and root material was also received to assist with diagnosing plant-parasitic nematode problems.

Materials and methods

General methods are described in detail in appendix 2.

Results and discussion

The results of the diagnostic soil samples (Table 1) determined that Meloidogyne spp., (root-knot nematode) was the most commonly detected nematode pest in sweetpotato (Table 1). Forty-two of the 61 sites (69%) across all regions were identified with root-knot nematode present with numbers ranging from 1 – 10,599/200 g dry weight soil in Central Qld. In Wide Bay, 19 of 25 sites (76%) were found to have Meloidogyne spp., with 1 of 1 site (100%) in northern NSW, 9 of 18 sites (50%) in Central Qld, 4 of 5 sites (80%) in southern Qld and 9 of 12 sites (75%) in North Qld all similarly infested with Meloidogyne spp.

Rotylenchulus reniformis (reniform nematode) which is a major pest in the USA was present at some sites, mainly in the warmer areas with 6 of 25 sites (24%) in Wide Bay, 14 of 18 sites (78%) in Central Q and 1 of 12 sites (8%) in North Qld. Numbers ranged from 1- 1,257/200 g dry weight soil in Central Qld.

Pratylenchus zeae was found from 9 sites (36%) in Wide Bay, 9 sites (50%) in Central Qld, 2 sites (40%) in southern Qld and 9 sites (75%) in North Qld.

Many other species of plant-parasitic nematode were present (Table 1), but these species are not considered to be pathogenic on sweetpotato crops.

Table 1 Plant-parasitic nematodes in sweetpotato production from diagnostic soil samples received from 2018 –2023.

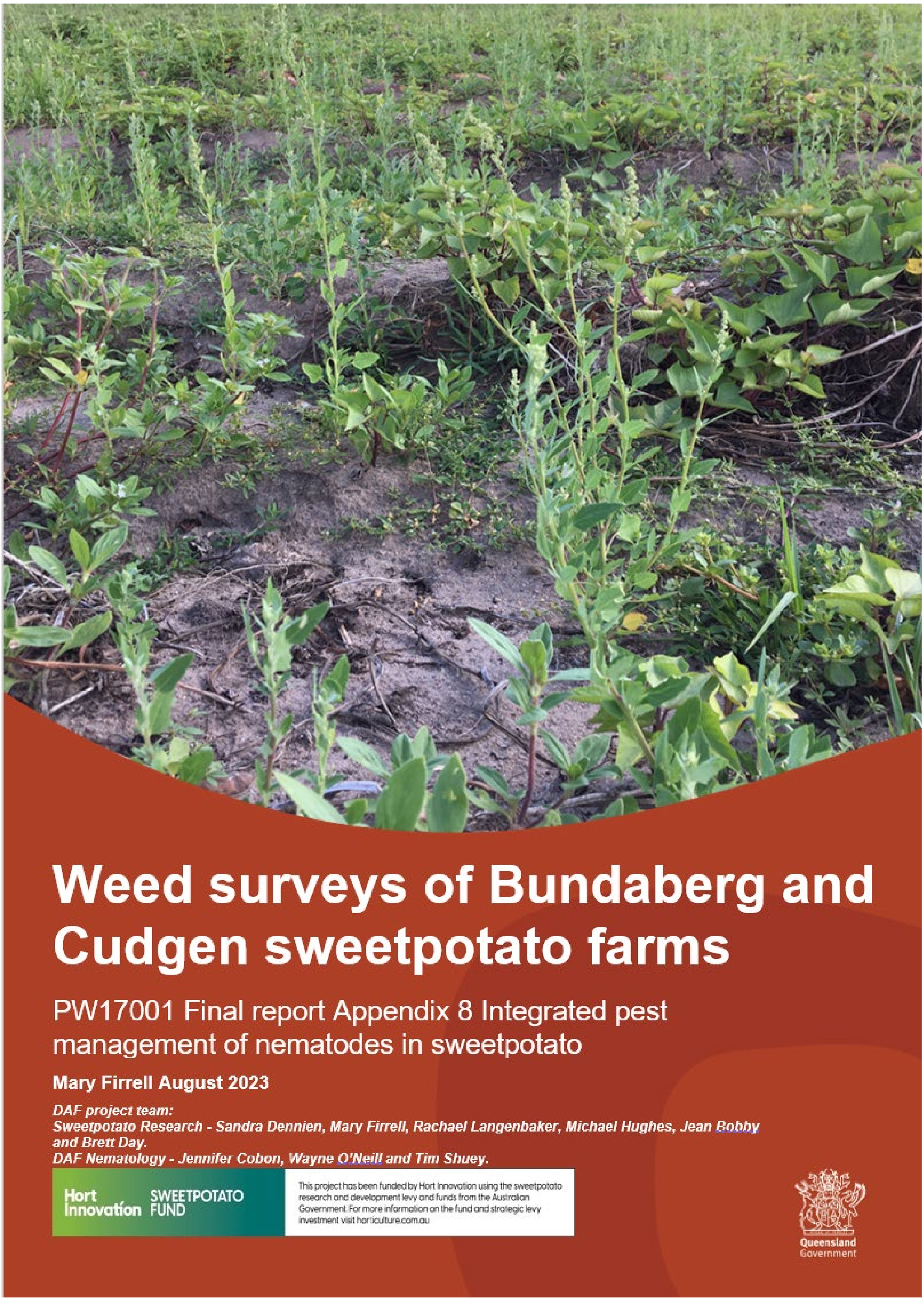
		Plant-parasitic nematodes /200 g DW soil										
Grower ID	Region	Root-knot *Meloidogyne* spp.	Reniform *Rotylenchulus reniformis*	Lesion *Pratylenchus* spp.	Reniform *Rotylenchulus parvus*	Spiral *Helicotylenchus dihystera*	Spiral *Rotylenchus brevicaudatus*	Stubby *Paratrichodorus* sp.	Dagger *Xiphinema* sp.	Stunt *Tylenchorhynchus* sp.	Ring *Criconemella* sp.	Total Free-living nematodes
D01 b	Wide Bay Qld	191	0	0	0	2725	0	0	0	0	0	1362
D03	Wide Bay Qld	871	0	0	0	0	0	0	0	0	0	3399
D04	Wide Bay Qld	8	0	0	0	59	164	40	0	0	0	
D06	Wide Bay Qld	51	0	48	0	11	0	5	0	0	0	2326
D23B	Wide Bay Qld	223	0	0	0	0	1414	0	0	0	0	1646
D24	Wide Bay Qld	20	0	3	9	97	0	3	0	0	0	3167
D25	Wide Bay Qld	0	0	0	0	0	0	0	0	0	0	463
D30	Wide Bay Qld	1078	0	0	0	0	0	0	0	0	0	2777
D35	Wide Bay Qld	104	0	11	0	0	0	2	0	0	1	2064
D41	Wide Bay Qld	1	1	0	0	161	0	0	0	0	0	470
D42	Wide Bay Qld	276	0	0	12	35	2	12	0	75	0	1246
D43	Wide Bay Qld	0	0	0	0	0	0	0	0	7	0	602
D44	Wide Bay Qld	1	0	4	0	0	136	0	0	0	0	532
D45	Wide Bay Qld	5	0	1	0	0	269	0	0	0	0	1238
D46	Wide Bay Qld	27	0	4	0	0	87	0	0	0	2	1090

D47	Wide Bay Qld	0	576	0	0	0	0	0	0	0	0	576
D47.1	Wide Bay Qld	64	1421	0	0	0	0	0	0	0	0	
D47.2	Wide Bay Qld	17	67	0	0	0	0	0	0	0	0	
D47.3	Wide Bay Qld	4	23	0	0	0	0	0	0	0	0	
D47.4	Wide Bay Qld	0	12	0	0	0	0	0	0	0	0	
GS02A	Wide Bay Qld	0	0	11	1	1	0	0	0	0	0	456
GS02B	Wide Bay Qld	0	0	22	19	6	0	0	0	0	0	296
C7 meth	Wide Bay Qld	140	0	0	0	10	0	0	0	0	2	140
C7 no m	Wide Bay Qld	269	0	0	0	16	0	0	0	0	5	269
D34A&B	Wide Bay Qld	84	0	1	0	0	0	1	0	0	1	84
TB01	northern NSW	88	0	0	0	84	0	2	0	0	2	877
D12	Central Qld	5	0	0	0	0	0	0	0	0	0	696
D13	Central Qld	0	163	0	0	3	0	0	0	0	0	589
D36	Central Qld	1	0	0	0	0	42	0	0	0	0	624
D37	Central Qld	0	57	0	0	0	1	0	0	0	0	541
D38	Central Qld	0	42	0	0	0	0	1	0	8	5	612
D39	Central Qld	1	1	0	0	0	0	0	0	6	0	1079
D40	Central Qld	12	0	4	0	0	0	0	0	0	0	1810
D50	Central Qld	10599	0	0	0	0	0	0	0	0	89	1191
D54	Central Qld	0	330	23	0	0	0	0	0	0	0	2192
D55	Central Qld	1	4	0	0	0	0	0	0	2	1	3165
D61	Central Qld	0	35	23	0	4	0	0	0	0	1	1675
D62	Central Qld	0	1	4	0	21	0	0	0	0	0	2640
D63	Central Qld	1829	10	17	0	0	0	0	0	0	0	915

D64	Central Qld	0	7	1	0	0	0	0	0	0	0	3679
D65	Central Qld	2	2	7	0	0	0	0	0	0	0	2413
D66	Central Qld	0	1	7	0	0	0	0	0	0	0	3857
D67	Central Qld	191	1	0	0	0	0	0	0	0	0	3216
EC10	Central Qld	2114	1257	0	0	0	0	0	0	0	0	0
D32	southeast Qld	5	0	0	0	5	14	0	0	0	0	1413
D57	southeast Qld	79	0	0	0	113	21	1	0	0	0	5551
D58	southeast Qld	0	0	3	0	64	1	0	0	0	0	3667
D59	southeast Qld	4	0	3	0	112	0	0	0	0	0	3294
D60	southeast Qld	11	0	0	0	7	0	0	0	0	0	2935
D26	North Qld	1246	12	0	48	0	0	0	0	0	0	2516
D27	North Qld	53	0	0	25	0	0	0	0	0	0	4665
D28	North Qld	3707	0	0	0	0	0	0	0	0	0	6516
D31	North Qld	1	0	8	0	0	0	0	0	0	0	7274
D48	North Qld	28	0	69	8	0	0	0	0	0	0	2841
D49	North Qld	0	0	33	19	0	0	0	0	0	0	5295
D51	North Qld	248	0	157	0	0	0	0	0	0	0	2329
D52	North Qld	11	0	153	0	0	0	0	0	0	0	5838
D53	North Qld	234	0	4	0	0	0	0	0	0	0	3761
MHa	North Qld	0	0	3	0	0	0	1	0	0	0	3246
MHb	North Qld	0	0	730	0	0	7	0	0	0	0	9252
MHc	North Qld	3	0	1	33	1	0	0	0	0	0	2903

Appendix 8

Weed Surveys of Bundaberg and Cudgen Sweetpotato Farms



Weed surveys of Bundaberg and Cudgen sweetpotato farms

PW17001 Final report Appendix 8 Integrated pest management of nematodes in sweetpotato

Mary Firrell August 2023

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

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Queensland Government

Weed Surveys of Bundaberg and Cudgen Sweetpotato Farms

Summary

Surveys of commonly occurring weeds in sweetpotato crops were made at intervals from November 2019 – September 2022 at both Cudgen and Bundaberg.

The weeds were identified to species or genus level and the nematode-host database, Nemaplex, was used to determine if the most commonly occurring weeds identified, were root knot nematode hosts. As this is a large database with multiple entries for many species, some conflicting host status has been reported, no doubt due to genetic, edaphic and climatic factors affecting both plant and nematode.

A list of weeds surveyed, was tabulated with the common and scientific names of the weeds, the season and district they were found in and the susceptibility of these weeds to *Meloidogyne javanica, M. incognita* and M. *enterolobii* and to *Rotylenchulus reniformis*. This susceptibility information is sourced solely from the Nemaplex database and although the status of *M enterolobii* (Guava root knot nematode) is often unknown, it would be reasonable to assume for each weed, that this would be similar to other Meloidogyne species. The table is contained in Appendix 8.

Despite a mature sweetpotato crop giving good coverage which should out compete weeds, crops were observed during the survey, with heavy, nematode susceptible, weed infestations.

During the field surveys, observations were also made of paddocks with nematode resistant cover crops which had been mulched and left on the soil surface to provide a dense trash blanket. This was extremely effective in suppressing weed growth, while allowing the cover crop to regrow and provide more biomass for later incorporation.

Although the tabulated information in appendix 8 lists susceptibility or resistance status of weeds to root knot nematode, the best method of avoiding the proliferation of plant pathogenic nematodes is cover cropping with a known nematode resistant cover crop, as even relatively poor hosts can allow root-knot nematode to persist in a field between crops.

Bare fallow is also an effective strategy for reducing nematode populations, however, is not recommended from a soil health perspective and control of weeds in bare fallow is essential.

Ad hoc sampling of weeds in field trials and during grower visits revealed the presence of root-knot nematode on many common horticultural weeds and demonstrated the very wide host range of the pests. Even relatively poor hosts can allow root-knot nematode to persist in a field at elevated levels between sweetpotato crops, so control of weeds in bare fallows and resistant rotations is essential. Due to the very wide host range, it is wise to assume that all weeds are hosts for root-knot nematode.

Key points

A table has been produced identifying the most commonly encountered weeds in sweetpotato crops and the host status recorded of susceptibility to root knot nematode. See appendix 8.

As root knot nematode have a very wide host range all weeds should be considered hosts.

Control of weeds in a resistant cover crop or bare fallow is essential.

Introduction

Information on the host status of the most common weeds was obtained, and by using the Nemaplex website and other literature to locate published information. by checking roots for galling and egg masses representative collection of weeds in the field

Methodology

During the project, a number of weed species were identified during soil sampling trips to grower's farms in Cudgen and Bundaberg.

Collections were made in:

- November 2019
- October 2020
- January 2021
- September 2021
- April 2022
- September 2022

Only species that were commonly occurring in a single paddock or were occurring across a range of farms were identified for use with the nematode – host database, Nemaplex.

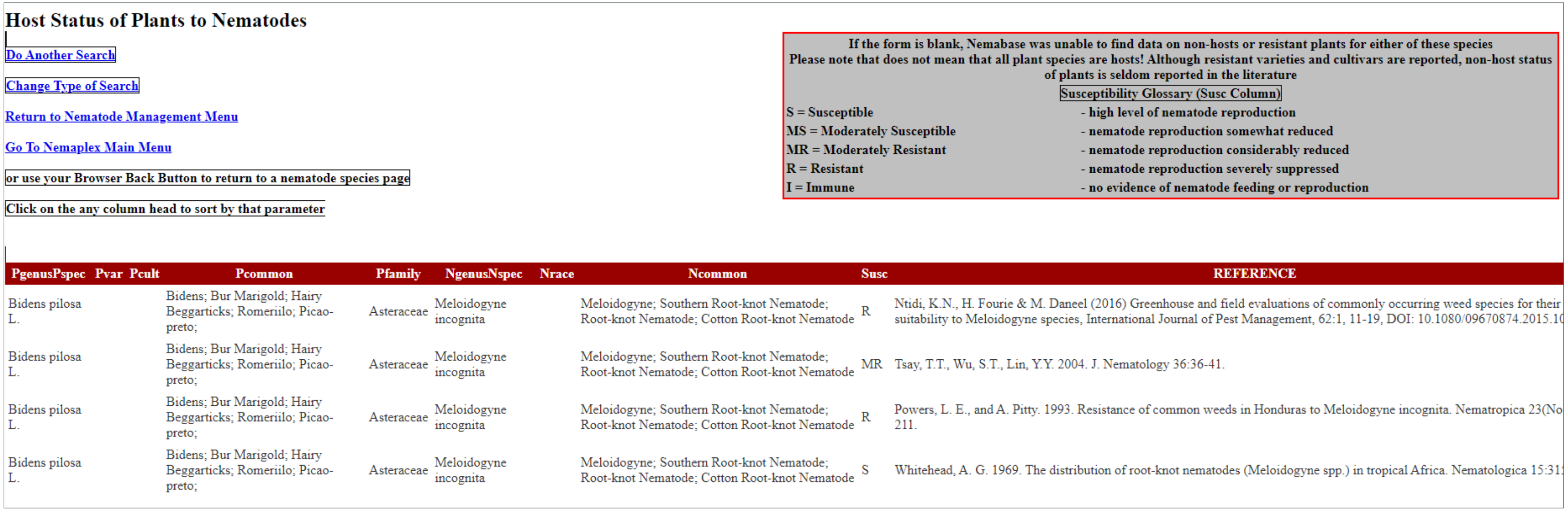
The database 'Nemaplex' was developed by Howard Ferris at University of California Davis in 1999, and is a continually updated and maintained international, interactive database which can be accessed through a web browser. Research papers are referenced, and information extracted and compiled to give a host status of plants. Currently Nemabase has 61,701 entries with data on 7,285 different plants from 236 plant families and 1,614 nematode species. It references publications from all countries and over many years with some from the 1950s to the present.

Within Nemaplex, is a database of plant - host status and this was used to summarise and produce a table to compile information about the most commonly encountered weeds in sweetpotato paddocks in both Bundaberg and Cudgen. Some weeds were assessed for nematodes through observation of galls either in-field (image 3) or by growing field-collected seed in nematode inoculated pots in the GRF glasshouse where observation of galling was made (image 4). This was an opportunistic study as not all weeds were treated this way, but it allowed for casual observation using some readily available resources.

Results and discussion

Nemaplex is a large database with many entries for each weed species and some have conflicting susceptibility status, reported by various references (Figure 1 and Figure 2). As this is an international database, these differences could perhaps be attributed to different races of nematodes or even variations within weed species between countries. Where multiple entries document conflicting status, the worst case (and often the most frequently reported is used) in the table. The table contains duplicate entries of the same weed to capture the occurrence of a species throughout the seasons and regions e.g.: Blackberry nightshade (Solanum nigrum) was present in Bundaberg in late spring and summer and in Cudgen in mid-spring. Naturally, it may also occur at other times throughout the year, but our survey represents a snapshot of a particular location (farm) and time. Visual identification of cultivars and sometimes species, in field collected plants isn't always possible, so in some cases genus only, is used to identify the weed e.g.: Sorghum spp. This presents a complication as susceptibility can be cultivar dependent.

Table 1 below lists the common and scientific names of the weeds observed, the season and district they were found in and the susceptibility of these weeds to Meloidogyne javanica, incognita and enterolobii and to Rotylenchulus reniformis. This susceptibility information is sourced solely from the Nemaplex database and although the status of M enterolobii (Guava root knot nematode) is often not specified or unknown, it would be reasonable to assume, for each weed this would be similar to other Meloidogyne species.



Host Status of Plants to Nematodes

Do Another Search

Change Type of Search

Return to Nematode Management Menu

Go To Nemaplex Main Menu

or use your Browser Back Button to return to a nematode species page

Click on the any column head to sort by that parameter

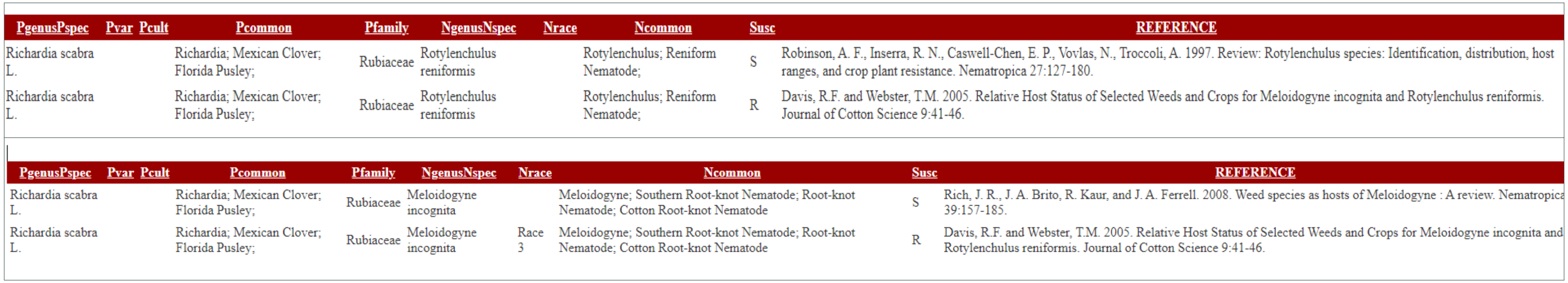
If the form is blank, Nemabase was unable to find data on non-hosts or resistant plants for either of these species
Please note that does not mean that all plant species are hosts! Although resistant varieties and cultivars are reported, non-host status of plants is seldom reported in the literature

Susceptibility Glossary (Susc Column)

S = Susceptible	**- high level of nematode reproduction**
MS = Moderately Susceptible	**- nematode reproduction somewhat reduced**
MR = Moderately Resistant	**- nematode reproduction considerably reduced**
R = Resistant	**- nematode reproduction severely suppressed**
I = Immune	**- no evidence of nematode feeding or reproduction**

PgenusPspec	Pvar	Pcult	Pcommon	Pfamily	NgenusNspec	Nrace	Ncommon	Susc	REFERENCE
Bidens pilosa L.			Bidens; Bur Marigold; Hairy Beggarticks; Romeriilo; Picao-preto;	Asteraceae	Meloidogyne incognita		Meloidogyne; Southern Root-knot Nematode; Root-knot Nematode; Cotton Root-knot Nematode	R	Ntidi, K.N., H. Fourie & M. Daneel (2016) Greenhouse and field evaluations of commonly occurring weed species for their suitability to Meloidogyne species, International Journal of Pest Management, 62:1, 11-19, DOI: 10.1080/09670874.2015.1
Bidens pilosa L.			Bidens; Bur Marigold; Hairy Beggarticks; Romeriilo; Picao-preto;	Asteraceae	Meloidogyne incognita		Meloidogyne; Southern Root-knot Nematode; Root-knot Nematode; Cotton Root-knot Nematode	MR	Tsay, T.T., Wu, S.T., Lin, Y.Y. 2004. J. Nematology 36:36-41.
Bidens pilosa L.			Bidens; Bur Marigold; Hairy Beggarticks; Romeriilo; Picao-preto;	Asteraceae	Meloidogyne incognita		Meloidogyne; Southern Root-knot Nematode; Root-knot Nematode; Cotton Root-knot Nematode	R	Powers, L. E., and A. Pitty. 1993. Resistance of common weeds in Honduras to Meloidogyne incognita. Nematropica 23(No 211.
Bidens pilosa L.			Bidens; Bur Marigold; Hairy Beggarticks; Romeriilo; Picao-preto;	Asteraceae	Meloidogyne incognita		Meloidogyne; Southern Root-knot Nematode; Root-knot Nematode; Cotton Root-knot Nematode	S	Whitehead, A. G. 1969. The distribution of root-knot nematodes (Meloidogyne spp.) in tropical Africa. Nematologica 15:31

Figure 3 An extract from Nemaplex showing conflicting susceptibility status of Cobblers peg (Bidens Pilosa) to Meloiogyne incognita



PgenusPspec	Pvar	Pcult	Pcommon	Pfamily	NgenusNspec	Nrace	Ncommon	Susc	REFERENCE
Richardia scabra L.			Richardia; Mexican Clover; Florida Pusley;	Rubiaceae	Rotylenchulus reniformis		Rotylenchulus; Reniform Nematode;	S	Robinson, A. F., Inserra, R. N., Caswell-Chen, E. P., Vovlas, N., Troccoli, A. 1997. Review: Rotylenchulus species: Identification, distribution, host ranges, and crop plant resistance. Nematropica 27:127-180.
Richardia scabra L.			Richardia; Mexican Clover; Florida Pusley;	Rubiaceae	Rotylenchulus reniformis		Rotylenchulus; Reniform Nematode;	R	Davis, R.F. and Webster, T.M. 2005. Relative Host Status of Selected Weeds and Crops for Meloidogyne incognita and Rotylenchulus reniformis. Journal of Cotton Science 9:41-46.

PgenusPspec	Pvar	Pcult	Pcommon	Pfamily	NgenusNspec	Nrace	Ncommon	Susc	REFERENCE
Richardia scabra L.			Richardia; Mexican Clover; Florida Pusley;	Rubiaceae	Meloidogyne incognita		Meloidogyne; Southern Root-knot Nematode; Root-knot Nematode; Cotton Root-knot Nematode	S	Rich, J. R., J. A. Brito, R. Kaur, and J. A. Ferrell. 2008. Weed species as hosts of Meloidogyne : A review. Nematropica 39:157-185.
Richardia scabra L.			Richardia; Mexican Clover; Florida Pusley;	Rubiaceae	Meloidogyne incognita	Race 3	Meloidogyne; Southern Root-knot Nematode; Root-knot Nematode; Cotton Root-knot Nematode	R	Davis, R.F. and Webster, T.M. 2005. Relative Host Status of Selected Weeds and Crops for Meloidogyne incognita and Rotylenchulus reniformis. Journal of Cotton Science 9:41-46.

Figure 4 An extract from Nemaplex showing the conflicting susceptibility status of White eye (Richardia scabra) to R. reniformis (top) and Meloidogyne incognita (bottom).

Table 12 List of broadleaf weeds occurring in sweetpotato fields.

List of broadleaf weeds occurring in sweetpotato production fields. Mary Firrell DAF, August 2023.									
Common Name	**Scientific Name**	**Family**	**Region**	**Date**	**Season**	**Host Status M javanica**	**Host status M. incognita**	**Host status M. enterolobii**	**Rotylenchulus reniformis**
Bellvine	Ipomoea plebia	Convolvulaceae	Bundaberg	November 2019	Late Spring	Not specified	Not specified	Not specified	Not specified
Blackberry nightshade	Solanum nigrum	Solanaceae	Bundaberg	November 2019	Late Spring	Susceptible	Susceptible	Not specified	Susceptible
Fleabane	Conyza species	Asteraceae	Cudgen	November 2019	Late Spring	Susceptible	Susceptible	Not specified	Susceptible
Wild Radish	Raphanus raphanistrum	Brassicaceae	Cudgen	November 2019	Late Spring	Not specified	Susceptible	Not specified	Not specified
Thickhead	Crassocephalum crepidoides	Asteraceae	Cudgen	November 2019	Late Spring	Susceptible	Susceptible	Not specified	Not specified
Peppercress	Lepidium spp	Brassicaceae	Cudgen	November 2019	Late Spring	Susceptible	Susceptible	Not specified	Susceptible
Cobblers Peg	Bidens pilosa	Asteraceae	Cudgen	October 2020	Spring	Susceptible	Susceptible	Not specified	Susceptible
Blackberry Nightshade	Solanum nigrum	Solanaceae	Cudgen	October 2020	Spring	Susceptible	Susceptible	Not specified	Susceptible
Cress	Coronopus spp	Brassicaceae	Cudgen	October 2020	Spring	Susceptible	Susceptible	Not specified	Susceptible
Wild Hops or Apple of Peru	Nicandra physalodes	Solanaceae	Cudgen	October 2020	Spring	Susceptible	Susceptible	Not specified	Not Specified
Fat Hen	Chenopodium album or (less likely C murale)	Chenopodiaceae	Cudgen	October 2020	Spring	Susceptible	Susceptible	Not specified	Mod susceptible - Immune
Amaranth	Amaranthus sp	Amaranthaceae	Cudgen	October 2020	Spring	Susceptible	Susceptible	Not specified	Mod resistant
Milk thistle or Sow thistle	Sonchus oleraceus	Asteraceae	Cudgen	October 2020	Spring	Susceptible	Susceptible	Not specified	Susceptible
Castor oil	Ricinus communis	Euphorbiaceae	Cudgen	October 2020	Spring	Susceptible	Susceptible	Not specified	Susceptible
Fat Hen	Chenopodium album or (less likely C murale)	Chenopodiaceae	Cudgen	October 2020	Spring	Susceptible	Susceptible	Not specified	Mod susceptible - Immune
Wild Turnip	Brassica tournefortii -B. spp	Brassicaceae	Cudgen	October 2020	Spring	Susceptible	Susceptible	Not specified	Susceptible
Volunteer sweetpotato	Ipomoea batatas	Convolvulaceae	Cudgen	October 2020	Spring	Variety dependent	Variety dependent	Variety dependent	Variety dependent
Nut Grass	Cyperus rotundus or C esculentus	Cyperaceae	Cudgen	October 2020	Spring	Susceptible	Susceptible	Susceptible	Mod resistant
Sorghum	Sorghum spp	Poaceae	Cudgen	October 2020	Spring	Mod susceptible - Mod resistant	Mod susceptible - Mod resistant	Resistant	Susceptible
Volunteer sweetpotato	Ipomoea batatas	Convolvulaceae	Cudgen	October 2020	Spring	Variety dependent	Variety dependent	Variety dependent	Variety dependent
Phasey Bean	Macroptilium lathyroides	Fabaceae	Bundaberg	January 2021	Summer	Not specified	Susceptible	Not specified	Not specified
Nutgrass	Cyperus rotundus or C esculentus	Cyperaceae	Bundaberg	January 2021	Summer	Susceptible	Susceptible	Susceptible	Mod susceptible - Resistant
Blue Heliotrope	Heliotropum amplexicaule	Boraginaceae	Bundaberg	January 2021	Summer	Not specified	Not specified	Not specified	Not specified
Black Pigweed	Trianthema portulacastrum	Aizoacaea	Bundaberg	January 2021	Summer	Susceptible	Not specified	Not specified	Immune
White eye/ Mexican clover	Richardia scabra	Rubiaceae	Bundaberg	January 2021	Summer	Not specified	Susceptible	Not specified	Susceptible
Blackberry nightshade	Solanum nigrum	Solanaceae	Bundaberg	January 2021	Summer	Susceptible	Susceptible	Not specified	Susceptible
Bellvine	Ipomoea plebia	Convolvulaceae	Bundaberg	January 2021	Summer	Not specified	Not specified	Not specified	Not specified

Pigweed	Portulaca oleraceae	Portulacaceae	Bundaberg	January 2021	Summer	Susceptible	Susceptible	Susceptible	Susceptible
Potato weed	Galinsoga parviflora	Asteraceae	Bundaberg	January 2021	Summer	Susceptible	Susceptible	Not specified	Susceptible
Blue billygoat weed	Ageratum houstonianum and A conyzoides	Asteraceae	Bundaberg	January 2021	Summer	Susceptible	Susceptible	Not specified	Susceptible
Couch grass	Cynodon spp	Poaceae	Bundaberg	January 2021	Summer	Susceptible	Susceptible	Not specified	Mod Resistant
White eye	Richardia scabra	Rubiaceae	Bundaberg	September 2021	Spring	Not specified	Susceptible	Not specified	Susceptible
Blue billygoat weed	Ageratum houstonianum and A conyzoides	Asteraceae	Bundaberg	September 2021	Spring	Susceptible	Susceptible	Unknown	Susceptible
Potato weed	Galinsoga parviflora	Asteraceae	Bundaberg	September 2021	Spring	Susceptible	Susceptible	Not specified	Susceptible
Volunteer sweetpotato	Ipomoea batatas	Convolvulaceae	Bundaberg	September 2021	Spring	Variety dependent	Variety dependent	Variety dependent	Variety dependent
Milk thistle	Sonchus oleraceus	Asteraceae	Cudgen	April 2022	Autumn	Susceptible	Susceptible	Not specified	Susceptible
Nutgrass	Cyperus rotundus or C esculentus	Cyperaceae	Cudgen	April 2022	Autumn	Susceptible	Susceptible	Susceptible	Mod susceptible - resistant
Sedge	Cyperus iria or C difformis	Cyperaceae	Cudgen	April 2022	Autumn	Not specified	Not specified	Not specified	Not specified
Wild Hops	Nicandra physalodes	Solanaceae	Cudgen	April 2022	Autumn	Susceptible	Susceptible	Not specified	Not specified
Stinking Roger	Tagetes minuta	Asteraceae	Cudgen	April 2022	Autumn	Mod Resistant	Resistant	Not specified	Not specified
Rhodes grass	Chloris gayana	Poaceae	Cudgen	April 2022	Autumn	Variety dependent	Susceptible	Not specified	Immune
Siratro	Macroptilium atropurpureum	Fabaceae	Cudgen	April 2022	Autumn	Not specified	Susceptible	Not specified	Not specified
Rattlepod	Crotalaria spp	Fabaceae	Cudgen	April 2022	Autumn	Not specified	Not specified	Not specified	Not specified
Capeweed	Arctotheca calendula	Asteraceae	Cudgen	September 2022	Spring	Not specified	Not specified	Not specified	Not specified
Wild radish	Raphanus raphanistrum	Brassicaceae	Cudgen	September 2022	Spring	Not specified	Susceptible	Not specified	Not specified

Observations of note during the in-field surveys are as follows.

Despite a mature sweetpotato crop giving good coverage which should out compete weeds, crops were observed during the survey, with heavy, nematode susceptible, weed infestations.

Image 10 A sweetpotato crop with an infestation of potato weed (Galinsoga parviflora)

During the field surveys, observations were also made of paddocks with nematode resistant cover crops which had been mulched and left on the soil surface to provide a dense trash blanket. This was extremely effective in suppressing weed growth, while allowing the cover crop to regrow and provide more biomass for later incorporation.

Image 11 A sorghum cover crop with a dense trash blanket suppressing weed growth.

Image 12 Gooseberry (*Physalis angulata*) weed from a sweetpotato field with galling on the root.

Image 13 Amaranth spp., collected from a sweetpotato field and grown in a pot inoculated with nematode (b) galling on the root of the amaranth plant (c).

Photographs were taken and images of some weeds identified during the survey are included below.

Image 14 Left, Blue heliotrope (Heliotropum amplexicaule). Right, Black Pigweed (Trianthema portulacastrum)

Image 15 Left, Siratro (Macroptilium atropurpureum). Right, Bellvine (Ipomoea plebia).

Image 16 Left, Blackberry nightshade (Solanum nigrum). Right, Capeweed (Arctotherca calendula).

Image 17 Mexican poppy (Argemone spp)

Conclusion

Ad hoc sampling of weeds in field trials and during grower visits revealed the presence of root-knot nematode on many common horticultural weeds and demonstrated the very wide host range of the pests. While table 1 in appendix 8 lists susceptibility or resistance status of weeds to root knot nematode, the best method of avoiding the proliferation of plant pathogenic nematodes is cover cropping with a known nematode resistant cover crop, as even relatively poor hosts can allow root-knot nematode to persist in a field between crops.

Bare fallow is also an effective strategy for reducing nematode populations, however, is not recommended from a soil health perspective and control of weeds in bare fallow is essential. Due to the very wide host range, it is wise to assume that all weeds are hosts for root-knot nematode.

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Weeds of Queensland, Kleinschmidt, H.E. and Johnson R.W., Queensland Department of Primary Industries.

Appendix 9

The effect of pre-plant herbicide application on growth of sweetpotato cuttings.

The effect of pre-plant herbicide application on growth of sweetpotato cuttings.

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Michael Hughes

Hort Innovation SWEETPOTATO FUND

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Summary

A pot trial was conducted to study the residual effect pre-plant herbicide applications used in land management prior to the planting of sweetpotato crops may have on sweetpotato cuttings when planted. 12 herbicides were tested at maximum rates. The two pre-emergents (metolachlor and pendimethalin) and the four pre- and post-emergent herbicides (imazethapyr, oxyfluorfen, prometryn and terbuthylazine) were all applied as pre-emergents 60 days prior to planting, simulating a crop rotation or fallow management application. Six post-emergent herbicides (2,4-DB, glyphosate, dicamba, fluroxypyr, glufosinate ammonium and MCPA) were applied 24 hours before planting simulating last minute pre plant weed control.

Glyphosate was the only post-emergent herbicide which did not show a residual effect, while fluroxypyr exhibited the strongest residual effect. Several pre-emergent herbicides, while not showing visual signs of affecting plant health, did have an effect on early storage root development. Imazethapyr most affected storage root development.

This trial highlights the need to carefully consider herbicide use in crop rotations used prior to planting a sweetpotato crop or weed management near planting.

Introduction

With an annual farm gate value of $90 M (ASPG pers.com.), sweetpotato is a nutritious root vegetable primarily grown in Queensland and northern New South Wales. Sweetpotato is vegetatively propagated and typically it is planted using unrooted apical cuttings taken from seedbed produced sprouts, although on occasions cuttings may be taken from field planted crops and occasionally back cuttings (cutting obtained from the middle portion of the vine) may also be used.

Being a root crop, sweetpotato is particularly sensitive to soil borne pests, the most destructive of these being nematodes that are estimated to cost the industry $20 M annually (ASPG pers. comm.). Nematodes reduce root size, the efficiency with which roots forage for water and nutrients, and can affect storage roots by causing cracking, internal and external lesions and galling (pimpling), (Overstreet 2013, Noling 2016). They can rapidly multiply with one female root knot nematode being able to lay up to 3,000 eggs.

Unfortunately for producers, nematodes are well suited to all Australia's main sweetpotato production soils. Surveys by DAF and Biological Crop Protection have indicated that root-knot nematodes are present in virtually all sweetpotato fields. Due to sweetpotatoes' susceptibility and the nematode's ability to rapidly increase in number, management strategies are being developed to manage this pest. These strategies utilise crop rotations, including fallows or cover crops and have a particular emphasis on controlling of sweetpotato volunteers, a preferred nematode host.

In addition to being a host for nematodes, weeds at planting can affect the later productivity of the crop. Seem et al. (2003), identified the critical weed free period for Beauregard variety is two to six weeks after transplanting. It is likely similar for other varieties. Monks et al. (2019) summarises numerous authors identifying detrimental impacts of weeds on growth, and storage root development, identifying that it is critical to plant sweetpotato vine cuttings into soils free of emerged and emerging weeds. As there are only five herbicide active ingredients registered for use in Australian sweetpotato crops (Australian Pesticides and Veterinary Medicines Authority – APVMA, accessed May 2021), preplant weed control is important.

A concern for sweetpotato growers is herbicides, which may possibly be used in crop rotations or fallow weed control, might have plant back periods (time it is safe to plant a crop after herbicide application) that could affect planted sweetpotato vine cuttings. There is minimal research on how herbicides, particularly those registered for Ipomoea sp. control, applied prior to planting may affect sweetpotato crops. This trial was developed to gain information on the plant-back effect of several pre- and post-plant herbicides that may potentially be used in fallow weed control, on transplanted sweetpotato vine cuttings.

Materials and Methods

A pot trial was conducted in the Walkamin Research Facility (WRF) open roof screenhouse (17°08'09" S, 145°25'37" E, 600 masl). A randomized split plot design with 13 treatments (Table 1), and three planting periods, replicated four times was used. The herbicides selected all have registration to kill an Ipomoea sp. weed, the family (Convolvulaceae) to which sweetpotato belongs. These herbicides could be used in fallow, crop rotation or pre-plant weed control before planting sweetpotato. Herbicides were applied at maximum label rates (Table 1).

Table 1. List of herbicides trialled

Active ingredient	Application time	Mode of action group	Rate /ha
2,4-DB 500 g/L	Post emergent	I	3.2 L/ha
glyphosate 570 g/L	Post emergent	M	3.7 L/ha
dicamba 500 g/L	Post emergent	I	560 mL/ha
fluroxypyr 333 g/L	Post emergent	I	1.8 L/ha
glufosinate ammonium 200 g/L	Post emergent	N	5 L/ha
imazethapyr 700 g/kg	Pre and post emergent	B	140 g/ha
MCPA 750 g/L	Post emergent	I	1.4 L/ha
metolachlor 720 g/L	Pre-emergent	K	4 L/ha
oxyfluorfen 240 g/L	Pre and post emergent	G	6 L/ha
pendimethalin 455 g/L	Pre-emergent	D	3.3 L/ha
prometryn	Pre and post emergent	C	2.2 kg/ha

terbuthylazine	Pre and post emergent	C	1.2 kg/ha
control (water)	nil	nil	-

Treatments

2,4-DB is a systemic herbicide that can be used to control annual and perennial broadleaf weeds. In the plant the 2,4-DB compound changes to 2,4-D and inhibits the growing points of stems and roots (Gupta. 2018). It is absorbed through foliage and translocated around the plant via the plants vascular system. It induces a response in plant auxins (a plant growth regulator) causing abnormal growth in the plant such as twisting, bending of stems and petioles; leaf curling and cupping, and development of abnormal tissues and secondary roots resulting in eventual plant death. Plant death can take three to five weeks (Cobb and Reade 2010, Cornell University undated).

Glyphosate is a non-selective herbicide for control of both grasses and broadleaf weeds. In the plant, glyphosate affects the manufacture of amino acids by affecting their production pathways. Production of anthocyanins, flavonoids lignin and chloroplasts are some compounds affected. Glyphosate is readily absorbed by leaves and translocated through the plant in the vascular system. Growth is affected soon after application. There is a general yellowing in the immature leaves and growing tips which then spreads. Plant death can occur within four to seven days with susceptible species and may take up to 20 days with less susceptible species (Cornell University undated). Glyphosate is rapidly and strongly adsorbed to soil particles, particularly as clay content and cation exchange capacities (CEC) increase and soil pH and phosphorus decrease. Due to this, it has little or no herbicide activity once it touches soil (Tu et al. 2001).

Dicamba is a selective herbicide for control of broadleaf weeds. It disrupts the plants transport systems and interferes with the metabolism of nucleic acid. It is readily absorbed through roots, stems and the foliage and then translocated through the plant in the vascular system. It induces a response in plant auxins (a plant growth regulator) causing abnormal growth in the plant such as twisting, bending of stems and petioles; leaf curling and cupping, and development of abnormal tissues and secondary roots resulting in eventual plant death. Symptoms may occur within hours of the herbicide application, but plant death may take three to five weeks (Cobb and Reade 2010, Cornell University undated).

Fluroxypyr is a selective post-emergent herbicide for control of a wide range broadleaf weeds. Foliar absorption and translocation is the main route of the chemical into the plant, although there is minor root absorption. When absorbed in the plant it accumulates in the growing tissues and causes an auxin overdose which interferes with the plants ability to use nitrogen and produce enzymes. It causes abnormal growth eventually resulting in death. Fluroxypyr has some residual activity and growers need to be aware of plant back periods. Generally, there is little residual activity although, in soils containing less than 25% clay. Susceptible crops may require up to a 12 month break before planting. Hard water should also be avoided, or if unavoidable a water conditioning agent added (EPA 1998, Guo et al. 2019, Corveta Agriscience undated, Herbiguide1 undated).

Glufosinate ammonium is a non-selective herbicide for the control of broadleaf weeds and grasses. It is not recognised as having residual herbicide activity. It is not actively translocated in the plant, so will only kill the foliage/stem areas it contacts. Due to rapid microbial breakdown, it has minimal if any root absorption. It causes peroxidation in the cell membranes and a build-up of ammonium in the plant that destroys cells and stops photosynthesis. Glufosinate ammonium usually causes yellowing and wilting within three to five days and death within one to two weeks. Bright sunlight, high humidity and moist soil increase the rate of plant death (Takano and Dayan 2020, Cornell University undated).

Imazethapyr is a pre- or post-emergence herbicide for control of broad leaf weeds and some grasses. It can have long term residual activity and plant back periods for some crops in dryland conditions can be up to 34 months. Some plant back periods may be reduced when greater than 2,000 mm of rainfall/irrigation has been applied (ADAMA 20191). Imazethapyr is readily absorbed by foliage and slightly slower by roots. It is translocated around the plant in the vascular system. It works by inhibiting the production of a key enzyme required for the manufacture of certain amino acids (Cornell University undated). It has also been found to affect genes involved in the photosynthesis process (Sun et al. 2016). Susceptible plants growth may be inhibited within a few hours of application. The growing points may start dying within one to two weeks, followed by a slow yellowing and dying of the plant (Cornell University undated).

MCPA is a systemic post-emergence herbicide for control of broadleaf weeds. It is absorbed through foliage and translocated in the vascular system to growing points. It can also be absorbed through the soil (Kogan and Henandez, 1991). It acts as the plant growth hormone, auxin, causing uncontrollable growth and eventual plant death (Anon. 2017). Plant symptoms can include twisting and bending, leaf cupping and curling, thickening and elongation of leaves, dying of the growing point and wilting. Death may take up three or more weeks (Nufarm undated).

Metolachlor is a short residual, pre-emergent herbicide for control of broadleaf and annual grasses. It is primarily absorbed from the soil through the germination coleoptile (shoot) although there can be root absorption. Metolachlor stops or reduces seedling growth by inhibiting the formation of long chain fatty acids. It can be translocated through the xylem. Metolachlor needs to be irrigated after application to ensure the chemical is in the weed seed zone. (Butts et al. undated, Kenso 2004, Mann undated). Metolachlor breaks down faster in high organic matter soil, particularly when they are warm and moist as microbial action is increased under these conditions (Long et al. 2014). Metolachlor is registered for use in sweetpotato, to be applied within 24 hours of transplanting sweetpotato vines before weeds have germinated, with sufficient irrigation to wet the soil through the weed zone (Kenso Agcare 2004).

Oxyfluorfen is a pre- and post-emergent selective herbicide for control of annual broadleaf and grassy weeds. It is rapidly absorbed by shoots, less so by roots and is poorly translocated through the plant. Oxyfluorfen works by attacking the fats and proteins of the plant cell membranes. This causes breakdown in the cell membrane and cell desiccation It is persistent and relatively immobile in soils and the soil surface should not be disturbed after application. Plant symptoms can include leaves having a water-soaked appearance, then followed by necrotic spots. Depending on the crop, plant back intervals may be as long as 180 days (Vanstone and Stobbe 1978, Anon 2017, ADAMA 20192, Fenimore undated).

Pendimethalin is a pre-emergence selective herbicide for control of annual grasses and some broadleaf weeds. It inhibits pre-emergent seedling development, by affecting root and shoot growth. It is readily absorbed by young roots, but there is minimal translocation. Cell division in young roots, particularly root tips is inhibited, and they become thick and stubby. Pendimethalin works best when it is thoroughly mixed in the soil, either by mechanical incorporation or watered in. With some crops pendimethalin may have a 12 month plant back period (BASF 2013, Cornell University undated).

Prometryn is a selective pre- and post-emergence herbicide for control of broadleaf weeds and some grasses. It is mainly absorbed through the roots, although it is also absorbed through foliage, and translocated in the xylem where it accumulates in meristems and leaves. It inhibits electron transports affecting the photosynthetic system. Prometryn requires rain or irrigation soon after spraying for best activity. It works best on germinating seedlings or young and actively plantlets growing in moist soil. Young plants may stop growing then yellow and slowly die over 3-4 weeks (EPA 1996, Nufarm 2009, Herbiguide2 undated, OXON1 undated). With some crops there may have a plant back period of six months (Nufarm 2009) to eight months (EPA 1996).

Terbuthylazine is a selective pre- and post-emergence herbicide for control of annual broadleaf weed and some grasses. It is mainly absorbed through the roots or seedlings and to some extent by emerging cotyledons. It can also be absorbed through foliage. It is translocated in the xylem and accumulates in meristems and leaves. It inhibits electron transport which affect the photosynthetic system. Plants may yellow and die. There may be a plant back period more than six months for some crops (Kuechler et al. 2003, FAR 2007, Nufarm 2009, Herbiguide3 undated, OXON2 undated)

Trial process: Polystyrene boxes (internal measurement 44.5 cm L x 27.5 cm W x 12.0 cm H) were filled to within 5 cm of the top with red basaltic Mapee soil, common to the Walkamin cropping area. Mapee soils are deep red uniform light to medium clay soils formed from basalt (Malcolm and Heiner 1996). The soil was taken from a newly cultivated fallow block on WRF. In the past 10 years, there was no recorded use of herbicide on this block. Complete fertilizer in the form of slow-release pellets (N14 P1.4 K9.0 S7.0 Ca3.6 + Si, Fe, Mg, Mn, Zn, Cu, B, Mo) was incorporated into the soil mix which was then watered to field capacity. Three days later boxes were lightly watered, and the following day pre-emergent herbicides were applied.

Pre-emergent herbicides, imazethapyr, metolachlor, oxyfluorfen, pendimethalin, prometryn and terbuthylazine were applied 60 days before planting to simulate their application at the planting of a rotation crop prior to sweetpotatoes. After pre-emergent spray application, the boxes were watered to ensure the herbicide was incorporated into the soil profile as per label recommendations. Post-emergent weed herbicides, 2,4-DB, glyphosate, dicamba, fluroxypyr, glusosinate ammonium and MCPA were applied to the bare soil 24 hours before the first planting of sweetpotato vines. All herbicides were applied using a 500 ml hand sprayer containing 200 ml of spray solution. The spray was applied to provide coverage of the box (similar to that achieved from a field spray unit).

Orleans was the sweetpotato variety used in the trial. Three plantings, each of one cutting were made into each box (plot). Planting 1 was made 24 hours after the post-emergent herbicide application, planting 2 was 9 days later and planting 3 was 16 days after the herbicide application. The vine cuttings for each planting were selected in the morning, stored in a bucket with 15 cm of water and planted in the cool of the late afternoon. All the cuttings were apical vine cuttings 28-32 mm long with 3 nodes within 15 cm of the cut end of the vine. Cuttings were planted horizontally at a depth of 2 cm, with the apical end tip and leaves above the soil (image 1). As soon as the vines were planted, the pots were watered to field capacity.

The trial was lightly watered three times per week, except when conditions were wet. When possible, daily observations were made of the plants. If this was not possible observations were made on the second day. A five point rating scale was given to the visual symptoms the plants were showing;

Plants are healthy growing and showing no sign of herbicide application or other issues affecting crop growth.

Plants are showing symptoms which may affect plant growth, such as wilting of leaves or stems. This may have reduced growth to some degree but if symptoms remain at this level, the plants will continue to grow.

Plants showing moderate effects affecting their growth. The plants are wilting strongly or have bleaching, burnt or senesced leaves and stem. They still have a visual assessment of 50% green leaves and stems and may or may not be able to grow out of this damage.

Plant showing considerable effect of the herbicide application. They still have some green leaves or stems, but it is unlikely they will be able to grow out of the damage.

Plants dead.

In addition to the rating a description was made of the visual appearance of the plot, (e.g., stems wilting, leaves bleached or leaves bronzed, leaves senescing). The trial concluded 38 days after planting 1 was made.

Image 1. Planting 1 (bottom middle in box), planting 2 (bottom right in box) and planting 3 (top left in box)

Results

In Planting 1, five of the herbicides, 2,4-DB, dicamba, fluroxypyr, glusosinate ammonium and MCPA killed the planted vine cuttings within10 days of planting. There appeared to be an anomaly in the dicamba replication 1, plot and glusosinate ammonium replication 4, plot. In both of these plots the herbicide application appeared to have no effect. For dicamba, the plants in the other three replications were all dead by day 10, and by day 13 for the glusosinate ammonium treatments. All the herbicides which caused plant death were post-emergents applied 24 hours before planting. During the first 10 days, the other treatments, including the control, showed a slight to moderate sign of wilting, probably transplant shock. Of the treatments that did not result in plant death, the metolachlor treatment did show slightly more wilting for the first 14 days than did the other treatments (figure 1).

Planting 2, which occurred 10 days after the post-emergent herbicide application showed a reduction in plant death from the herbicide treatments. Three of the four replications of the fluroxypyr treatment were dead by 13 days after planting. This was 22 days after the herbicide application and the plant in the remaining replication was only just surviving. By day eight after planting (17 days after post-emergent herbicide application) plants in two of the four the glusosinate ammonium treated plots were dead. The plants in the two remaining plots although sick and weak with strongly yellowed or senesced leaves began to reshoot and new vines were developing by the trial’s conclusion. Plants in the MCPA treatment also showed apical senescence wilting and yellowing of leaves. Although not killing the plants, there was a noticeable visual effect on their growth. The health of these plants improved throughout the trial, looking healthy by its completion. There was minimal disruption to plant growth in the other treatments (Figure 2).

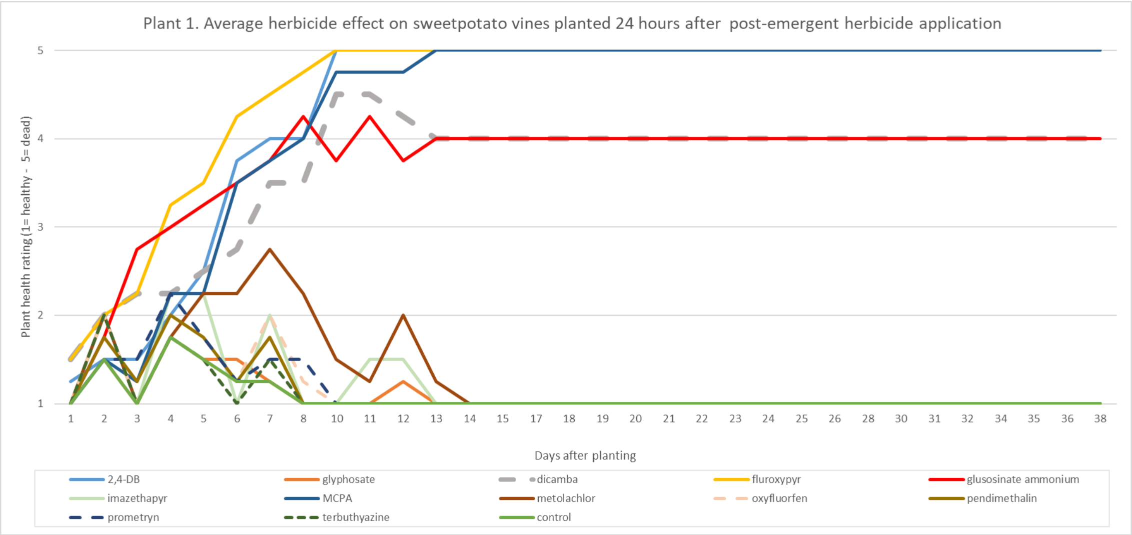


Figure 1. Sweetpotato vine cutting establishment and growth when planted 24 hours after herbicide application

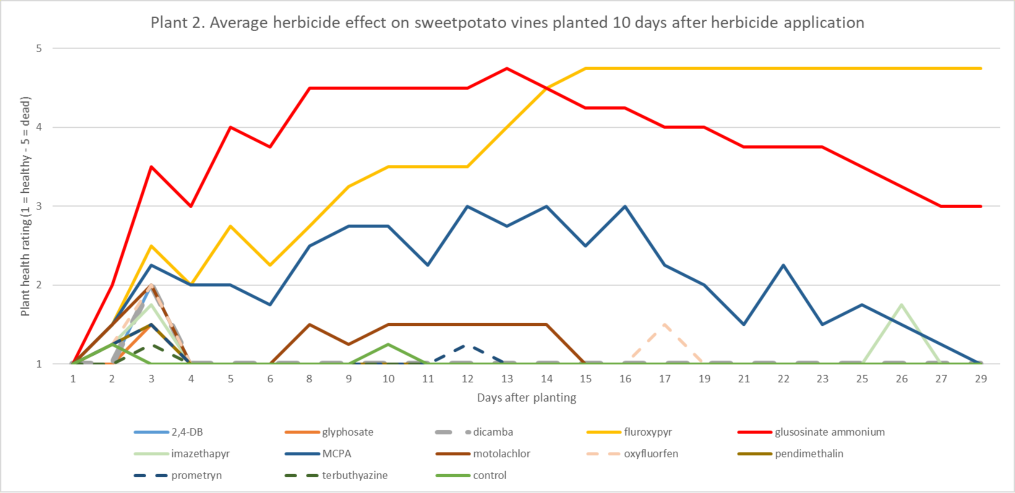


Figure 2. Sweetpotato vine cutting, establishment and growth when planted 10 days after herbicide application

As can be seen by the control treatment in Planting 3 (Figure 3), the vine cuttings did not establish as well in planting three as they had in the other plantings, probably due in some part to compaction and waterlogging of the soil in the pots from constant rain. Fluroxypyr treatments again showed a negative relationship to plant health, with plants in three of the four replications dying by 14 days after planting (31 days after post-emergent herbicide application) and the fourth replication remaining at a four rating (senesced apical tip, senesced new leaves and pale yellow stem with only a single green leaf). MCPA and dicamba treatments appeared to slightly affect the plants and metolachor showed small effect till day nine after which the plants regained their health (Figure 3).

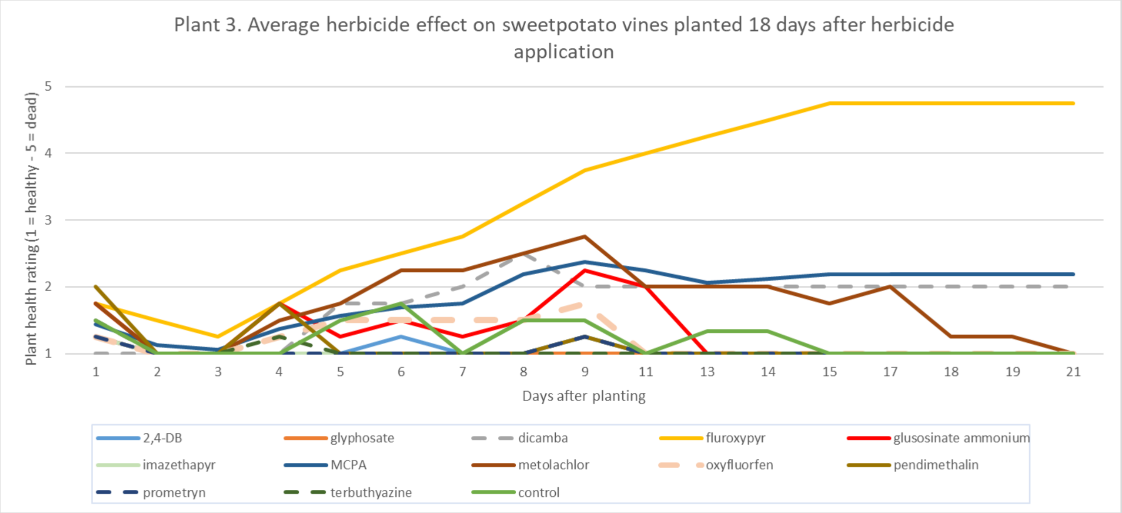


Figure 3. Sweetpotato vine cutting, establishment and growth when planted 18 days after herbicide application

In Planting 1. there was no significant difference between any treatment in the number of storage roots produced by vines. There were differences in other storage root parameters. The average storage root diameter was significantly smaller for imazethapyr and metolachlor treatments than the other treatments (Figure 4). This also occurred for average storage root length (Figure 5). In both these measurements the glusosinate ammonium results should be treated with caution as they represent the one abnormal replication.

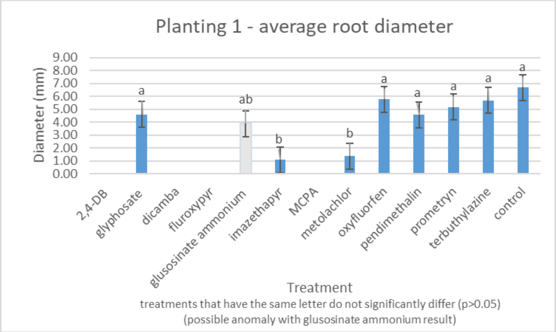


Figure 4. Average diameter of storage roots in Planting 1.

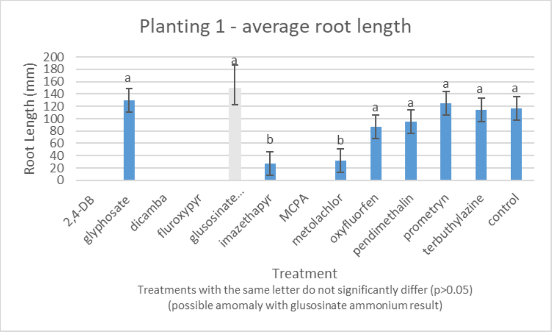
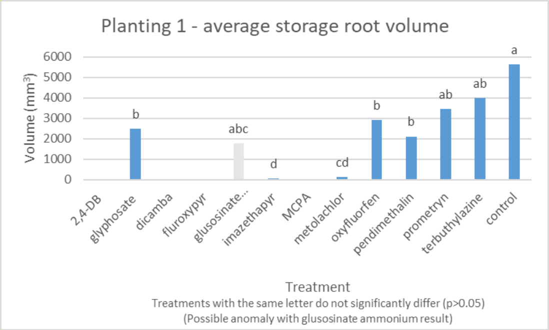


Figure 5. Average length of storage roots in Planting 1.

The control treatment in Planting 1 has the greatest average root volume, which was significantly similar to the terbuthylazine and prometryn treatments. Oxyfluorfen, glyphosate and pendimethalin treatments while equivalent to terbuthylazine, prometryn and glyphosate, were significantly better than metolachlor and imazethapyr (Figure 6). As previously stated, care needs to be taken when interpreting the glusosinate ammonium result.

The control treatment produced the heaviest storage roots in Planting 1. This was statistically equivalent to terbuthylazine, prometryn and glyphosate treatments. Prometryn, pendimethalin glyphosate and oxyfluorfen were also statistically similar in root weights. Both imazethapyr and metolachlor treatments were significantly less than the other treatments (Figure 7).



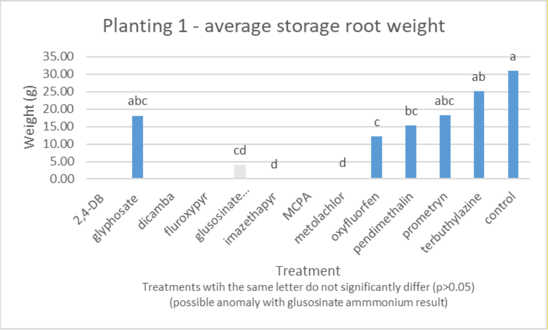


Figure 6. Average volume of storage roots in Planting 1.

Figure 7. Average weight of storage roots in planting 1.

There were differences in the average length of vines in the various treatments of Planting 1. Terbuthylazine, prometryn and the control treatments statistically had the longest vines, followed by glyphosate and pendimethalin treatments. Oxyfluorfen, metolachlor and imazethapyr treatments had significantly shorter vines than the other treatments. The glusosinate ammonium result should be regarded as an anomaly (Figure 8)

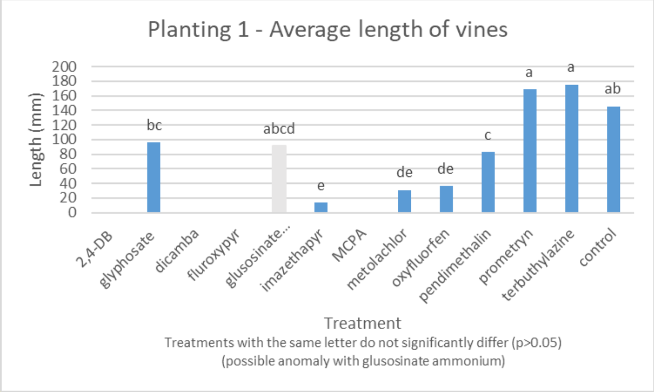
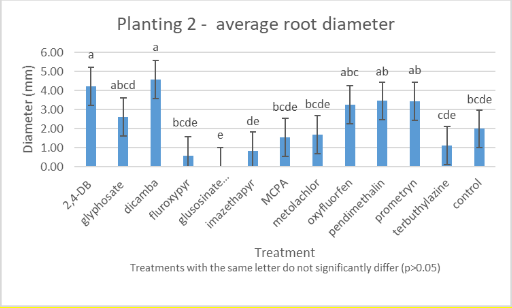


Figure 8. Average length of sweetpotato vines in Planting 1.

In Planting 2, the dicamba, 2,4-DB, pendimethalin, prometryn, oxyfluorfen and glyphosate treatments were all significantly similar, and produced the largest diameter storage roots. The control treatment produced significantly thinner roots than the dicamba and 2,4-DB treatments and was similar to all other treatments. Although glusosinate ammonium produced the thinnest roots, they were statistically similar to fluroxypyr, imazethapyr, terbuthylazine, MCPA, metolachlor and the control (Figure 9).

Glyphosate, 2,4-DB, dicamba, prometryn and oxyfluorfen treatments produced the longest roots in Planting 2. Glusosinate ammonium, fluroxypyr and imazethapyr treatments, while producing the shortest roots, were statistically similar to the control, MCPA and terbuthylazine treatments (Figure 10).



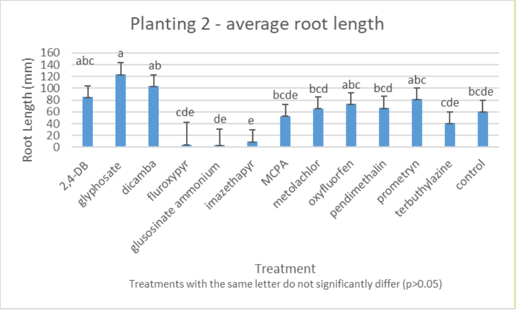


Figure 9. Average diameter of storage roots in Planting 2.

Figure 10. Average length of storage roots in Planting 2.

Dicamba, 2,4-DB, prometryn, oxyfluorfen, pendimethalin and glyphosate were all statistically similar in storage root volume in Planting 2. The control treatment had a slightly smaller volume. Glusosinate ammonium, imazethapyr, fluroxypyr, terbuthylazine metolachlor and MCPA all had significantly smaller root volumes (Figure 11).

Average root weight in Planting 2 identified dicamba and 2,4-D as having significantly higher average root weight than glusosinate ammonium and imazethapyr treatments. Dicamba also had significantly heavier roots than MCPA and terbuthylazine treatments. There was no significant difference between the control and all other treatments (Figure 12).

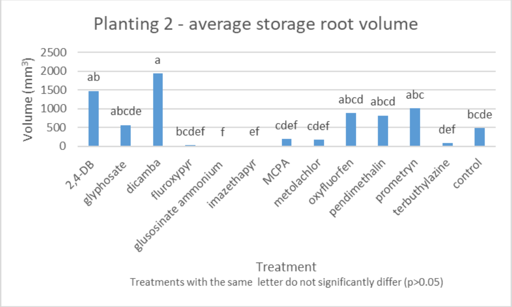


Figure 11. Average volume of storage roots in Planting 2.

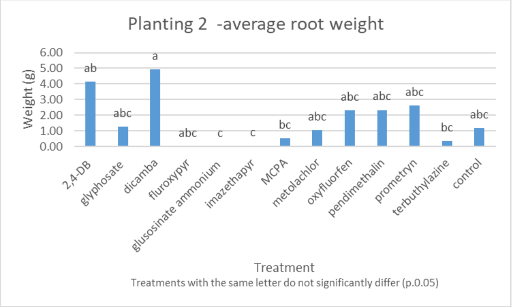


Figure 12. Average weight of storage roots in planting 2.

Planting 2 control treatment had on average the longest plant vines, but this was only significantly different to MCPA, fluroxypyr, glusosinate ammonium and imazethapyr treatments (Figure 13).

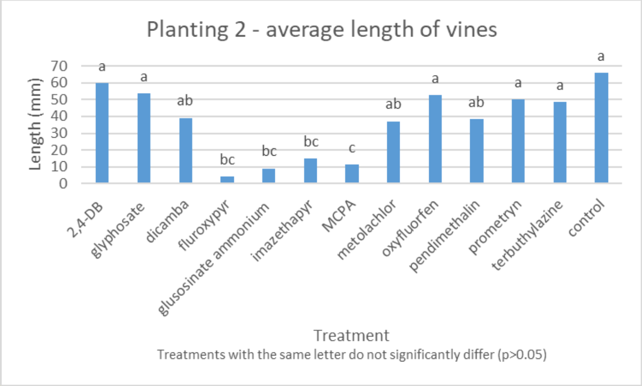


Figure 13. Average length of sweetpotato vines in Planting 2.

No root development data is presented for Planting 3. The vines were only in the soil for 21 days, before the trial harvest. During this period there was minimal root development. Vine length measurements were made at harvest. While there was a trend for the metolachlor, MCPA and imazethapyr treatments to have shorter vine lengths than the other treatments, this was not significantly different to any other treatment (Figure 14). No data was available for the fluroxypyr treatment as three of the four replications had died and the fourth was barely surviving.

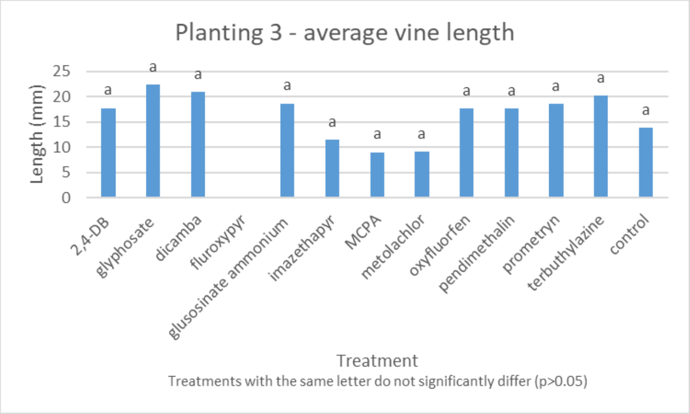


Figure 14. Average length to sweetpotato vines in Planting 3.

Discussion

The only herbicides which killed the planted sweetpotato cuttings were the post-emergent herbicides. Of the five herbicide treatments that killed or severely injured sweetpotato cuttings in Planting 1, fluroxypyr was most destructive across all three planting periods (Figure 15). The fluroxypyr label identifies that if soils have less than 25% clay susceptible crops may require up to a 12 month break (Corveta Agriscience undated). Even on the red volcanic Mapee soil with a clay content of 51% (Malcolm and Heiner 1996), fluroxoypyr still showed a strong residual activity, indicating that sweetpotato is sensitive to this herbicide when it is used at high rates. Cotton is identified as having a 28 day plant back and the indications of this trial are that the plant back for sweetpotato would be no less and potentially very much longer.

2,4-DB persistence had been identified by Howerda and Ekanayake (1991), but no time period was given. This trial found that while 2,4-DB was lethal to sweetpotato 24 hours after application, the persistence quickly dropped away and was minimal if at all at the second planting (Figure 15).

Tokana and Dayan (2020) identified glusosinate ammonia as having a one to seven days residual. This trial found that high rates of glusosinate ammonium showed strong herbicidal effects on sweetpotato for at least 16 days after planting, indicating that planted sweetpotato cuttings may be quite susceptible to this herbicide (Figure 15). By 16 days after spray application the effect of glusosinate ammonium on sweetpotato transplant growth had reduced considerably.

Like glusosinate ammonium, although with reduced effect, the MCPA treatments killed the sweetpotato cuttings at the first planting and were still showing an effect at the second planting. Planting 3 still showed a slightly greater effect that the control treatment (Figure 15). Dicamba a chemical similar to MCPA, both being phenoxyalkonoic acids, showed minimal if any effect at Planting 2 and a similar response at Planting 3, where there was slight wilting of the plants (Figure 15).

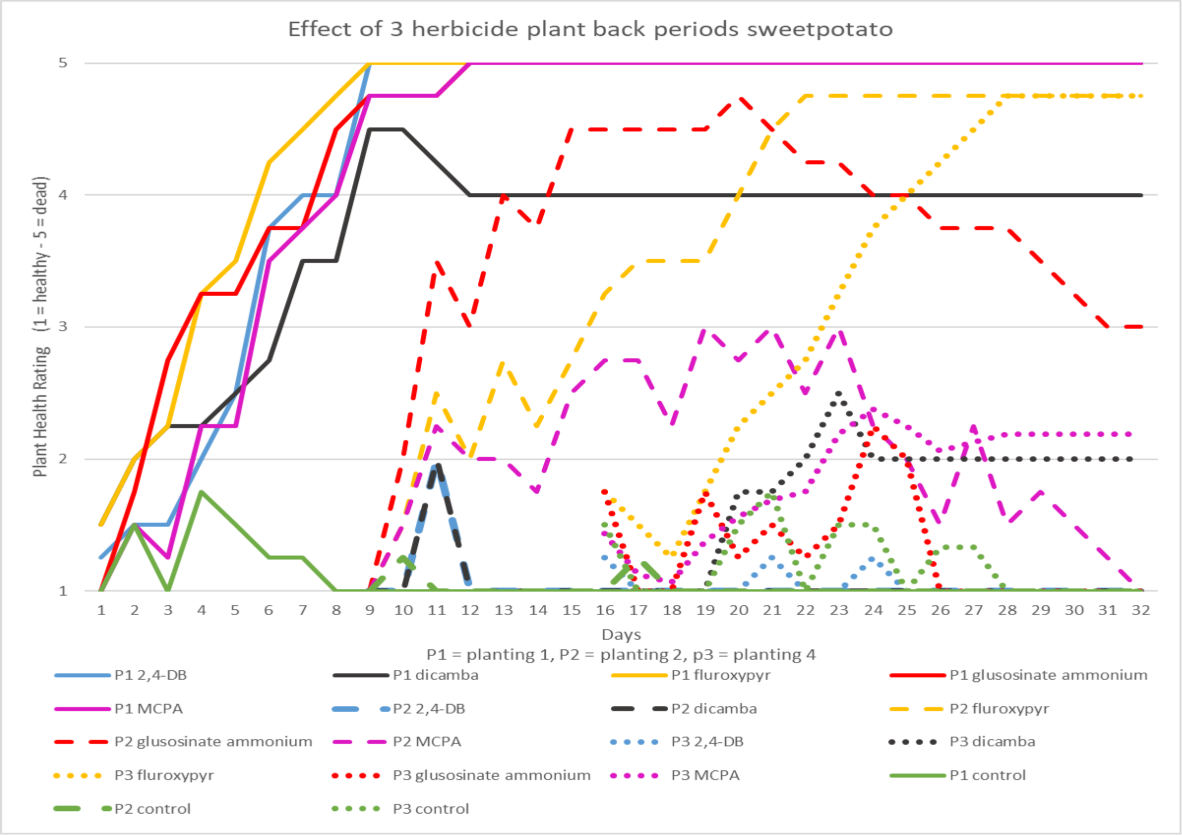


Figure 15. The effect of different plant back periods on lethality of five herbicides to planted sweetpotato cuttings.

Glyphosate was the only post-emergent herbicide to show no plant back effect on sweetpotato. This agrees with the Tu et al. (2001) who states glyphosate has little or no residual activity once it touches soil as it is rapidly and strongly absorbed to soil particles, particularly as clay content and CEC increases.

There were no serious visual effects on the sweetpotato cuttings from the pre-emergent and pre/post-emergent herbicides which had been applied 60 days before Planting 1. Compared to the other pre-emergents, metolachlor did show slightly more distressed/wilted plants for the first 13 days after planting in both Plant 1 and Plant 3, but there may also be an element of transplant shock in this result.

Interestingly, where there does appear to be effects from the pre-emergent herbicides is in the developing storage roots. For all root measurements (root diameter, root length, root volume and root weight) in both Planting 1 and Planting 2, imazethapyr produced significantly lower than the best values. The vines of imazethapyr treated plants were also significantly shorter in Planting1 and Planting 2 and one of the shorter vines (not significant) in Plant 3. Imazethapyr is known to have long term residual effects on some plants, particularly in dry conditions the residual can last up to 34 months. In irrigated cropping where the rainfall/irrigation in excess of 2,000 mm this may reduce to 18 months. This trial shows that 69 days after application imazethapyr still had a strong effect on sweetpotato root development.

Although registered for post-plant use in sweetpotato, metolachlor also appeared to influence the sweetpotato root development parameters with the effect reducing slightly between Planting 1 and Planting 2. While there has been no previous trial work done on plant back effects of using metolachlor, there have been several USA trials studying the effect of metolachlor on sweetpotato growth. Porter (1995) stated that metolachlor had no significant effect on sweetpotato varieties and Meyers et al. (2012) quotes Monks et al. (1998) as also finding no adverse effect from use of metolachlor. On the other hand, both Meyers et al. (2012), Abukari et al. (2015)1 and Abukari et al. (2015) 2 showed metolachlor effects on sweetpotato growth. Predominately the effect of metolachlor becomes more noticeable as the rate of active ingredient increases. This effect may also be compounded by increased levels of irrigation, particularly if the herbicide is applied just after transplanting, Meyers et al. (2012), Abukari et al. (2015)1 and Abukari et al. (2015) 2. Their recommendation is to apply as low a dose as possible and follow weather forecasts to avoid irrigation when heavy rainfall events are predicted (Meyers et al. 2015, Abukari et al. 20152, Smith and Miller undated). As this trial applied metolachlor at maximum rates and there was considerable rain (150 mm rainfall from

Plant 1 till harvest) over the trial period, the results show, given adverse conditions there can be a herbicide effect 60 days after application.

In Planting 1, oxyfluorfen treatments produced significantly lower root volumes, root weights and length of vines than the control treatment. This difference was not seen in Planting 2. Xue and Dai, 2020 found that oxyfluorfen applied at up to three days before planting gave the crop good weed control without affecting the crop. Lewthwaite et al. (2010) found oxyfluorfen had potential to be phytotoxic to sweetpotato when applied as a post-emergent. ADAMA 20192) does identify potatoes need a 60 day plant back period, brassicas, capsicum and carrots require 90 days plant back and for onions it may be as long as 180 days.

Similar to oxyfluorfen in Planting 1, pendimethalin treatments produced significantly lower root volumes, root weights and length of vines than the control treatment

In an earlier trial studying management of volunteer sweetpotato roots, conducted as part of the Hort Innovation project PW 17001 Integrated pest management of nematodes in sweetpotatoes, the pendimethalin treatment while not affecting plant emergence or vine length did cause misshapen true leaves. This effect did not occur in this trial. Lewthwaite and Triggs (2000) found that pendimethalin did reduce yields compared to some other herbicides and hand weeding and Meyers et al. 2019 found pendimethalin produced varying results stating that sweetpotato stunting following pendimethalin application is minimal and temporary. BASF (2013) identifies plant back periods of two months for carrots, parsnips, and potatoes, five months for turnips radish and onions and up to 12 months for beetroot, spinach and silverbeet.

This trial while not continuing to full storage root development does support the theory that pendimethalin may have an influence on root development in the early stages of plant growth.

Prometryn was applied as a pre-emergent was not significantly different to the control or best treatments in any of attribute. Studies on prometryn in sweetpotato are minimal. An undated Chinese study abstract by Zhang et al. found prometryn detrimental to sweetpotato. Nufarm (2009) identifies a possible plant back period of up to six months in Australia when high rates of prometryn have been used. In the USA, a plant back of up to eight months is recognised (EPA 1996).

Terbuthylazine was not significantly different to the control or best treatments in any attribute in Planting 1, and in Planting 2 it did not significantly differ from the control treatment, although it was smaller for root diameter, root length, storage root volume and average root weight. Terbuthylazine may have a plant back period as long as 12 months with a minimum rainfall of 175 mm (Nufarm 2020). In this trial 458 mm of the rain had fallen between spray application and planting, assisting in the reduction of the plant back for sweetpotato. There is minimal, if any research on the effects of terbuthylazine on sweetpotato.

This trial did highlight that sweetpotato is sensitive to many herbicides and that growers need to be especially aware of plant back periods, particularly if looking at controlling weeds near planting. There are also factors which can influence a herbicides life in the soil. Melo et al. 2016 has identified them as;

- Soil – microorganisms, humidity, texture, structure, porosity, organic carbon content and pH
- Environmental conditions – temperature, management, rainfall and the plant growth
- Physico-chemical properties of the chemical – degree of retention, half-life, ionization constant, dose, vapour pressure and solubility.

The results produced by this trial were with a Walkamin soil, growing in summer during the wet season, so they may well vary when crops are planted in other regions and at different times of the year with different rainfall and temperature effects. Care must always be taken to read herbicide labels before use, and to consider the length of the plant back period required before planting the next sweetpotato crop.

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Appendix 10

Controlling sweetpotato volunteers with herbicides

Controlling sweetpotato volunteers with herbicides

December 2020

Michael Hughes

Hort Innovation SWEETPOTATO FUND

This project has been funded by Hort Innovation using the sweetpotato research and development levy and funds from the Australian Government. For more information on the fund and strategic levy investment visit horticulture.com.au

Queensland Government

Summary

A pot trial was conducted to test the ability of herbicides to control sweetpotato volunteers. Two pre-emergent (metolachlor and pendimethalin), four pre- and post-emergent (imazethapyr, oxyfluorfen, prometryn and terbuthylazine) and six post-emergent (2,4-DB, glyphosate, dicamba, fluroxypyr, glusosinate ammonium and MCPA) herbicides were tested. The six post-emergent herbicides killed or seriously set back plant vine growth. The pre and pre/post emergent herbicides were not as effective in controlling plant growth.

Introduction

Sweetpotato, a nutritious root crop, predominately grown in Queensland and northern New South Wales has an annual farm gate value of $90 M (ASPG pers. com.). Grading of sweetpotatoes is based on size and visual appearance. Merchants and retailers want roots that have smooth skins, are rich and vibrant in colour and fresh, firm and unblemished (Wolfenden et al. 2014). There is minimal tolerance for defects such as cracking, uneven shape, twisted or bumpy roots, insect damage holes, feeding marks, pimpling or skin lesions.

Sweetpotato being a root crop, is particularly sensitive to soil borne pests. Of these pests, nematodes are the most destructive causing an annual estimated $20 M loss to the industry (ASPG per. com.). Nematodes reduce root size, the efficiency with which roots forage for water and nutrients and can affect storage roots by causing cracking, internal and external lesions and galling (pimpling), (Overstreet 2013, Noling 2016). They can rapidly multiply with one female root knot nematode being able to lay up to 3,000 eggs.

Unfortunately for producers, nematodes are well suited to all Australia's main sweetpotato production soils. Surveys by DAF and Biological Crop Protection have indicated that Root-knot nematodes are present in virtually all sweetpotato fields. Although, in Australia, economic thresholds for nematode numbers in sweetpotato crops have not been established, it is assumed to be very low, possibly 0 or 1 nematodes per 200 mL soil (pers. comm. Project Reference Group, Hort Innovation project PW 17001 Integrated management of nematodes in sweetpotatoes).

There is no single 'silver bullet' for controlling nematodes. While nematicides are available, Integrated Pest Management programs, in which chemicals are a tool, are the recommended strategy for nematode management (Overstreet 2013, Adama 2015), Critical to this type of strategy is crop rotation with non-nematode host plants. To ensure the effectiveness of these rotations, all volunteer sweetpotato plants must be removed from the field to ensure there are not viable food sources remaining through the rotation period. Herbicides can play and important role in the management of these volunteers. This trial looked at the impact of several herbicides and in controlling sweetpotato storage root vines.

Materials and Methods

A pot trial was conducted in the Walkamin Research Facility (WRF) open roof screenhouse (17°08'09" S, 145°25'37" E, 600 masl). A randomized block design with 12 herbicide treatments and a nil herbicide control (Table 1) replicated four times was used. As there are no herbicides specifically registered to kill sweetpotato, the herbicides selected all have registration to kill an Ipomoea sp. weed species, the genus that sweetpotato (Ipomoea batatas) belongs to.

Table 1. List of herbicides trialled

Active ingredient	Application time	Mode of action group	Rate /ha
2,4-DB 500g/L	Post emergent	I	3.2 L/ha
glyphosate 570 g/L	Post emergent	M	3.7 L/ha
dicamba 500 g/L	Post emergent	I	560 mL/ha
fluroxypyr 333 g/L	Post emergent	I	1.8 L/ha
glufosinate ammonium 200 g/L	Post emergent	N	5 L/ha
imazethapyr 700 g/kg	Pre and post emergent	B	140 g/ha
MCPA 750 g/L	Post emergent	I	1.4 L/ha
metolachlor 720 g/L	Pre-emergent	K	4 L/ha
oxyfluorfen 240 g/L	Pre and post emergent	G	6 L/ha
pendimethalin 455 g/L	Pre-emergent	D	3.3 L/ha
prometryn	Pre and post emergent	C	2.2 kg/ha
terbuthylazine	Pre and post emergent	C	1.2 kg/ha
control (water)	nil	nil	-

Treatments

2,4-DB is a systemic herbicide that can be used to control annual and perennial broadleaf weeds. In the plant the 2,4-DB compound changes to 2,4-D and inhibits the growing points of stems and roots (Gupta P. 2018). It is absorbed through foliage and translocated around the plant via the plants vascular system. It induces abnormal growth in the plant such as twisting, bending of stems and petioles; leaf curling and cupping, and development of abnormal tissues and secondary roots resulting in eventual plant death. Plant death can take three to five weeks. (Cornell University undated)

Glyphosate is a non-selective herbicide for control of both grasses and broadleaf weeds. In the plant glyphosate affects the manufacture of amino acids by affecting their production pathways. Production of anthocyanins, flavonoids lignin and chloroplasts are some compounds affected. Glyphosate is readily absorbed by leaves and translocated through the plant in the vascular system. Growth is affected soon after application. There is a general yellowing in the immature leaves and growing tips which then spreads. Plant death can occur within four to seven days with susceptible species and may take up to 20 days with less susceptible species (Cornell University undated).

Dicamba is a selective herbicide for control of broadleaf weeds. It disrupts the plants transport systems and interferes with the metabolism of nucleic acid. It is readily absorbed through roots, stems and the foliage and then translocated through the plant in the vascular system. It causes abnormal growth in the plant such as twisting, bending of stems and petioles; leaf curling and cupping, and development of abnormal tissues and secondary roots resulting in eventual plant death. Symptoms may occur within hours of the herbicide application, but plant death may take three to five weeks (Cornell University undated).

Fluroxypyr is a selective post-emergent herbicide for control of a wide range broadleaf weeds. Foliar absorption and translocation is the main route of the chemical into the plant, although there is minor root absorption. When absorbed in the plant it accumulates in the growing tissues and causes an auxin overdose which interferes with the plants ability to use nitrogen and produce enzymes. It causes abnormal growth eventually resulting in death. Fluroxypyr has some residual activity and growers need to be aware of plant back periods. Generally, there is little residual activity although, in soils containing less than 25% clay. susceptible crops may require up to a 12 month break before planting. Hard water should also be avoided, or if unavoidable a water conditioning agent added (EPA 1998, Guo et al. 2019, Corveta Agriscience undated, Herbiguide1 undated)

Glufosinate ammonium is a non-selective herbicide for the control of broadleaf weeds and grasses. It has no residual activity. It is not actively translocated in the plant, so will only kill the foliage/stem areas it contacts. Due to rapid microbial breakdown, it has minimal if any root absorption. It causes a build-up of ammonium in the plant that destroys cells and stops photosynthesis. Glufosinate ammonium usually causes yellowing and wilting within three to five days and death within one to two weeks. Bright sunlight, high humidity and moist soil increase the rate of plant death. (Cornell University undated)

Imazethapyr is a pre- or post-emergence herbicide for control of broad leaf weeds and some grasses. It can have long term residual activity and plant back periods for some crops in dryland conditions can be up to 34 months. Some plant back periods may be reduced when greater than 2,000 mm of rainfall/irrigation has been applied (ADAMA 20191). Imazethapyr is readily absorbed by foliage and slightly slower by roots. It is translocated around the plant in the vascular system. It works by inhibiting the production of a key enzyme required for the manufacture of certain amino acids. Susceptible plants growth may be inhibited within a few hours of application. The growing points may start dying within one to two weeks, followed by a slow yellowing and dying of the plant (Cornell University undated)

MCPA is a systemic post-emergence herbicide for control of broadleaf weeds. It is absorbed through foliage and translocated in the vascular system to growing points. It can also be absorbed through the soil (Kogan and Henandez, 1991). It acts as the plant growth hormone, auxin, causing uncontrollable growth and eventual plant death (Anon. 2017). Plant symptoms can include twisting and bending, leaf cupping and curling, thickening and elongation of leaves, dying of the growing point and wilting. Death may take up three or more weeks (Nufarm undated).

Metolachlor is a short residual, pre-emergent herbicide for control of broadleaf and annual grasses. It is primarily absorbed from the soil through the germination coleoptile (shoot) although there can be root absorption. Metolachlor stops or reduces seedling growth by inhibiting the formation of long chain fatty acids. It can be translocated through the xylem. Metolachlor needs to be irrigated after application to ensure the chemical is in the weed seed zone. (Butts et al. undated, Kenso 2004, Mann undated). Metolachlor breaks down faster in high organic matter soil, particularly when they are warm and moist as microbial action is increased under these conditions (Long et al. 2014). Metolachlor is registered for use in sweetpotato, to be applied immediately after transplanting sweetpotato vines, before weeds have germinated. This trial is looking at the effect on germinating/emerging sweetpotato roots. This is outside the registered label use for the product.

Oxyfluorfen is a pre- and post-emergent selective herbicide for control of annual broadleaf and grassy weeds. It is rapidly absorbed by shoots, less so by roots and is poorly translocated through the plant. Oxyfluorfen works by attacking the fats and proteins of the plant cell membranes. This causes breakdown in the cell membrane and cell desiccation It is persistent and relatively immobile in soils and the soil surface should not be disturbed after application. Plant symptoms can include leaves having a water-soaked appearance, then followed by necrotic spots., Depending on the crop, plant back intervals may be as long as 180 days (Vanstone and Stobbe 1978, Anon 2017, ADAMA 20192, Fenimore undated).

Pendimethalin is a pre-emergence selective herbicide for control of annual grasses and some broadleaf weeds. It inhibits pre-emergent seedling development, by affecting root and shoot growth. It is readily absorbed by young roots, but there is minimal translocation. Cell division in young roots, particularly root tips is inhibited, and they become thick and stubby. Pendimethalin works best when it is thoroughly mixed in the soil, either by mechanical incorporation or watered in. With some crops pendimethalin may have a 12 month plant back period (BASF 2013, Cornell University undated).

Prometryn is a selective pre- and post-emergence herbicide for control of broadleaf weeds and some grasses. It is mainly absorbed through the roots, although it is also absorbed through foliage, and translocated in the xylem where it accumulates in meristems and leaves. It inhibits electron transports affecting the photosynthetic system. Prometryn requires rain or irrigation soon after spraying for best activity. It works best on germinating seedlings or young and actively plantlets growing in moist soil. Young plants may stop growing then yellow and slowly die over 3-4 weeks. With some crops it may have a plant back period of up to eight months (EPA 1996, Nufarm 2009, Herbiguide2 undated, OXON1 undated)

Terbuthylazine is a selective pre- and post-emergence herbicide for control of annual broadleaf weed and some grasses. It is mainly absorbed through the roots or seedlings and to some extent by emerging cotyledons. It can also be absorbed through foliage. It is translocated in the xylem and accumulates in meristems and leaves. It inhibits electron transport which affect the photosynthetic system. Plants may yellow and die. There may be a plant back period in excess of six months for some crops (Kuechler et al. 2003, FAR 2007, Nufarm 2009, Herbiguide3 undated, OXON2 undated)

Trial process

Polystyrene boxes (internal measurement 44.5 cm L x 27.5 cm W x 12.0 cm H) were filled with a 2 cm layer of red basaltic Mapee soil, the soil common to the Walkamin cropping area. These soils are deep red uniform light to medium clay soils formed from basalt (Malcolm and Heiner 1996). The soil was taken from a newly cultivated fallow block on WRF. In the past 10 years, there was no recorded use of herbicide on this block.

Into each box seven sweetpotato storage roots (two large, two medium and three small) were placed on the layer of soil, positioned as shown in Image 1. More soil was then added to cover the roots to a depth of 2 cm. When planted, the boxes were watered to field capacity. The next day the boxes were inspected and boxes in which the soil had settled were topped to their original level and lightly watered.

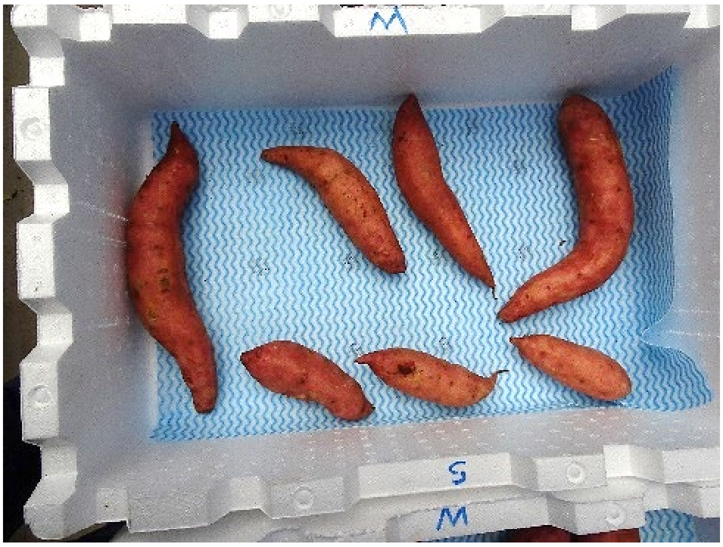


Image 5. Placement of large, medium and small roots in box (In the trial these were sitting on 2cm of soil).

Due to rainy conditions, the pre-emergent herbicides were not applied till six days after planting the storage roots. Herbicides were applied using a 500 ml hand sprayer with 200 ml of solution in the sprayer. The spray was applied to provide target coverage (similar to that achieved from a field spray unit). After pre-emergent spray application, the boxes were watered to ensure the herbicide was incorporated in the soil profile. Plants were checked three times per week to gauge the effect of the pre-emergent herbicide.

Post-emergent herbicides were not applied until all boxes had emerged plants that were actively growing. Cool weather came through soon after emergence and plant growth stopped until warmer weather returned (100 days). The pre and pre/post-emergent herbicides did not stop vine emergence, so the pre/post emergent herbicides were applied again, this time as a post-emergent spray. All herbicides were applied using a 500 ml hand sprayer with 200 ml of spray solution in the sprayer. The spray was applied to provide coverage of the box and plants (similar to that achieved from a field spray unit).

The trial was lightly watered three times per week, except when conditions were wet. Records of the herbicide effects were also made at these times. Each plot (box) was observed and a five point rating scale given to the visuals symptoms the plants were showing;

Plants are healthy growing and showing no sign of herbicide application.

Plants are showing symptoms which may affect plant growth, such as wilting, of leaves or stem. This may have retarded growth to some degree but if symptoms remain at this level, the plants will continue to grow.

Plants showing moderate effects affecting their growth. The plants are wilting strongly or have bleaching, burnt or senesced leaves and stem. They still have a visual assessment of 50% green leaves, stems and growing tips and may or may not be able to grow out of this damage.

Plant showing considerable effect of the herbicide application. They still have some green leaves or stems, but it is unlikely they will be able to grow out of the damage.

Plants dead

In addition to the rating a description was made of the visual appearance of the plot, (e.g., stems wilting, leaves bleached or leaves bronzed, leaves senescing). The trial concluded 45 days after pre-emergent herbicide applications were made.

Results

Pre-emergent Herbicides

The two pre-emergent herbicides, metolachlor and pendimethalin, did not stop the emergence of sweetpotato vines. Neither did the pre- and post-emergent herbicides, imazethapyr, oxyfluorfen, prometryn and terbuthylazine. Pendimethalin while not stopping emergence or growth did cause the true leaves to be misshapen (Images 2 & 3).

Images 2 & 3. Leaf deformation seen in pendimethalin treatments.

Caution needs to be applied to the results for pre-emergent herbicide applications. This is due to the way the plants grew in the pots. The clay content of the Walkamin Mapee soils caused the soils to pull away from the pot edges creating a space (Image 4). A number of sprouts from sweetpotato roots did grow into these spaces and up the side of the pot. This may have resulted in these sprouts not growing through the herbicide layer and may in part be responsible for the lack of control evidenced by these treatments.

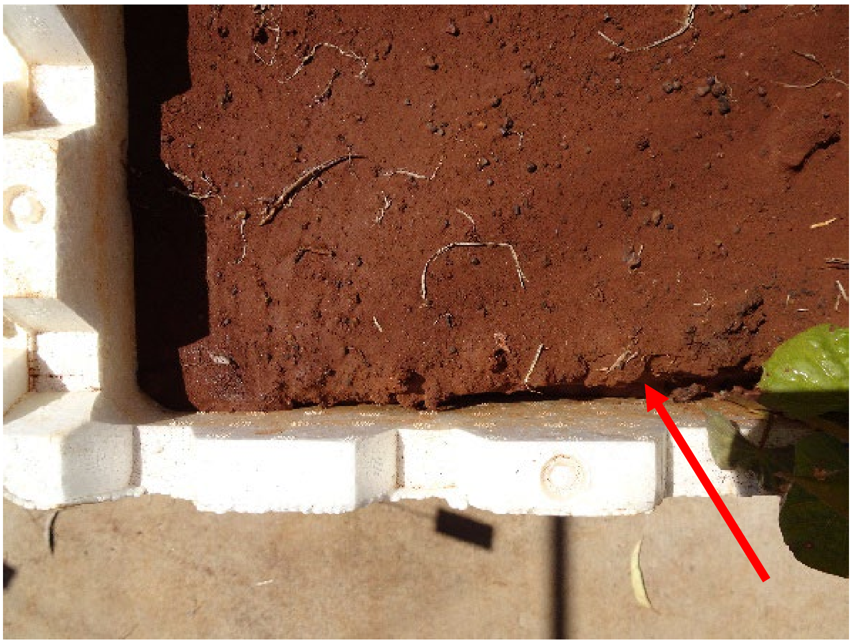


Image 4. Soil media pulled away from the side of the pot.

Herbicide application after sweetpotato emergence

Figure 1. graphs the various effects the post-emergent herbicide application had on the sweetpotato plants. Imazethapyr, oxyfluorfen, prometryn and terbuthylazine, the pre- and post-emergent herbicides had both pre and post applications made.

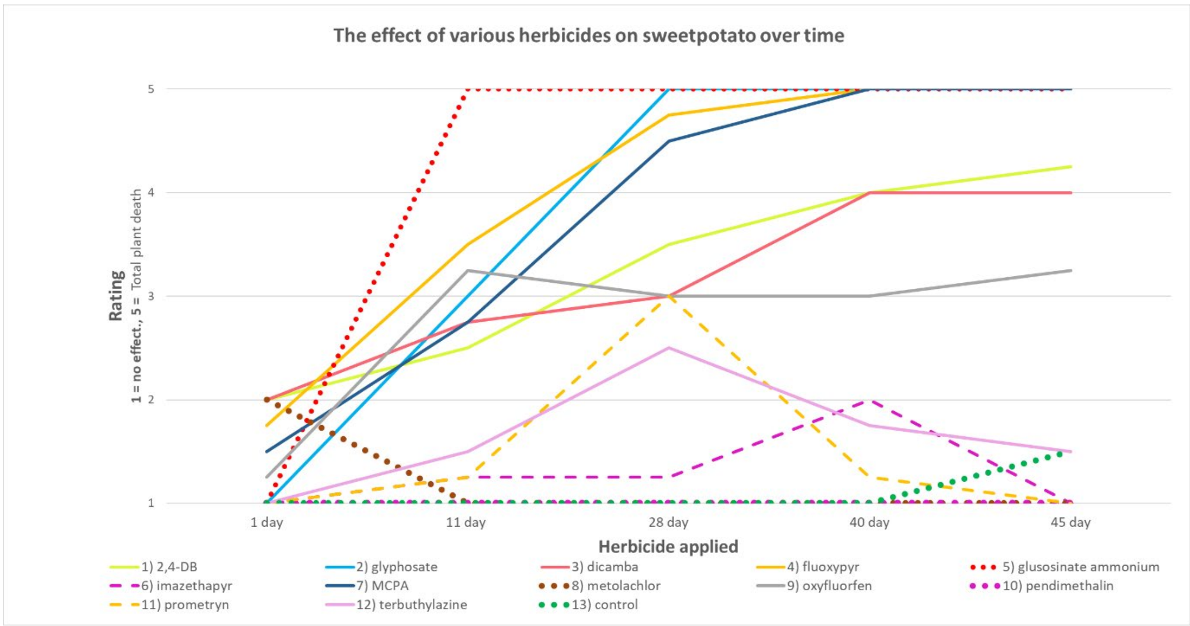


Figure 1. The effect of pre and post-emergent herbicide applied to sweetpotatoes.

Post-emergent herbicides

2,4-DB showed slight wilting of plants within 24 hours of application. By day four, a few plants were showing slight yellowing. This then progressed to some vein clearing, curling and bronzing of leaves. By day 15 the plants were at a seriously damaged and continued to slowly progress towards complete death.

Glyphosate did not start showing any obvious signs of plant damage until day 8. By day 8 there was sign of leaf yellowing, bronzing and some older leaf senescence. By day 11 plants were seriously damaged and by day 28 all plants were dead.

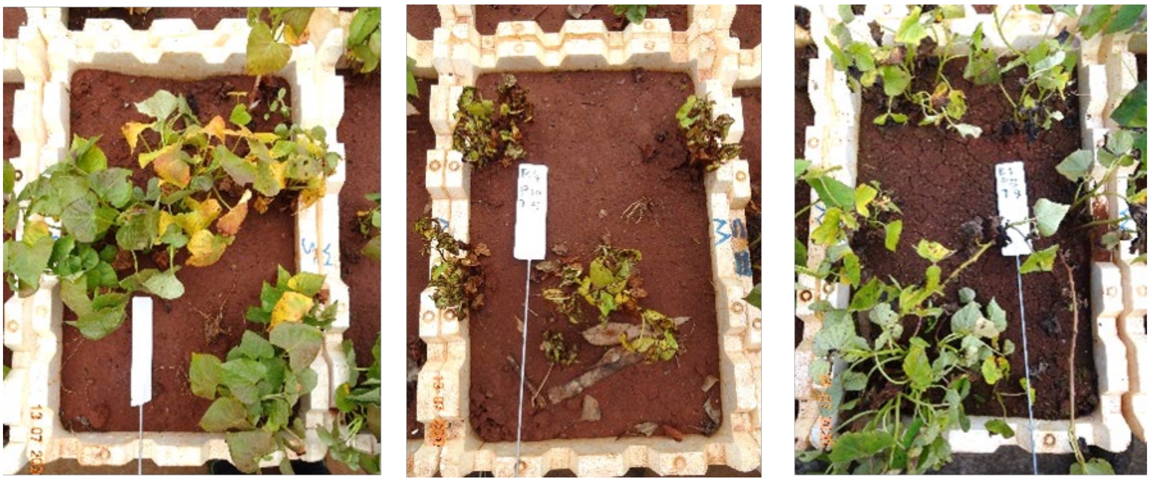
Dicamba sprayed plants were exhibiting signs of wilting within 24 hours of herbicide application. By day 4, plants were exhibiting wilting, leaf yellowing, bronzing and leaf burn symptoms. These continued to worsen and by day 17 had reached a level 3 rating and day 40 a level 4 rating. By the end of the trial, the plants remained at a rating 4.

Images 5, 6 & 7 (left to right) Plants affected by 2,4-DB, glyphosate and dicamba

Fluroxypyr was showing yellowing leaves, leaf bronzing and senescence and slight wilting by day 4. These symptoms continued to develop reaching a rating of 3 by day 8. By day 17, many of the plants were showing a high portion of senesced leaves, and plants virtually dead by day 26.

Glufosinate ammonium plants were showing some slight yellowing within 24 hours, but otherwise were looking healthy. Within four days, this had developed considerably. There was obvious leaf burn, and some leaves were senescing. Plants were totally dead by day 11. Glufosinate ammonium was the fastest acting herbicide in this trial.

MCPA was showing some leaf burn after 24 hours. By day 4 plants older leaves were yellowing and leaf edges senescing. Other leaves were pale in colour and plants tips were showing slight wilting. By day 24 plants were severely damaged (rating 4) and plants completely died by day 40.



Images 8, 9 & 10 (left to right) Plants affected by fluroxypyr, glufosinate-ammonium and MCPA

Post -emergent applied pre- and post-emergent herbicides

Imazethapyr treated plants did show a few reddened leaves and some yellow edges by day 15, but this receded until days 28 to 35 when symptoms appeared again. These stayed until day 42 and again disappeared.

Oxyfluorfen was showing reddened and bronzed leaves and some wilting after 24 hours of herbicide application. In one plot leaves were senescing. By day 6 plants were severely damaged and given a 3 rating. Most leaves were yellow, bronzed or red and the plants were wilting slightly. From this point until the end of the trial symptoms remained stable. The plants were not growing nor were they not showing signs of dying.

Prometryn showed some slight reddening and bronzing of the leaf in the first 8 days, but not enough to move it from a rating 1. Over the next 20 days symptoms slowly developed on the plants. By day 26, plants had whitened leaves with brown patches and leaf senescence and drop was occurring. From day 28 till 42 plants recovered from these effects and by the trial conclusion appeared to be growing well again.

Terbuthylazine plants grew well until day 11, when plants showed some reddening of leaves and a few older leaves yellowing with senescing leaf margins. These progressed to day 33 when older leaves had dropped, and many remaining leaves had yellowed or whitened. Leaves were also starting to curl upwards. From day 33 to the trials end the plants recovered.

Images 11, 12 & 13 (left to right) Plants affected by imazethapyr, oxyfluorfen, prometryn and terbuthylazine

Discussion

Four herbicides, glyphosate, fluroxypyr, glusosinate ammonium and MCPA successfully killed the sweetpotato vine within the timeframe of the trial. A censored analysis of variance (ANOVA), only looking at treatments that showed plant death indicated that glusosinate ammonium sprayed plants died significantly faster than the other treatments and predicted that 2.4-DB sprayed plants would have died soon after the completion of the trial (Table 2). Two other herbicides dicamba and oxyfluorfen severely limited the plants growth. Given the extent of damage to the plants it could be expected that dicamba sprayed plants and possibly the oxyfluorfen sprayed plants may have also succumbed. With the exception of oxyfluorfen, all of these chemicals were post-emergent herbicides. It should be noted that the oxyfluorfen plots were actually treated twice with the herbicide, once as a pre-emergent spray and again as a post-emergent. Although the pre-emergent spray did not show an effect on plant growth, it is not known if the post-emergent spray or the combination of the spray applications caused the toxic effect on the plants.

Table 2. Sweetpotato time to death after herbicide application

Treatment	Mean days to death
2,4-DB	46.5 c
glyphosate	23.6 b
fluoxypyr	29.0 b
glusosinate ammonium	8.7 a
MCPA	32.2 b

lsd= 13.04

Over time the pre-emergents imazethapyr, prometryn and terbuthylazine showed an effect on sweetpotato plant growth. However, in each of these cases the plants were able to overcome the herbicide effect. Again, it is not known if the effect on plants was caused by the post-emergent application of the herbicide or if it was a combination effect caused by the two herbicides.

Pendimethalin a pre-emergent herbicide while not seeming to affect the plants growth rate or leaf colour, did cause leaf deformation and this continued for the life of the experiment, indicating there may have been a continual effect from this residual herbicide.

Of the herbicides trialled in this experiment, the post-emergent herbicides best controlled sweetpotato vine growth. It would be interesting in future work to look at the post-emergent effect of oxyfluorfen and see if it does have a capacity to kill sweetpotato. Due to the onset of cold weather, this trial did not look at possible storage root regrowth. This is an issue that may need to be considered in field applications. Also, the trial did not consider any plant back intervals for follow on crops post herbicide application. These are stated on herbicide labels and must be adhered to.

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Appendix 11.

Herbicides for the Australian sweetpotato industry: a review of possible products

Herbicides for the Australian sweetpotato industry: a review of possible products

Nil herbicide treatment

Herbicide treatment

Michael Hughes

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Queensland Government

Summary

Essential to the maximisation of sweetpotato yield is the minimisation of production constraints. Weeds are recognised as a constraint affecting growth and productivity, that if not controlled, can cause severe yield losses.

In Australia, there are currently only six (6) herbicides registered for use in sweetpotato crops. Three are weed pre-emergent herbicides, two are herbicides specifically for grass control, and one is a non-selective contact herbicide for spraying off the crop prior to harvest (pre-harvest crop desiccation).

This review identifies herbicide options that are currently available or being researched in other countries with highly commercialised sweetpotato systems, in particular the United States of America (USA) and Canada. There are fourteen (14) herbicides available to north American sweetpotato growers. Seven are applied to the soil before transplanting sweetpotato vines. There are four herbicides registered for post-transplant application. Three herbicides are registered for grass control. Five of these registered herbicides are also able to be used as directed sprays between rows before the plant canopies cover all crop and interrow areas.

The review also identifies six herbicides which have been researched for use in sweetpotato but are not registered in Australia and four herbicide mixes that have been trialled though not yet registered for use in Australia.

While no single herbicide will solve weed problems in sweetpotato production systems, further research and validation of a number of the reviewed products (bicyclopyrone, flumioaxin, clomazone, metribuzin, oryzalin) could potentially increase the weed control options in Australia. By having a wider range of herbicide 'mode of action' groups available, growers would be strengthening their defence against weeds developing herbicide resistance.

Introduction

Sweetpotato is a year-round crop in Australia, with 102,754 tonne worth $73.9 M being produced in the year ending June 2021 (Hort Innovation 2023). Globally, Australian sweetpotato growers produce the highest commercial yields per hectare of sweetpotato (100/t/ha) (Dennien et al. 2017). Essential to maximising yield is minimising production constraints, weeds are widely recognised as a constraint affecting sweetpotato growth and productivity.

If not controlled, weeds can cause severe yield losses. Nedunzhiyan et al. (1998), quotes research identifying 22% yield loss in Hawaii, 91% in Nigeria and 70% to 91% in India. In the USA, La Bonte et al. (1999) found yield loss due to weeds could be between 55% and 63%. This is supported by Harrison and Jackson (2011), whose trials showed weeds caused 50% yield loss.

After the vines reach row closure, sweetpotatoes suppress weeds well, so the critical period for weed control occurs pre-row closure (Nedunzhiyan et al. 1998, Seem et al. 2003). Research indicates the important period to control weeds is between two weeks after transplanting (WAT) and six to eight WAT (Nedunzhiyan et al. 1988, Levett 1992, Seem et al. 2003, Harrison and Jackson 2011). This time-period can change with variety and seasonality or time of planting, and other environmental conditions that affect both sweetpotato and weed growth (Levett 1992, Harrison and Jackson 2011). From a practical production aspect, planting into weed free fields is an important first step in growing sweetpotato (Dutta et al. 2018, Phillips 2022).

Currently in Australia, there are only six herbicides registered for use in sweetpotato crops. Three of them are weed pre-emergent herbicides (chlorthal-dimethyl, metolachlor and S-metolachlor [different isomer of metolachlor]). Two are herbicides specifically for grass control (fluazifop-P [minor use permit till 30 November 2027] and sethoxydim), and one non-selective contact herbicide for spraying off the crop prior to harvest (diquat) (APVMA 2022, Infopest 2022). In October 2023, diquat is under review by APVMA with a proposed regulatory decision expected in May 2024 (APVMA 2023). In addition to these chemicals, there are several herbicides that can be used in fallows and in preparation of a clean bed for sowing. There are no registered herbicides that can be sprayed over the sweetpotato crop canopy to control broadleaf weeds (APVMA 2022, Infopest 2022).

To date, Australia has 48 weed species (21 grasses and 28 broadleaf) recorded as having resistance to at least one herbicide mode or action group (Anon 2022b). With sweetpotato registered herbicides only covering four herbicide mode of action groups, (groups 1, 3 15 and 22), the concern of herbicide resistance does need to be respected by the Australian sweetpotato industry.

This review will provide the sweetpotato industry with knowledge of herbicide options that are available in other countries with highly commercialised sweetpotato systems, in particular the USA and Canada. The report also looks at herbicide trials that have been conducted for products that are not yet registered in these and other production systems.

This document does not recommend the practices or herbicides being reviewed, or whether they should be used in Australian sweetpotato farming systems. By law only chemicals that have been assessed and registered for Australian use can be used on Australian farms. This review does provide some background information, that may assist the sweetpotato industry in deciding whether there may be benefit in facilitating the process having these herbicides registered.

Herbicide currently available for sweetpotato farmers in USA and Canada

Herbicides applied to the soil before transplanting sweetpotato vines

There are eight herbicides available to north American sweetpotato growers that are applied to the soil before transplanting sweetpotato vines. Six of these herbicides, caprylic acid + capric acid, carfentrazon-ethyl, glyphosate, paraquat, pelargonic acid and pyraflufen-ethyl are plant contact herbicides that are registered for pre-crop, post-emergent weed control. The other herbicides, bicyclopyrone and flumioxazin have both pre-emergent and post-emergent activity.

There herbicides are discussed below in terms of their current or potential use in Australia, highlighting key information about their use in the USA and Canada.

- **Bicyclopyrone** has systemic pre-emergent and post-emergent broadleaf weed control and may partially control some grasses. Care needs to be taken when using it on low organic matter soils. While bicyclopyrone has APVMA approval for use in Australia, it is currently only available as a herbicide mixture in the product Talinor®. Talinor® is registered for post-emergent control of broadleaf weeds in wheat and barley (APVMA 2023). Bicyclopyrone belongs to group 27 herbicide mode of action group (MoA) (previously H) (APVMA 2017a).

Syngenta USA label precautions associated with bicyclopyrone (sold as Optogen® in USA) use are;

  - The 257 ml/ha rate may be used on coarse textured soils for extended weed control but the risk for unacceptable crop injury is higher than the 190 ml/ha rate.
  - If sweetpotato roots are not sealed prior to application, irrigation or rainfall within 2-3 days after application increases the risk of unacceptable crop injury.
  - Application to sweetpotatoes grown on sandy loam soils with <1% organic matter (OM) is at a higher risk for unacceptable crop injury than soils with >1% OM.
  - Tank mixtures with other herbicides may increase the risk of crop injury.
  - Under adverse weather conditions (cool, wet, poor growth), temporary crop bleaching may be observed following application.

Cutulle (2017) identified that there may be some differences in sweetpotato variety tolerances to bicyclopyrone. Smith et al. (2019) showed that this herbicide may have potential use in weed control in seed beds, applied after soil coverage of the mother roots. (Appendix 1).

- **Flumioxazin** controls broadleaf weeds but only suppresses annual grasses. It has pre-emergence activity through root absorption and post-emergence through foliar contact. In the USA the label has a has a number of conditions when used with sweetpotato;
  - Do not use with transplants that have been harvested more than two days prior to transplanting.
  - Do not use on any variety other than Beauregard without first testing it and checking the variety has an acceptable tolerance level.
  - Significant injury can occur from applications made on poorly drained soils or application made under wet conditions.

  In Australia, flumioxazin (group 14 MoA, previously G) is registered for use in cotton, several field crops, lucerne and sugarcane. The Valor® 500 WG label (APVMA PubCRIS 2022) identifies a plant back period for sweetpotato of eight months if the product is used in sugarcane at the 700 g/ha rate and the soil has been thoroughly cultivated after the sugarcane has been grown and before sweetpotato is planted. Rates used with sweetpotato crops in north America are much lower than 700 g/ha. In Canada the application rate is 105 g/ha, while in the USA 2 oz/acre (120 g/ha approx.) or less (Note: product and active ingredient [ai] rates differ in both countries). (Appendix 1).
- **Caprylic** acid + capric acid does not have registration or APVMA permit for use in Australia. It is a non-selective, post-emergent weed herbicide that is not translocated in the plant, necessitating good plant coverage for effective weed control. It is registered for use with numerous vegetables, field and tree crops and non-agricultural sites in the USA. Stoddard (2016) found it showed promise as a herbicide for organic sweetpotato production. (Appendix 1).
- **Carfentrazone-ethyl** is a group 14 MoA (previously G) herbicide and has registration in Australia. In cropping situations, it is used in pre-plant broadacre weed control and for broadleaf weed control in winter cereals. It is a rapid knockdown contact herbicide that is non-residual. It is often mixed with other herbicides to broaden the weed control spectrum (NRA 2000). (Appendix 1).
- **Glyphosate** is a group 9 MoA (previously G) herbicide and has registration in Australia. It is a broad spectrum, non-selective, post-emergent systemic herbicide. It kills or suppresses most plants and is used to control annual and perennial broadleaf and grass weeds in both agricultural and non-agricultural settings (APVMA 2017b). In Australian sweetpotato production it is often used in planting preparation prior to sowing. While effective in controlling a wide range of weeds, it does not control later germinations and emergence (AgAware Consulting 2014). (Appendix 1).
- **Paraquat** is a group 22 MoA (previously L) herbicide and is registered in Australia. It is a non-selective strictly contact herbicide that is applied to emerged weeds. It controls annual grasses and most broadleaf weeds. It is often used to control emerged weeds prior to crop planting or crop emergence. It is also used as a shielded spray to control interrow weeds. (Appendix 1).
- **Pelargonic acid** (also known as nonanoic acid) has registration for use in Australia. Pelargonic acid belongs to the group 0 MoA (previously O) herbicides. It is an organic contact herbicide that is registered for use in orchards, vineyards and fallow soil for control of seedling and young broadleaf and grass weeds. Established weeds and perennial species are generally only suppressed. (Appendix 1).

Herbicides that may be applied after transplanting sweetpotato vines

There are four herbicides available to north American sweetpotato growers that may be applied after transplanting sweetpotato vines (Appendix 2). They are clomazone, chlorthal-dimethyl, napropamide and S-metolachlor.

- **Clomazone** is registered in Australia for use on cucurbits, green beans, Navy beans, potatoes, poppies, rice and tobacco. It is a pre-emergent weed control herbicide belonging to group 13 MoA (previously Q). Cucurbit transplants are sensitive to the chemical as are emerged potatoes.

  The Australian label states clomazone should not be applied to soils with organic carbon levels less than 2% and clay content less than 15%. In the USA clomazone is one of the most widely used herbicides on sweet potato, used in 50-85% of the production area (Wadl et al. 2020). It can cause temporary injury (whitening of leaf or stem tissue) to the sweet potato crop, from which the crop will recover (Wadl et al. 2020). Porter (1990) found that sweetpotato was tolerant to clomazone when applied at rates more than 1.7 kg/ha, although at 3.4 kg/ha temporary chlorosis lasting one week was seen. Porter (1990) found clomazone provided good weed control in the weed spectrum he tested, (being the then main weeds in many USA production areas). In 2016, Barkley et al. found it provided poor weed control of Palmer amaranth (Amaranthus palmeri), by then one of the most common and problematic weeds in North Carolina. Hughes (2001) found it only provided moderate control to weeds in pumpkin trials in far north Queensland. (Appendix 2)
- **Chlorthal-dimethyl** is currently registered in Australia for use with sweetpotatoes. It is a group 3 MoA (previously D) herbicide. Chlorthal-dimethyl is a general knockdown and residual herbicide that can be sprayed at transplanting and a lay-by application made up to six weeks after transplanting. Harper et al. (1990) review of four sweetpotato herbicide comparison trials between 1984 and 1987 found chlorthal-dimethyl preformed poorly in comparison to the other herbicides, and on one occasion when there was a four-hour delay before incorporation by rainfall, this herbicide caused phytotoxic symptoms in sweetpotato. (Appendix 2)
- **Napropamide** is a group 0 MoA (previously D) herbicide. In Australia, it is registered for use in almonds, grape vines, stone fruit, tomatoes and canola. It also has minor use permits for basil and transplanted brassica vegetables. Napropamide is used for pre-emergent weed control. It is particularly sensitive to photodegradation, so needs to be irrigated or incorporated into the soil soon after application. High temperatures also accelerate its breakdown.

  Napropamide is the only herbicide registered in the USA for use in plant propagation beds (Smith et al. 2019). It appears to have shown good results in trials in the 1990's but there does not appear to have been much research done with it since then. A University of Arkansas trial in 2001 found napropamide applied post-transplant to be safe for sweetpotato but was limited in its weed control ability (Talbert et al. 2004). Barley et al. (2016) found it provided inconsistent control of Palmer amaranth. (Appendix 2)
- **S-metolachlor** is a group 15 MoA (previously K) herbicide that is registered for use in sweetpotato crops in Australia. It controls and suppresses a wide range of grass and small seeded broadleaf weeds and in the USA is the only registered herbicide that has activity on yellow nutgrass (Cyperus esculentus) (Beam and Jennings 2018). In Australia S-metolachlor is not registered for yellow nutgrass control.

  Care needs to be taken when timing S-metolachlor application. Excessive rainfall, particularly if the herbicide is applied immediately after transplanting, can have a detrimental effect on plant growth. This can be further exacerbated with high temperatures (Meyers et al. 2012, Abukari et al 2015a, Abukari et al. 2015b). Many Australian growers are cautious about using S-metolachlor for this reason.

  Between 1984 and 1987 Queensland Department of Primary Industry officers conducted four trials examining potential herbicides for broadleaf and grass control in sweetpotato. Over all trials, metolachlor ranked first for overall sweetpotato yield and third for overall weed control (Harper et al. 1990). (Appendix 2)

Herbicides that may be applied between rows of sweetpotato

There are five herbicides available to north American sweetpotato growers for spay application between rows before the vines reach row closure. These herbicides are all toxic to sweetpotato and must be applied by directed nozzles, covered/hooded/shielded sprayers or wipers to ensure the herbicide does not contact the sweetpotato plants.

Carfentrazone-ethyl, glyphosate and pelargonic acid (nonanoic acid) do have registration in Australia, but not for specific use in sweetpotato. Bicyclopyrone has registration for use in Australia as part of a mixed product herbicide for control of broadleaf weeds in wheat and barley. For more details refer to the section above 'Herbicides applied to the soil before transplanting'. (Appendix 3)

Herbicides specifically for grass control in sweetpotato crops

North American sweetpotato growers have four herbicides available for use in controlling grass weeds in their crops. These herbicides will not control sedges or broadleaf weeds (Appendix 4).

- **Clethodim** a group 1 MoA (previously A) is registered in Australia for control of certain grass weeds in numerous crops but is not specifically registered for use in sweetpotato. In the USA it is used as a post-transplant application for control of emerged grass weeds. (Appendix 4)
- **Fluazifop-P** is a group 1 MoA (previously A) herbicide. It has a minor use permit in Australia for use in sweetpotato crops until 30 November 2027. In the USA it is used as a post-transplant application for control of emerged grass weeds. (Appendix 4)
- **Sethoxydim** is a group 1 MoA (previously A) herbicide. It is registered in Australia for use on sweetpotato. It should be applied when most grasses are in the two to six leaf stage and are actively growing. (Appendix 4)

Herbicides being researched but not yet registered for use in sweetpotato

There are six herbicides which are not registered for use in the USA or Canada, that have been researched for their ability to control weeds in sweetpotato crops.

- **Fluridone** is a group 12 MoA herbicide. In addition to being a herbicide, fluridone can act as a seed germination stimulant to create more uniform weed seed germination, reducing the soils seedbank. It binds to organic matter so is most efficient in low organic matter soils. Until 2000, it was used in Australia under APVMA permits for control of aquatic weeds. It has been trialled as a herbicide for southern Australian field cropping situations (Goggin and Powles 2014) but there is no current registration. In Australia herbicide resistance has been found to group 12 herbicides in populations of wild radish (Raphanus raphanistrum) and Indian hedge mustard (Sisymbrium orientale) (Anon 2022a).

  Field studies by Meyers et al. (2014) found minimal sweetpotato damage (<6%) from pre-plant application of fluridone and good control of Palmer amaranth and red root pigweed (Amaranthus retroflexus). Post-emergent application resulted in up to 30% damage levels to sweetpotato. In several trials yields equalled those of hand weeded plots. Between 2015 and 2017, trials at University of Delaware using fluridone as a pre-transplant application showed variable results. Weed control was not as good as the control treatment and there was significant early season injury to sweetpotato, although this did not necessarily result in final yield reduction. One occasion when higher rates were trialled there was a 24% yield reduction (Scott and VanGessel 2018). 2016 trial results in California found significant injury when fluridone was used pre-transplanting, and less injury when applied post-transplanting. The post-transplant application still caused extensive, although slight, crop injury which was still visible two weeks after application (Stoddard 2016). Data presented to the 52nd Annual Sweetpotato Meeting (UCCE Classroom, Merced CA, February 7, 2017) showed fluridone at all rates caused unacceptable levels of crop injury and poor weed control with significant yield losses.
- **Fomesafen** is a group 14 MoA herbicide (previously G). It is registered in Australia for the control of broadleaf weeds when applied prior to sowing or post-sowing, pre-emergence in chickpeas, narrow leaf lupins, lentils, field peas, faba beans and vetch. It is a soil applied residual herbicide that is absorbed through the roots.

  In the USA, in addition to dry beans, it is also registered for use in cotton, potatoes, and soybean. In trials at the University of Delaware, Scott and VanGessel (2018) found that fomesafen provided weed control equal to the standard, although in the 2015 trial it was less effective on morning glory spp (Ipomoea spp.) and in the 2017 trial less effective in controlling smooth pigweed (Amaranthus hybridus). Barkley et al. (2016) found fomesafen provided good control of Palmer amaranth with minimal injury to sweetpotato.
- It should be noted that the USA label, Reflex®, does state the planting time from last herbicide application till sweetpotato planting is 12 months.
- **Linuron** is a group 5 MoA herbicide (previously C). In Australia, it is registered for use in several crops (wheat, barley, oats, potatoes, carrots, parsnips, coriander seed crops, onions, soybean, maize and sweetcorn). From 1984-1987, it was trialled in Australia for use in sweetpotato. In some trials it gave good weed control, but in others there was significantly reduced sweetpotato plant population or severe phytotoxic effects on the plants. Overall, linuron did not consistently perform as well as metolachlor (Harper et al.1990).

In the USA, trials have been conducted with Linuron alone or combined with other herbicides to control Palmer amaranth a significant weed pest which can reduce sweetpotato yield by 80-85% if left uncontrolled. These trials have shown increased phytotoxicity as the linuron rates are increased and in some cases crop stunting (Beam et al. 2018, Scott and VanGessel 2018, Moore et al. 2021). Scott and VanGessel (2018) found linuron applied as a single application gave poor weed control, although when a second application was made 14 days later weed control was acceptable. If a level of crop injury is accepted, it may have a role in herbicide combination strategies to control Palmer amaranth.

In a research study in Brazil (dos Santos et al. 2018) saw that while there were some cultivar differences, linuron treatments yielded 24% less than mechanical weeding.

- **Metribuzin** is a group 5 MoA herbicide (previously C). It is registered in Australia for selective weed control in barley, chickpeas, faba beans, lentils, vetch, lupins, and some broadleaf weeds and may be used pre- or post-emergent depending on the crop and situation. Metribuzin may cause damage to crops grown on sandy soils or those low in organic matter.

  Meyers et al. (2017) noted that multiple trials in the 1980's and 1990's showed minimal toxicity from metribuzin applied pre- or post-transplant, when applied at ai rates of less than 900 g/ha, although there was some varietal sensitivity to the chemical. Meyers et al. (2017) trials indicated that metribuzin provided good control of Palmer amaranth and sweetpotato injury was limited when applied at 140g/ha and the application was delayed until at least two weeks after planting.
- **Oryzalin** is a group 3 MoA (previously D) herbicide. In Australia, oryzalin is registered for pre-emergent control of certain annual grasses and broadleaf weeds in fruit and nut orchards, vineyard, nursery stock, ornamentals, amenity plantings and turf. Areas to be planted need to be free of established weeds. It kills plants by inhibiting cell division in the roots stopping development of germinating weed seeds (Chaudhari et al. 2018).

  Glaze and Hall (1990) found that oryzalin controlled a level of weeds and had no effect on sweetpotato yield of variety 'Georgia Jet'. On susceptible varieties, oxyzalin will cause plant stunting and leaf distortion for up to 10-14 weeks after planting. Less injury is caused when the herbicide is applied directly after transplanting (3-7%) than when applied two weeks later (11-13%) (Meyers et al. 2017, Chaudhari et al. 2018). Plants grow out of the injury and the stunting and distortion does not seem to affect marketable yields which were found to be comparable to the hand-weeded control (Meyers et al. 2017, Chaudhari et al. 2018). It is sill unknown what effects soil incorporation and/or rainfall that may place oxyzalin in direct contact with sweetpotato during the root initiation phase could do to crop development (Chaudhari et al. 2018).
- **Pendimethalin** is a group 3 MoA (previously D) herbicide. It is a pre-emergent selective herbicide for control of annual grasses and some broadleaf weeds. In Australia, it is registered for use in numerous vegetable, field and tree crops. Meyers et al. (2019) conducted multi-site trials in the USA on using pendimethalin for weed control. They found that pendimethalin caused a minimal level of plant stunting which the plants outgrew and reduced the cannery grade yield but not other sizes or total marketable yield. Meyers et al. (2019) also noted that pendimethalin would need to be used with other herbicides, as alone it did not provide enough long season weed control. Trials in New Zealand by Lewthwaite and Triggs (2000), did not find any evidence of plant damage by pendimethalin, but storage root yields were significantly less than the best treatments in the trial. A trial by Hughes (2021) provided support to the theory that pendimethalin may have a detrimental influence on root development in the early stages of plant growth.

Herbicide Combinations

With few new herbicides suitable for sweetpotato production being made available, a number of researchers have studied the effects of herbicide combinations to better manage weeds in sweetpotato crops. Much of the USA research has been to find a method to control Palmer amaranth, a serious weed for sweetpotato farmers. Palmer amaranth is such a serious pest, American growers are willing to accept a small level of damage to their sweetpotato crops if the weed can be controlled.

- **Atrazine + S-metolachlor** De Lima et al. (2022) studied post-emergent herbicides for application to sweetpotato being grown for biofuel in Brazil. They found a mixture of atrazine and S-metolachlor applied at 3.5 L/ha, despite showing some initial effects, did not affect yield quantity and quality parameters. They also noted Nigerian studies that did show a decrease in yield when using rates higher than 1.5 kg/ha ai (de Lima et al. 2022). Unfortunately, the ai rates were not given in the publication, so it is not known if both authors were comparing the same products (Appendix 5). In an earlier Brazilian study, Lima et al. (2020) found a mixture of atrazine (370 g/ha ai) and S-metolachlor (290 g/ha ai) while affecting some early growth did not affect yield of sweetpotato variety 'Duda', a variety bred for ethanol production. This trial also showed no significant difference with the single S-metolachlor treatment (Appendix 5).

Note – due to recognised health risks, the European Union banned the use of atrazine in 2003 (Berthsass and Colangelo 2013). In 2008 the Australian Pesticides and Veterinary Medicines Authority (APVMA) completed a review on atrazine and was satisfied that atrazine registered products continue to meet the conditions prescribes by the Agvet Codes (APVMA 2008).

- **Clomazone + flumioxazin** Kelly et al. (2006) trialled a combination of clomazone (840 g/ha) and flumioxazin (three rates – 36, 72 and 109 g/ha) as both pre- and post-transplant applications. The pre-emergent application showed no damage to sweetpotato plants at any of the three rates of flumioxazin. Post-transplant application showed increasing injury to sweetpotato as the rate of flumioxazin increased. The combination provided high control rates for broadleaf signal grass (Urochloa platyphylla) and morning glory. Their recommendation was the combination be applied pre-transplant for improved broadleaf and grass weed control. (Appendix 5)
- **Linuron + S-metolachlor** Smith et al. (2018) studying weed control in plant propagation beds found that the combination of linuron (560 g/ha ai) + S-metolachlor (800 g/ha ai) too phytotoxic to recommend for sweetpotato production. (Appendix 5)
- **S-metolachlor + clomozone** Lima et al. (2020) trialled the mixture S-metolachlor (960 g/ha ai) and clomazone (500 g/ha ai) on the Brazilian bioethanol variety 'Cuda'. Thery found the herbicide mix did not affect sweetpotato productivity, although there was also no significant difference between the mixed treatment and single application of either S-metolachlor or clomazone. (Appendix 5)

Follow on sprays

USA sweetpotato growers are faced with several difficult to control weeds, in particular Palmer amaranth and pigweeds. Palmer amaranth has resistance to glyphosate in 28 USA states and there are reports of resistance in South America and Asia. Samples have also shown resistance to eight herbicide MoA groups (Noguera et al. 2021).

Traditionally USA sweetpotato growers have tended to only rely on one herbicide application to control weeds, and most information available to producers revolves around single herbicide application (Meyers et al. 2013). Meyers et al. 2010, found that application of flumioxazin pre-transplant followed by S-metolachlor after transplanting could provide effective control of Palmer amaranth. Unfortunately, this result was not consistent in all the trials that were conducted in that study. In a later trial series (Myers et al. 2013), the results were verified. By 2020, flumioxazin (107 g/ha) followed at seven to ten days post-transplant by S-metolachlor (800 g/ha) had become the current recommendation for Palmer amaranth control (Lindley et al. 2020, Moore et al. 2021).

Other trials studying herbicide follow on application such as. Pre-plant clomazone followed by post-transplant S-metolachlor and pre-plant linuron followed by post-transplant S-metolachlor have had mixed results (Lindley et al. 2020, Moore et al. 2021).

Discussion

Worldwide there are still no 'silver bullet' herbicides for weed control is sweetpotato, particularly those that control broadleaf weeds during crop growth. Effective weed control relies on an ongoing integrated management system, of which herbicides are one of the multiple tools used. The vision for integrated weed management systems is that the practices would be implemented using an area wide/regional approach including by farmers, councils, state authorities, environmental groups and other bodies (refer – YouTube -Beyond the fenceline. An area wide approach to weed management).

As regional scale approaches are typically difficult to implement, at least a 'whole of farm' approach to weed control needs to be considered. This should include but is not limited to herbicides, non-chemical control (tillage, rod weeding, rouging, cleaning of machinery to stop weed seed spread, etc.) and agronomic techniques (crop rotation, narrow row spacing of grains or green manure crops in the rotation, use of mulches, use of stale seedbeds [where seeds are allowed to germinate and then killed prior to planting the crop]).

Weed spectrums change with time, farming practices and in some cases as resistance to herbicides develops. Palmer amaranth is the most problematic weed in USA sweetpotato production (Moore et al. 2021). This weed has resistance to multiple herbicides in both the USA and worldwide (IHRWD 2023). Much of the herbicide research conducted in the USA has focused on managing this weed. Fortunately for the Australian sweetpotato industry, Palmer amaranth is not yet in country. This does not mean that the Australian industry can afford to be nonchalant about herbicide use and weed control, as Australia already 48 weed species with some level of herbicide resistance (Anon 2022b).

Herbicide performance is also affected by environmental factors such as sunlight, temperature, humidity, moisture stress and physical barriers (Hughes 2020). Sweetpotato varieties may also have different tolerance to herbicides (Cutulle et al. 2017, Campbell et al. 2018, Wadl et al 2020). Excessive moisture after herbicide application can also be an issue. S-metolachlor, metolachlor and oryzalin are all capable of movement in the soil with high rainfall and should not be applied if more than 12.5 mmm of rain is forecast. This is an important consideration for most Australian producers. Table 1 shows that on average the four months, April, July, August and September have less than one day with 12.5 mm in Bundaberg. This suggests that these soil leachable herbicides may have a role in Bundaberg production systems, although careful observations of weather forecasts would still be required due to rainfall variability. Much greater caution is needed if using these herbicides in the Cudgen region. Table 2 indicates that on average, all months of the year have at least one day with greater than 12.5 mm rainfall. Again, careful monitoring of forecasts and local knowledge will be important factors when considering if and when to use leachable herbicides.

Table 1. Bundaberg rainfall statistics 2000 - 2022

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average number of days per month with rainfall > 12.5 mm	2.8	3.4	2.9	0.7	1.0	1.3	0.4	0.7	0.7	1.6	2.1	3.4
Median rainfall per month (mm)	40.6	42.6	31.0	19.0	12.2	13.4	8.4	7.6	8.8	18.0	29.6	32.2
Highest daily rainfall recorded in the month (mm)	252.0	169.0	101.2	82.2	91.8	172.0	5802	105.0	85.0	238.8	114.0	165.2

Data calculated from Bureau of Meteorology data for Bundaberg Post Office.

Table 2. Cudgen rainfall statistics 2000 - 2022

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average number of days per month with rainfall > 12.5 mm	3.3	3.5	4.4	2.6	2.7	3.4	1.0	1.0	1.1	2.0	2.3	3.2
Median rainfall per month (mm)	40.0	64.2	62.6	30.6	29.0	32.0	13.8	15.0	15.8	27.6	20.0	37.8
Highest daily rainfall recorded in the month (mm)	164.0	295.0	260.0	157.2	90.6	240.8	70.2	74.0	69.8	129.0	127.0	228.6

Data calculated from Bureau of Meteorology data Kingscliff (Woram Place).
Data for years 2008, 2009, 2010 &2011 is missing.

Conclusion

This review has identified several herbicides, some registered in Australia for use on other crops and some not, that could potentially find a role in Australian sweetpotato production systems. None of these herbicides are going to solve all problems nor are they without considerations for their use. As they are from different mode of action groups to those already registered for sweetpotato in Australia (groups 1, 3, 15 and 22), they would provide further tools to reduce the likelihood of weeds developing herbicide resistance.

Bicyclopyrone (group 27 MoA) has shown an ability to control weeds in seedbeds, although there are a number of precautionary statements with its use, and some sweetpotato varieties may be affected by it. Flumioxazin (group 14 MoA) used pre-transplant at low rates may be worth investigating although it does have precautions on varietal effects and application to poorly drained soils or in cool wet conditions. Although it did not stand out in Hughes (2001) north Queensland trials, clomazone (group 13 MoA) is the most widely used herbicide on sweetpotato in the USA. It may be worth re-evaluating for weed control effectiveness in the major sweetpotato production regions. Although the herbicides metribuzin and oryzalin are not registered for use in north America, they have had some success in weed control if farmers are willing to accept a level of injury to their crops.

It is not a given that these products will work in the Australian sweetpotato production systems and their environments. Further research, ideally on-farm and multi-locational would be required to ensure their effectiveness and value both agronomically and economically.

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Appendix 1 – Herbicides available for use in the USA and/or Canada that may be applied before transplanting vines

Active ingredient (ai)	Notes on applications for sweetpotato crops in USA/Canada	Selection of Australian Trade Names (if registered in Australia	Australian label description and other comments
bicyclopyrone	Systemic pre-emergent and post-emergent broadleaf weed control. May partially control some grasses. Do not apply to sweetpotatoes grown on sand or loamy sand soils with less than 1% organic matter. Dry conditions may reduce pre-emergent activity. If 6 mm rain is not received in 7-10 days, rotary hoeing may activate the herbicide. Minimize the movement of treated soil during the transplanting process. For best results apply irrigation prior to transplanting and avoid tillage after application.	Approved for use in Australia - not available as a single ai product.	When mixed with other ai's is used to control broadleaf weeds in wheat and barley.
caprylic acid + capric acid	Non-selective, non-systemic, post-emergent weed control. Effective on grasses and broadleaf weeds. May have potential in organic sweetpotato production (Stoddard 2016).	Not registered in Australia.	Not registered in Australia.
carfentrazone -ethyl	Post-emergent weed control. Applied as a pre-plant burndown for emerged broadleaf weeds. There is no pre-transplant interval. When applying post-transplant, apply as a hooded spray in-row as the chemical will cause damage to sweetpotato stems and leaves.	Carfent, Carfentrazone, Carfentrosix, Chipper, Clobbertime, Consort, Elevate, Fullguard, Pummel, Rage, Squatter	For improvement in the control of marshmallow and certain other broadleaf weeds prior to establishment of broadacre crops, fallows or forest plantations, in commercial, industrial and public service areas, and around agricultural buildings and yards. For the control of certain annual broadleaf weeds in winter cereals and pyrethrum and aquatic weeds in rice.
flumioxazin	Flumioxazin controls many broadleaf weeds but only suppresses annual grasses. Tank mix with clomazone for pre-transplant or follow with a residual grass product to improve control of annual grasses. Has both pre-emergence activity through root absorption and post-emergence from foliar contact (minimal translocation). Apply 2- 5 days pre-transplant after all tillage has been completed. Limit disturbance of treated soil with transplant equipment. Do not use with transplants that have been harvested more than 2 days prior to transplanting. Do not apply over the top of sweetpotato. Do not use on any variety other than Beauregard without first testing it, and it having acceptable tolerance. Moisture is necessary to activate the chemical. Significant injury may occur from application made on poorly drained soils or application made under cool wet conditions.	Clipper, Flumioxazin, Payload, Pledge, Spektrum, Territory, Valor	For knockdown and residual control of broadleaf weeds and grasses in a range of broadacre crops and fallow, and in non-crop situations. For rapid knockdown and control of various broadleaf weeds when mixed with certain glyphosate/diquat herbicides and for control of cotton when applied alone, prior to sowing cotton and its rotation crops, or for rapid knockdown and control of various broadleaved weeds when applied as a directed spray in cotton. Note: It has been identified that sweetpotato should not be planted for 8 months after an application rate of 700g/ha has been applied to sugarcane, assuming the soil have been thoroughly cultivated after the cane has been grown.

Active ingredient (ai)	Notes on applications for sweetpotato crops in USA/Canada	Selection of Australian Trade Names (if registered in Australia	Australian label description and other comments
glyphosate	Can be applied as a preplant treatment for control of broadleaf and grass weeds. To obtain maximum benefit from preplant applications allow seven days before cultivation. For difficult to control weeds may apply glyphosate and 5-7 days later and at least 1 day prior to transplanting may follow up with application of paraquat.	Ancosafe, Blade, Clear up, Cropmaster, Devastate Plus, Di-Bak G, Dry Gly, Eraze, Fortin, Galigan, Glister, Glyphix, Glyphosate, Grown up Knockout, Max out 600 Duo, Musta, Panzer, Roundup, Weed Kill, Wipe out. + numerous other brands	Water soluble herbicide for non-selective control of many annual and perennial weeds in certain situations. For control of annual and perennial weeds prior to sowing of any crop. Edible and non-edible crop, but not prior to transplanting tomato seedlings.
paraquat	Post-emergent weed control. Applied to emerged weeds less than 15 cm tall prior to transplanting. Good spray coverage of weeds is required as is strictly a contact herbicide. For fields with difficult weeds, prior to planting apply glyphosate and 5-7 days later and at least 1 day before transplanting, apply paraquat.	Cruze, Dagger, Explode, Para, Paradox, Par-Q, Paraquat, Parashot, Powerquat, Rainquat, Spraytop	Controls annual grasses and most annual broadleaf weeds. Very dangerous, particularly the concentrate. Aid to cultivation – to minimise cultivation and prepare a clean bed for sowing. Where heavy weed growth is present at spraying a better seedbed will result if cultivation is delayed 3-5 days. Row crops, vegetables and market gardens. Pre-planting. – to control weeds in seedbeds. Treat no less than 3 days before sowing. Post-emergence inter-row weed control. Apply after transplanted crops are established. Direct the spray so it does not touch the crop. Use shielded nozzles.
pelargonic acid (also known as nonanoic acid)	A non-selective contact herbicide that controls many weeds. Bio-based herbicide.	Basher, Beloukha, Brut, Neo, Nonanoic Acid, Pelargonic, Slasher, Slayer	For non-selective control of seedling and young weeds, for suppression of established weeds and perennial species, control of moss and algae. Organic contact herbicide. Orchards and vineyards, fallow soil.
Pyraflufen-ethyl (acetic acid)	Contact herbicide requires thorough coverage for broadleaf weed control. Best control on leaves up to 100 mm in height or less or rosettes 75 mm in diameter or less.	Ecopar Forte, Pyraflufen-ethyl, Sledge Acetic Acid – Acetic weedkiller, Farmsafe Boost Plus, N Natural	Early post-emergence contact herbicide with rapid foliar uptake. For the control of annual broadleaf weeds in winter cereals and pastures. For improvement on the brownout of a range of broadleaf and grass weeds, the reduction in seed set and viability of weed seeds prior to harvest of wheat, barley, field pea, faba bean, chickpea, lentil, narrow leaf lupin, the control of volunteer cotton.

Appendix 2 – Herbicides available for use in USA and/or Canada that may be applied after transplanting sweetpotato vines

Active ingredient (ai)	Notes on applications for sweetpotato crops in USA/Canada	Selection of Australian Trade Names (if registered in Australia	Australian label description and other comments
clomazone	Pre- emergent weed control. Apply after transplanting and prior to weed emergence. Use lower rates on coarse textured soils low in organic matter and higher rates on fine textured soils and soils with high organic matter. Does not control pigweed sp. morning glory sp. and yellow nutsedge (Cyperus esculentus) (in Australia yellow nutgrass is also called yellow nutgrass, tiger nut, rush nut, northern nutgrass, earth almond or yellow nutsedge). Some temporary crop injury (whitening of leaf or stem tissue may occur). Complete recovery will occur from minor early injury without affecting yield or delaying maturity.	Caimen, Chrome, Clearance, Clomazone, Clomaquest, Command, Director, Magister, Soldier	For the control of certain annual broadleaf weeds in cucurbits, green beans, navy beans, potatoes, poppies, rice and tobacco. Do not apply through irrigation. Do not apply to soil intended for seedling transplants with the exception of tobacco. Do not apply to soils with organic carbon content less than 2% and clay content less than 15%.
chlorthal-dimethyl (dimethyl tetrachloroterephthalate)	Pre-emergent weed control. Apply at transplanting to 10-14 days after transplanting. Labelled for applications directly over transplants without injury. If weeds are present the crops should be weeded or cultivated prior to application. Can be applied up to 6 weeks after transplanting as last operation before row closure.	Chlorthal, Chlorthal-dimethyl, Dacthal, Dynamo, Prethal, Pterodactyl, Lawthal	Registered for use with sweetpotato. For pre-emergence weed control in certain vegetable crops including: brassicas, beans, peas, garlic, onions, carrots, lettuce, potatoes, turnips and for weed control in strawberries, cotton, lawns and ornamentals.
napropamide	Pre-emergent weed control. Control of annual grasses and certain broadleaf weeds will be supressed or controlled. Apply immediately after transplanting and prior to weed emergence. Florida can apply as a pre-plant burndown. Rainfall or irrigation within 24 hours of application improves performance.	Devrinol, Napropamide	For pre-emergence control of certain weeds in canola, direct seeded and transplanted tomatoes, almonds, grapevines and stone fruit. Current permit (15/03/2012 – 30/11/2024) for use with Oilseed Mustard. Current permit (22/08/2019 – 31/08/2027) for use with Brassica vegetables (transplanted only). Current permit (16/03/2020-31/10/2027) for use in Basil (field grown only). Restraint – Do not apply to peaty soils. Is particularly susceptible to photodegradation and the rate of breakdown in the soil is greatly accelerated by high temperatures. Irrigate in to 5cm depth after planting or incorporate to 2-5 cm within 10 days.
S-metolachlor	Pre-emergent weed control. Do not incorporate into the soil. Do not irrigate more than 12.5 mm of water in the first irrigation following application. To avoid concentrating the chemical over the top of sweetpotato transplants, fill the transplanter trench prior to application.	Bouncer, Boxer Gold, Boxmate A, Clincher Gold, Chaser S, Dual Gold, Gold, Heist, Hyena, Left Hook, Menace, Metal Gold, Metamore, Metoken Gold, Metolamax, Metola-S, Metor-S, S-Maestro, S-Met, S-Metol, S-Metolachlor, Primextra Gold, Pulsate, Rebelion, Storm	Registered for use with sweetpotato. Controls certain annual grasses and broadleaf weeds in certain crops such as rhubarb, brassica, leafy vegetables, mustard, spinach, silverbeet, spring onions, shallots, culinary herbs. Short residual pre-emergent herbicide. Registered for sweetpotato. Apply immediately after transplanting before weeds have germinated. Sufficient irrigation to wet the soil through the weed zone should be applied within 24 hours. Further weed germination may occur following hilling due to exposure of untreated soil. Restraints: Do not apply to waterlogged soils. Do not apply if heavy rains or storms that are likely to cause runoff are forecast within 2 days of irrigation.

Active ingredient (ai)	Notes on applications for sweetpotato crops in USA/Canada	Selection of Australian Trade Names (if registered in Australia	Australian label description and other comments
			Do not irrigate to the point of runoff for at least 2 days after application. Do not harvest sweetpotatoes, graze or cut for stock food for 23 weeks after application.

Appendix 3 – Herbicides available for use in USA and/or Canada that may be applied between the rows of a sweetpotato crop

Active ingredient (ai)	Notes on Sweetpotato crop application in USA/Canada	Selection of Australian Trade Names (if registered in Australia)	Australian label description
bicyclopyrone	Systemic pre-emergent and post-emergent broadleaf weed control. May partially control some grasses. Do not apply to sweetpotatoes grown on sand or loamy sand soils with less than 1% organic matter. Apply after transplanting to row middles. Avoid contacting the sweetpotato foliage during application or crop injury will occur. Use of a hooded or shielded sprayer will minimise crop injury. Add a non-ionic surfactant or crop oil concentrate. For optimal control make application to small weeds less than 50 mm.	Approved for use in Australia - not available as a single ai product.	When mixed with other ai's used to control broadleaf weeds in wheat and barley.
Caprylic acid + capric acid	Non-selective, non-systemic, post-emergent weed control. Effective on grasses and broadleaf weeds. Use with hooded or shielded sprayer as chemical will damage the crop.	Not registered in Australia.	Not registered in Australia.
carfentrazone -ethyl	Post-emergent weed control. Applied as a pre-plant burndown for emerged broadleaf weeds. There is no pre-transplant interval. When applying post-transplant, apply as a hooded spray in-row as the chemical will cause damage to sweetpotato stems and leaves.	Carfent, Carfentrazone, Carfentrosix, Chipper, Clobbertime, Consort, Elevate, Fullguard, Pummel, Rage, Squatter	For improvement in the control of marshmallow and certain other broadleaf weeds prior to establishment of broadacre crops, fallows or forest plantations, in commercial, industrial and public service areas, and around agricultural buildings and yards. Has expired permits for pyrethrum, volunteer potato, blackberry nightshade control.
Glyphosate	Apply between crop rows with wipers or hooded or shielded sprayers.	Ancosafe, Blade, Clear up, Cropmaster, Devastate Plus, Di-Bak G, Dry Gly, Eraze, Fortin, Galigan, Glister, Glyphix, Glyphosate, Grown up Knockout, Max out 600 Duo, Musta, Panzer, Roundup, Weed Kill, Wipe out. + numerous other brands	Water soluble herbicide for non-selective control of many annual and perennial weeds in certain situations. For control of annual and perennial weeds prior to sowing of any crop. Edible and non-edible crop, but not prior to transplanting tomato seedlings.
Pelargonic acid (also known as nonanoic acid)	A non-selective contact herbicide that controls many weeds. Bio-based herbicide.	Basher, Beloukha, Brut, Neo, Nonanoic Acid, Pelargonic, Slasher, Slayer	For non-selective control of seedling and young weeds, for suppression of established weeds and perennial species, control of moss and algae. Organic contact herbicide Orchards and vineyards, fallow soil.

Appendix 4 – Herbicides available for use in USA and/or Canada specifically for grass control in sweetpotato crops

Active ingredient (ai)	Notes on Sweetpotato crop application in USA/Canada	Selection of Australian Trade Names (if registered in Australia)	Australian label description
clethodim	Post-transplant application. Post-emergent grass control. Does not control sedges or broadleaf weeds.	Carbine, Cleth-D, Cleokey, Clethodim, Clethora, Client, Cluster, Cyclops, Exit, Grasdim, Havoc, Icasso, Platinum Xtra, Scalpel, Select, Sequence, Sumistatus, Uproot	For the control of certain grass weeds in beetroot, cabbage, canola, celery, cotton, forestry, lettuce, non-bearing fruit trees, onions, ornamentals, peanuts, pulses (including adzuki beans, broad beans, chickpeas, faba beans, field peas, lentils, lupins and mung beans) potatoes, soybeans, and pasture legume (lucerne, clover and medic), seed crops (and pastures).
Fluazifop-P	Post-transplant application. Post-emergence control of annual and perennial grass weeds. Will not control broadleaf weeds or sedges. Apply to actively growing grasses before they exceed the labelled growth stages. Do not apply within 55 days of harvest.	Cannonade 212, Flare 212, Flazz 212, Fluazifop, Fluazifop 212, Fluazaway 212, Fusilade, Fuzilier, Rootout 212, Salvo 212	Minor use permit for sweetpotato until 30 November 2027. For control of certain grasses in certain crops. Do not harvest sweetpotato for 10 weeks after application.
sethoxydim	Selective post-emergence control of annual and perennial grasses. Will not control broadleaf weeds or sedges. Do not apply within 30-60 days of harvest (depending on state regulations).	Sertin, Sethoxydim	Registered for use in sweetpotato. For control of specific emerged grass weeds in various crops. Apply when most grass weeds are in the 2 to 6 leaf stage and actively growing. No withholding period when used as directed.

Appendix 5 – Herbicide mixes trialled for use in sweetpotato weed management.

Active ingredient (ai)	Best rate used in trail / Comments	Selection of Australian Trade Names (if registered in Australia)	Australian label description
370 g/L atrazine + 290 g/L S-metolachlor	Rate unknown – trial product not specified.	Australian registered product Primextra Gold	Controls certain annual grasses and broadleaf weeds in maize, sugarcane and sweet corn, also in sorghum when previously treated with Concep® II or Epivio® C sorghum seed safener.
28.1% atrazine (2.67 lb per U.S. gal. of atrazine and related ai) + 35.8% metolachlor (3.33 lb per U.S. gal. ai)	Rate unknown- trial product not specified.	American Registered product Bicep II Magnum	---
33% atrazine (3.1 lb per U.S. gal. ai) + 26.1% metolachlor (2.4 lb per U.S. gal. ai)	Rate unknown- trial product not specified.	American Registered product Bicep II Magnum, Sharda Atrazine 33% + Metolachlor 26.1% SE Stalwart Xtra	---
atrazine + S-metolachlor	atrazine (370 g ai/ha) + S-metolachlor (290 g ai/ha).	Product unknown	---
clomozone + flumioxazine	clomazone (840 g/ha) + flumioxazine (36 g/ha or 72 g/ha or 109 g/ha).	Australian registered product clomazone Caimen, Chrome, Clearance, Clomazone, Clomaquest, Command, Director Magister, Soldier flumioxazin Clipper, Flumioxazin, Payload, Pledge, Spektrum, Territory, Valor	For the control of certain annual broadleaf weeds in cucurbits, green beans, navy beans, potatoes, poppies, rice and tobacco. For knockdown and residual control of broadleaf weeds and grasses in a range of broadacre crops and fallow, and in non-crop situations.
linuron + S-metolachlor	Linuron (560 g/ha ai) + S-metolachlor (800 g/ha ai) -used on plant propagation beds.	Australian registered product – linuron Leapfrog, Linurex, Linuron S-metolachlor Bouncer, Boxer Gold, Boxmate A, Chaser S, Clincher Gold, Dual Gold, Heist, Hyena 960, Left Hook, Menace, Metal Gold, Metamore, Metoken Gold, Metola-S, Metolmax, Metor-S, Pulsate, Rebellion Gold, S-Met, S-Metol, S-Metolachlor, S-Moc, Smart Gold, Storm	For control of certain weeds in wheat, barley, oats, potatoes, carrots, parsnips, coriander seed crops, onions, soybeans, maize and sweet corn. Controls certain annual grasses and broadleaf weeds in broccoli, brussels sprouts, cabbages, cauliflower, canola, cotton, green beans, navy beans, maize, sweet corn, pastures, peanuts, soybeans, sunflower, sugarcane, sweetpotatoes, tobacco, barley, oats, wheat, triticale.
S-metolachlor + clomazone	S-metolachlor (960 g ai/ha) + clomazone (500 g ai/ha).	Product unknown	---

Appendix 12.

Nematode resistance screening

Nematode resistance screening

PW17001 Final report Appendix 12 Integrated pest management of nematodes in sweetpotato

Jennifer Cobon, August 2023

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

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Summary

Potential rotation crops and sweetpotato cultivars were screened in pot trials for their host status to the several species of nematodes identified in the survey and for their suitability in sweetpotato production systems. Growing a non-host rotation crop can reduce the numbers of plant-parasitic nematodes in the soil for the proceeding crop as the food source, on which the nematodes feed, has been removed.

Host range studies in the glasshouse screened 103 cultivars from 33 plant species for resistance to two species of root-knot nematode (Meloidogyne incognita and M. javanica), reniform nematode (Rotylenchulus reniformis - 7 cultivars screened from 7 plant species) and lesion nematode (Pratylenchus zeae - 10 cultivars from 2 plant species). Twenty-four cultivars of sweetpotato were screened for resistance to two species of root-knot nematode and six of the commonly grown cultivars of sweetpotato were screened for resistance to reniform nematode.

Susceptible crops can support the development of plant-parasitic nematode populations, with a reproduction factor greater than 1. Resistant crops are those that do not support the reproduction of plant-parasitic nematodes with a reproduction factor less than 1. For root-knot nematode, susceptible crops are further categorised as highly, moderately and slightly susceptible according to the reproduction factors.

Thirty-six varieties were resistant or highly resistant to M. incognita, M. javanica or both. This includes 2 brassicas, 13 legumes and 14 grasses resistant to M. incognita and 8 legumes and 14 grasses resistant M. javanica. Cultivars of eight legumes (ground nut, sunn hemp and pigeon pea), two oats, three grasses and three forage sorghums were resistant to both M. incognita and M. javanica making these cultivars excellent rotation crops to reduce root-knot nematode numbers when the species of root-knot nematode is unknown.

Additional information on the host status of these plant species to other plant-parasitic nematodes of concern for sweetpotato production can be found on the Lucid key developed during this project.

Outputs

Lucid key development. This online key contains all information to date on crops and their resistance to several species of plant-parasitic nematodes.

Crop rotations and their resistance to plant-parasitic nematodes - Lucid4 Key Player (lucidcentral.org)

Up to date tables of possible rotation crops and sweetpotato cultivars and their resistance to several species of plant-parasitic nematodes have been published on the ASPG website.

Outputs

Thirty-six rotation crop species were identified as resistant or highly resistant to M. incognita, M. javanica or both (2 brassicas, 13 legumes and 14 grasses resistant to M. incognita and 8 legumes and 14 grasses resistant M. javanica.

This work identified eight legume species, (ground nut, sunn hemp and pigeon pea) two oats, three grasses and three forage sorghums with resistant to both M. incognita and M. javanica, making these cultivars excellent rotation crops to reduce root-knot nematode numbers when species of root-knot nematode is unknown.

Resistant options suitable for summer (e.g. sorghum) and winter (e.g. oats) were identified to suit different rotation timings.

Conference presentations.

Cobon, J.A., O'Neill, W.T., Shuey, T., Langenbaker, R., Dennien, S., 2021, Resistant Rotation Crops to reduce root-knot nematodes in sweetpotato production. Oral presentation at the 21st Australasian Plant pathology Society Conference, Tasmania (online conference), November 2021.

Cobon, J.A., O'Neill, W.T., Shuey, T., Langenbaker, R., Dennien, S., 2022. Glasshouse screening to identify rotation crops resistant to reniform nematode (Rotylenchulus reniformis) for the sweetpotato industry. Oral presentation at the 11th Australasian Soilborne Disease Symposium, Cairns, August 2022.

Cobon, J.A., O'Neill, W.T., Shuey, T., Langenbaker, R., Dennien, S., 2022. Plant-parasitic nematodes in sweetpotato production areas in Australia. Oral presentation at the 11th Australasian Soilborne Disease Symposium, Cairns, August 2022..

Introduction

Growing a non-host crop as a rotation is a good management strategy to reduce nematode numbers in the soil before planting a susceptible plant crop. If plant-parasitic nematodes do not have roots on which to feed, their numbers will reduce.

Glasshouse host range studies screened 103 cultivars from 33 plant species for resistance to two species of root-knot nematode (*Meloidogyne incognita* and *M. javanica*), reniform nematode (*Rotylenchulus reniformis* - 7 cultivars screened from 7 plant species) and lesion nematode (*Pratylenchus zeae* - 10 cultivars from 2 plant species). Twenty-four cultivars of sweetpotato were screened for resistance to two species of root-knot nematode and six of the commonly grown cultivars of sweetpotato were screened for resistance to reniform nematode.

Possible rotation crops and sweetpotato cultivars can be distinguished into two groups. Susceptible crops can support the development of plant-parasitic nematode populations, with a reproduction factor greater than 1. Resistant crops are those that do not support the reproduction of plant-parasitic nematodes with a reproduction factor less than 1. For root-knot nematode, susceptible crops are further categorised as highly, moderately and slightly susceptible.

Thirty-six varieties were resistant or highly resistant to *M. incognita*, *M. javanica* or both. This includes 2 brassicas, 13 legumes and 14 grasses resistant to *M. incognita* and 8 legumes and 14 grasses resistant *M. javanica*. Cultivars of eight legumes (ground nut, sunn hemp and pigeon pea) two oats, three grasses and three forage sorghums were resistant to both *M. incognita* and *M. javanica* making these cultivars excellent rotation crops to reduce root-knot nematode numbers when the species of root-knot nematode in a filed/block is unknown or a mix of the 2 species .Two cultivars were resistant to *M. incognita* while 13 were resistant to *M. javanica*. One sweetpotato cultivar of the six screened was resistant to *R. reniformis.*

This resistance screening work has expanded the range of suitable rotation options for sweetpotato growers to help manage a range of plant-parasitic nematode pests. Available varieties may frequently change, especially for crops such as forage sorghum. This assessment of some new varieties, and some crop types which haven't previously been screened, provides a useful update of resistant rotations for the Australian sweetpotato industry. Screening of sweetpotato cultivars for nematode resistance under Australian conditions using locally sourced nematode species provides valuable information on varietal selection for growers.

Materials and methods

General methods are described in detail elsewhere in this appendix.

Meloidogyne javanica and M. incognita experiments

Seeds of each plant cultivar or vines of sweetpotato variety were sown directly into 1.5 L pots filled with pasteurised sand mix and pots of each cultivar tested were inoculated with 10,000 eggs of both nematode species. The nematode treatment was replicated five times for each species and maintained in a glasshouse with plants fertilised fortnightly with a liquid fertiliser (Aquasol®). Tomato cv. Tiny Tim was grown and inoculated as the susceptible control. At harvest, nematode eggs were stripped from the roots and level of resistance or susceptibility determined.

Rotylenchulus reniformis experiments

Seeds of each plant cultivar or vines of sweetpotato variety were sown directly into 1.5 L pots filled with an 80/20 mix of pasteurised sand mix and a pasteurised red ferrosol field soil obtained from Redlands Research Station. Vines were grown for three weeks before inoculation so that a healthy roots system was available for the nematodes to infect. Pots were inoculated at the rate of 7,396 eggs per pot for the rotation experiment and 14,500 eggs for the sweetpotato cultivar experiment.The nematode treatment was replicated five times for each species and maintained in a glasshouse with plants fertilised fortnightly with a liquid fertiliser (Aquasol®). Tomato c.v. Tiny Tim was grown as the susceptible control. At harvest, 16 weeks after inoculation for the rotation experiment or 23 weeks for the sweetpotato cultivar experiment, nematode eggs were stripped from the roots and level of resistance or susceptibility determined.

Pratylenchus zeae experiments

Seeds of each plant cultivar were sown directly into 1.5 L pots of modified UC mix. Pots of each cultivar tested were inoculated with approx. 1000 live juvenile and adult females of P. zeae.

The nematode treatment was replicated five times for each species and maintained in a glasshouse with plants fertilised fortnightly with a liquid fertiliser (Aquasol®). Maize cv. Messenger was grown and inoculated as the susceptible control. At harvest, 13 weeks after inoculation with nematodes, the nematodes were extracted from the roots in a misting chamber over seven days and levels of resistance or susceptibility determined.

Results and discussion

Meloidogyne incognita and M. javanica experiments on rotation crops

Thirty-six varieties were resistant or highly resistant to M. incognita, M. javanica or both. This includes 2 brassicas, 13 legumes and 14 grasses resistant to M. incognita and 8 legumes and 14 grasses resistant M. javanica (Table 1). Cultivars of eight legumes (ground nut, sunn hemp and pigeon pea) two oats, three grasses and three forage sorghums were resistant to both M. incognita and M. javanica making these cultivars excellent rotation crops to reduce root-knot nematode numbers when species of root-knot nematode is unknown.

Resistant options suitable for summer (e.g. sorghum) and winter (e.g. oats) were identified to suit different rotation timings.

Table 13 Summary or resistance/susceptibility of potentially useful rotation crop cultivars to two species of *Meloidogyne* spp.

Common name	Species	Cultivar	Species of *Meloidogyne*	
			M. incognita	***M. javanica***
barley	*Hordeum vulgare*	Dictator	Moderately susceptible	Moderately susceptible
barley	*Hordeum vulgare*	Harpoon	Moderately susceptible	Moderately susceptible
barley	*Hordeum vulgare*	Moby	Moderately susceptible	Moderately susceptible
barley	*Hordeum vulgare*	Shepherd	Moderately susceptible	Moderately susceptible
Brassica/radish	*Sinapis alba* (White mustard)/*Raphanussativus* (Doublet oilseed radish)	Biofum	Moderately susceptible	Moderately susceptible
Brassica	*Brassica nigra*	black		Moderately susceptible
Brassica/radish	*Raphanus sativus*	Black Jack	Highly resistant	Moderately susceptible
Brassica/radish	*Brassica nigra* (Black mustard)/*Brassicacarinata* (Ethiopian mustard (cv. Cappucchino)	BQ Mulch	Moderately susceptible	Moderately susceptible
Brassica/radish	*Brassica juncea*	Caliente	Moderately susceptible	Highly susceptible
Brassica/radish	*Brassica carinata*	Cappucchino	Moderately susceptible	Moderately susceptible
Brassica/radish	*Brassica carinata* (Ethiopian mustard (cv. Cappucchino)/ *Raphanus sativus* (Terranovaoilseed radish)	FungiSol	Slightly susceptible	Moderately susceptible
Brassica/radish	*Brassica juncea*	Mustclean	Highly susceptible	Highly susceptible
Brassica/radish	*Raphanus sativus* (Terranova radish)/*Erucasativa* (Nemat)	Nemasol	Slightly susceptible	Moderately susceptible
Brassica/radish	*Eruca sativa*	Nemat	Slightly susceptible	Slightly susceptible
Brassica/radish	*Brassica napus*	Nemclear	Highly susceptible	Highly susceptible
Brassica/radish	*Brassica napus*	Nemcon	Moderately susceptible	Highly susceptible
Brassica/radish	*Raphanus sativus*	Terranova	Resistant	Moderately susceptible
Brassica/radish	*Raphanus sativus*	Tillage radish	Moderately susceptible	Moderately susceptible
buckwheat	*Fagopyrum esculentum*		Moderately susceptible	Highly susceptible
burgundy bean	*Macroptilium bracteatum*		Highly susceptible	Highly susceptible
butterfly pea	*Clitoria ternatea*		Resistant	Slightly susceptible
carpet grass, narrowleaf	*Axonopus fissifolius*		Moderately susceptible	Resistant
clover, crimson	*Trifolium incarnatum*		Highly susceptible	Highly susceptible
couch, green	*Cynodon dactylon*		Slightly susceptible	Slightly susceptible
cowpea	*Vigna unguiculata*	Caloona	Slightly susceptible	Highly susceptible
cowpea	*Vigna unguiculata*	Ebony	Moderately susceptible	Highly susceptible

cowpea	*Vigna unguiculata*	Red Caloona	Slightly susceptible	Highly susceptible
chicory	*Cichorium intybus*	Commander	Moderately susceptible	Highly susceptible
groundnut, peanut	*Arachis hypogaea*	Alloway	Highly resistant	Highly resistant
groundnut, peanut	*Arachis hypogaea*	A237	Highly resistant	Highly resistant
groundnut, peanut	*Arachis hypogaea*	Holt	Highly resistant	Highly resistant
groundnut, peanut	*Arachis hypogaea*	Kairi	Highly resistant	Highly resistant
groundnut, peanut	*Arachis hypogaea*	P85	Resistant	Highly resistant
groundnut, peanut	*Arachis hypogaea*	Wheller	Highly resistant	Highly resistant
lucerne	*Medicago sativa*	Alfacut	Moderately susceptible	Highly susceptible
lupins	*Lupinus albus*	Luxor	Moderately susceptible	Highly susceptible
maize	*Zea mays*	Monsoon8	Highly susceptible	Resistant
medic, snail	*Medicago scutellata*		Highly susceptible	Moderately susceptible
millet	*Echinochloa esculenta*	Japanese	Moderately susceptible	Moderately susceptible
millet	*Echinochloa esculenta*	Shirohie	Moderately susceptible	Moderately susceptible
millet	*Panicum miliaceum*	White French	Moderately susceptible	Moderately susceptible
millet	*Pennisetum glaucum*	Maxa	Moderately susceptible	Moderately susceptible
oats	*Avena sativa*	Algerian	Resistant	Slightly susceptible
oats	*Avena sativa*	Austin	Highly resistant	Slightly susceptible
oats	*Avena sativa*	Bannister	Slightly susceptible	Moderately susceptible
oats	*Avena sativa*	Carrolup	Resistant	Slightly susceptible
oats	*Avena sativa*	Comet	Resistant	Slightly susceptible
oats	*Avena sativa*	Culgoa II	Moderately susceptible	Moderately susceptible
oats	*Avena sativa*	Euro	Moderately susceptible	Moderately susceptible
oats	*Avena sativa*	Eurrabbie	Resistant	Slightly susceptible
oats	*Avena sativa*	Genie	Slightly susceptible	Moderately susceptible
oats	*Avena sativa*	Kojonup	Moderately susceptible	Highly susceptible
oats	*Avena sativa*	Swan	Highly resistant	Highly resistant
oats	*Avena sativa*	Williams	Resistant	Highly resistant
oats	*Avena strigosa*	Saia	Moderately susceptible	Resistant
pigeon pea	*Cajanus cajan*		Highly resistant	Resistant

ryecorn	*Secale cereale*		Moderately susceptible	Highly susceptible
ryegrass	*Lolium ridigum*		Moderately susceptible	Moderately susceptible
sabi grass	*Urochloa mosambicensis*		Resistant	Highly resistant
signal grass	*Urochloa decumbens*		Highly resistant	Resistant
sorghum	*Sorghum* spp.	BMR Octane	Slightly susceptible	Moderately susceptible
sorghum	*Sorghum* spp.	BMR Rocket	Moderately susceptible	Resistant
sorghum	*Sorghum* spp.	Dyna Dan	Resistant	Slightly susceptible
sorghum	*Sorghum* spp.	Dyna Powa	Resistant	Resistant
sorghum	*Sorghum* spp.	Jumbo	Highly resistant	Highly resistant
sorghum	*Sorghum* spp.	Lush	Slightly susceptible	Highly resistant
sorghum	*Sorghum* spp.	Scavenger	Moderately susceptible	Resistant
sorghum	*Sorghum* spp.	Sprint	Moderately susceptible	Slightly susceptible
sorghum	*Sorghum* spp.	Sugargraze	Highly susceptible	Moderately susceptible
sorghum	*Sorghum* spp.	Sweet Jumbo LPA	Resistant	Resistant
sorghum	*Sorghum* spp.	Banker	Moderately susceptible	Slightly susceptible
sorghum	*Sorghum* spp.	Lantern	Highly susceptible	Moderately susceptible
sorghum, grain	*Sorghum* spp.	Mr 43	Moderately susceptible	Moderately susceptible
sorghum, grain	*Sorghum* spp.	Mr Buster	Moderately susceptible	Slightly susceptible
sorghum, grain	*Sorghum* spp.	Mr Taurus	Moderately susceptible	Slightly susceptible
soybean	*Glycine max*	A6785	Resistant	Moderately susceptible
soybean	*Glycine max*	Bunya	Moderately susceptible	Moderately susceptible
soybean	*Glycine max*	Fernside	Highly resistant	Slightly susceptible
soybean	*Glycine max*	Hayman	Slightly susceptible	Moderately susceptible
soybean	*Glycine max*	Kuranda HB1	Highly resistant	Moderately susceptible
soybean	*Glycine max*	Moonbie	Slightly susceptible	Moderately susceptible
soybean	*Glycine max*	Mossman	Slightly susceptible	Slightly susceptible
soybean	*Glycine max*	New Bunya	Highly susceptible	Moderately susceptible
soybean	*Glycine max*	Soy 791	Slightly susceptible	Moderately susceptible
soybean	*Glycine max*	Stuart	Slightly susceptible	Moderately susceptible
soybean	*Glycine max*	T013 - 5	Highly resistant	Slightly susceptible

soybean	*Glycine max*	T183 - 3	Resistant	Slightly susceptible
sunflower	*Helianthus annuus*	Greystripe	Highly susceptible	Highly susceptible
sunn hemp	*Crotolaria juncea*		Resistant	Resistant
sweetcorn	*Zea mays*	Acceleration	Highly susceptible	Moderately susceptible
sweetcorn	*Zea mays*	Inception	Highly susceptible	Highly susceptible
sweetcorn	*Zea mays*	Messenger	Highly susceptible	Highly susceptible
sweetcorn	*Zea mays*	SV1446SD	Highly susceptible	Highly susceptible
sweet smother grass	*Dactyloctenium australe*		Highly resistant	Highly resistant
triticale	*X Triticosecale*		Moderately susceptible	Moderately susceptible
triticale	*X Triticosecale*	Crackerjack2	Moderately susceptible	Moderately susceptible
vetch	*Vicia faba*	Popany	Moderately susceptible	Moderately susceptible
wheat	*Triticum aestivum*	Bennett	Slightly susceptible	Highly susceptible
wheat	*Triticum aestivum*	Brennan	Moderately susceptible	Moderately susceptible
wheat	*Triticum aestivum*	Elmore	Slightly susceptible	Moderately susceptible
wheat	*Triticum aestivum*	Illabo	Moderately susceptible	Moderately susceptible
wheat	*Triticum aestivum*	Naparoo	Moderately susceptible	Moderately susceptible
zoysia grass	*Zoysia tenuifolia*		Moderately susceptible	Moderately susceptible

R. reniformis experiments on rotation crops

The reproductive factors of R. reniformis in resistant crops were less than 1 indicating that the final populations densities of R. reniformis decreased.

Seven potentially useful crops were tested for resistance and six were found not to increase the population of R. reniformis on the roots are therefore deemed resistant. These cultivars are Moonson8 maize, Maxa millet, Alloway peanuts, Callide Rhodes grass, Jumbo sorghum, and sunn hemp (Table 2)

Table 14 Summary of resistance/susceptibility of rotation crop cultivars to reniform nematode (*Rotylenchulus reniformis*)

Common name	Species	Cultivar	*Pratylenchus zeae*
maize	*Zea mays*	Monsoon 8	Resistant
millet	*Pennisetum glaucum*	Maxa	Resistant
peanut	*Arachis hypogaea*	Alloway	Resistant
Rhodes grass	*Chloris gayana*	Callide	Resistant
sorghum	*Sorghum* spp.	Jumbo	Resistant
soybean	*Glycine max*	A6785	Susceptible
sunn hemp	*Crotalaria juncea*	sunn hemp	Resistant
tomato	*Solanum lycopersicum*	Tiny Tim	Susceptible

P. zeae experiments on rotation crops

The reproductive factors of *P. zeae* in roots of resistant crops were less than 1 indicating that the final populations densities of *P. zeae* decreased.

Five cultivars of groundnut/peanut were resistant to *P. zeae* while five soybean cultivars were also resistant to *P. zeae*. These include the varieties Alloway, Holt, Kairi, P85 and Wheller peanuts and A6785, Hayman, Kuranda HB1, Mossman and New Bunya soybeans (Table 3)

Table 15 Summary of resistance/susceptibility of rotation crop cultivars to lesion nematode (Pratylenchus zeae)

Common name	**Species**	**Cultivar**	***Pratylenchus zeae***
groundnut	*Arachis hypogaea*	Alloway	Resistant
groundnut	*Arachis hypogaea*	Holt	Resistant
groundnut	*Arachis hypogaea*	Kairi	Resistant
groundnut	*Arachis hypogaea*	P85	Resistant
groundnut	*Arachis hypogaea*	Wheller	Resistant
soybean	*Glycine max*	A6785	Resistant
soybean	*Glycine max*	Hayman	Resistant
soybean	*Glycine max*	Kuranda HB1	Resistant
soybean	*Glycine max*	Mossman	Resistant
soybean	*Glycine max*	New Bunya	Resistant
maize	*Zea mays*	Messenger	Susceptible

Meloidogyne incognita, M. javanica and R. reniformis experiments on sweetpotato cultivars

Two cultivars were resistant to M. incognita while 13 were resistant to M. javanica. One sweetpotato cultivar of the six screened was resistant to R. reniformis (Table 4).

Two sweetpotato cultivars were resistant to *M. incognita* while 13 were resistant to *M. javanica*. One sweetpotato cultivar of the six screened was resistant to *R. reniformis* (Table 4).

Early in the project the sweetpotato cultivars Bellevue and Beauregard were tested for their susceptibility to local populations of *M. incognita* and *M. javanica* (Table 4). Information provided was that *M. javanica* would not complete its life cycle on Bellevue. However, Bellevue was moderately susceptible to *M. javanica* with a reproduction factor of 63 (data not shown) and slightly susceptible to *M. incognita* (for which it was breed) with a reproduction factor of 4. In the same experiment Beauregard was highly susceptible to both *M. incognita* and *M. javanica.*

Table 16 Summary of resistance/susceptibility of sweet potato cultivars to two species of root-knot nematode and reniform nematode

Crop	Cultivar	Root-knot nematode		Reniform nematode
		M. incognita	*M. javanica*	*R. reniformis*
sweetpotato	Beauregard	Highly susceptible	Highly susceptible	Susceptible
sweetpotato	Bellevue	Slightly susceptible	Moderately susceptible	Susceptible
sweetpotato	Bonita	Moderately susceptible	Resistant	
sweetpotato	Eclipse	Moderately susceptible	Slightly susceptible	
sweetpotato	Murasaki	Moderately susceptible	Moderately susceptible	Susceptible
sweetpotato	Northern Star	Slightly susceptible	Highly resistant	Susceptible
sweetpotato	Orleans	Highly susceptible	Highly susceptible	Susceptible
sweetpotato	Southern Star	Moderately susceptible	Moderately susceptible	
sweetpotato	WSPF	Moderately susceptible	Resistant	Resistant
sweetpotato	New Cultivar 1	Moderately susceptible	Resistant	
sweetpotato	New Cultivar 2	Highly resistant	Highly resistant	
sweetpotato	New Cultivar 4	Moderately susceptible	Highly resistant	
sweetpotato	New Cultivar 6	Highly susceptible	Slightly susceptible	
sweetpotato	New Cultivar 7	Highly susceptible	Resistant	
sweetpotato	New Cultivar 8	Highly susceptible	Highly resistant	
sweetpotato	New Cultivar 9	Moderately susceptible	Highly resistant	
sweetpotato	New Cultivar 10	Moderately susceptible	Highly resistant	
sweetpotato	New Cultivar 11p	Highly susceptible	Resistant	
sweetpotato	New Cultivar 12p	Moderately susceptible	Highly susceptible	
sweetpotato	New Cultivar 13	Moderately susceptible	Resistant	
sweetpotato	New Cultivar 14	Resistant	Moderately susceptible	
sweetpotato	New Cultivar 15	Moderately susceptible	Resistant	
sweetpotato	New Cultivar 16	Highly susceptible	Highly susceptible	
sweetpotato	New Cultivar 17	Highly susceptible	Highly susceptible	

Conclusion

Thirty-six varieties were resistant or highly resistant to *M. incognita*, *M. javanica* or both. This includes 2 brassicas, 13 legumes and 14 grasses resistant to *M. incognita* and 8 legumes and 14 grasses resistant *M. javanica*.

Cultivars of eight legumes (ground nut, sunn hemp and pigeon pea), two oats, three grasses and three forage sorghums were resistant to both *M. incognita* and *M. javanica* making these cultivars excellent rotation crops to reduce root-knot nematode numbers when the species of root-knot nematode in a field/block is unknown or a mix of the 2 species.

Two sweetpotato cultivars were resistant to *M. incognita* while 13 were resistant to *M. javanica*. One sweetpotato cultivar of the six screened was resistant to *R. reniformis* (Table 4).

This resistance screening work has expanded the range of suitable rotation options for sweetpotato growers to help manage a range of plant-parasitic nematode pests. Available varieties may frequently change, especially for crops such as forage sorghum. This assessment of some new varieties, and some crop types which haven't previously been screened, provides a useful update of resistant rotations for the Australian sweetpotato industry. Screening of sweetpotato cultivars for nematode resistance under Australian conditions using locally sourced nematode species provides valuable information on varietal selection for growers.

Image 1 Jennifer Cobon inoculating a potted plant species with nematodes during resistance screening.

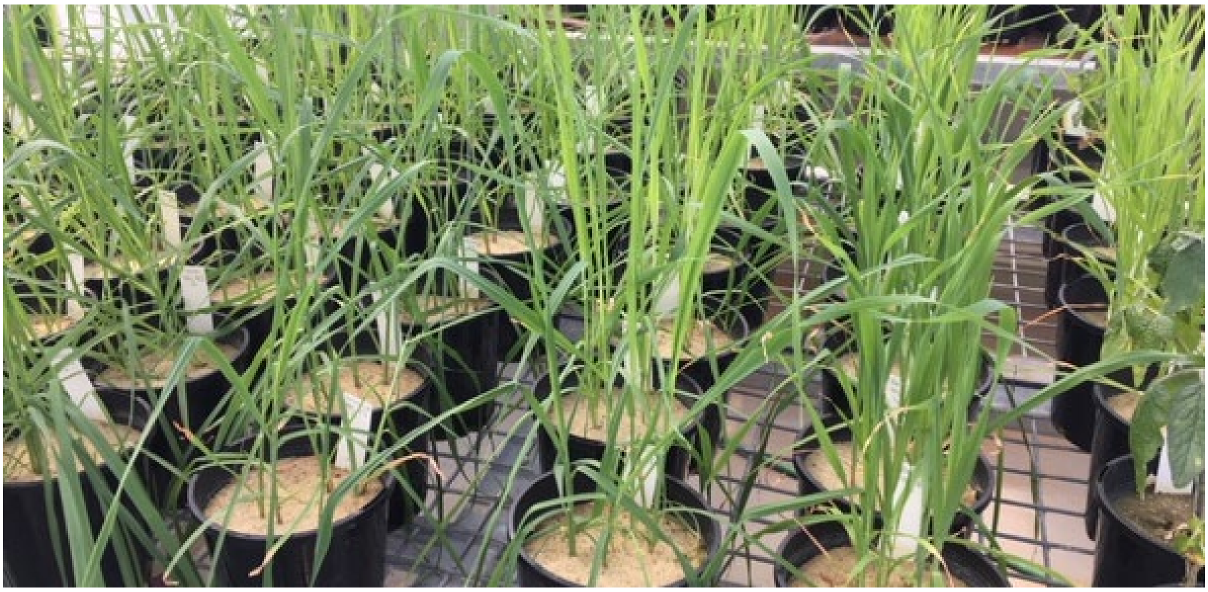

Image 2 Glasshouse pot trials inoculated with nematodes to test the host status of plant cultivars.

Appendix 13.

Field evaluation of cover crops

Field evaluation of cover crops

PW17001 Final report Appendix 13 Integrated pest management of nematodes in sweetpotato

Rachael Langenbaker, Brett Day and John Duff, August 2022

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

Hort Innovation SWEETPOTATO FUND

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Queensland Government

Introduction

An important output of this project is to investigate cover crops and their suitability to control plant parasitic nematodes. In some sectors of the vegetable industry, biofumigation is being promoted to reduce populations of nematodes and soilborne pathogens. Since the tissue maceration and soil pulverisation that is required to liberate the biofumigant is detrimental to the soil biology, research is required to check whether this process provides benefits from fumigation or the benefits obtained are similar to other green manure crops.

Pathogenicity screening of brassica biofumigants in this project has shown that most species are hosts of root-knot nematode. Are the glucosinolates released on maceration and incorporation of biofumigants still effective in overcoming nematode populations? Kirkegaard and Sarwar, 1998 have shown that different parts of the plant have different GSL profiles, which could in turn affect the various soilborne pathogens, including nematodes, to differing degrees. Are there enough GSL concentration in the tops to control those nematodes that can be found in the roots of the various brassica biofumigants? The report is included as Appendix 5.

A grower demonstration site was selected in Bundaberg and planted to eight different winter cover crops with a bare fallow used as a control. Cover crops from the grass (Poaceae) and Brassica families were chosen based on seasonal suitability and seed availability. The inclusion of biofumigants (Brassicas) allows investigation into claims that biofumigants can be effective in reducing soilborne pathogens. Any biofumigant effects will be investigated and glucosinolate levels determined at trial conclusion.

Materials and Methods

Prior to planting, a representative soil sample was taken from each treatment for nematode extraction. The block was planted on the 21st of May 2020. The soil was sampled at 13 weeks after planting and before and after biofumigant incorporation. A biomass assessment was conducted on the 2nd of September 2020, samples were placed into oven drying facilities at 60°C, ground then analysed for glucosinolates.

Cover crops in the demonstration trial included:

- A mix of Terranova Radish and Saia Oats
- Terranova Radish
- Saia Oats
- Genie Oats
- Nemsol (Terranova radish and Nemat)
- Fungisol (Terranova radish and Ethiopian mustard)
- Bare Fallow
- Caliente
- White French millet

Image 1. Left, Rach Langenbaker (BRF), grower collaborator Daniel Zunker measuring seed. Centre, Genie Oats and right, Nemsol.

Image 2. Left to right, cover crop trial site, biomass and flowering assessment.

Results and discussion

Nematode counts decreased at 11 weeks after establishment and again at 24 weeks in all treatments except Terranova and Terranova + Saia oats (Figure 1). While the different cover crop treatments showed a reduction of RKN between sampling periods, the results must be looked at with caution. This was an observation trial and not replicated, so cannot be interpreted by a statistician. There is a possibility that sampling variation could be a source of the lower counts, as nematode numbers are often patchy across a field or along a row. Cooler winter temperatures may also have had an effect on lowering the nematode numbers.

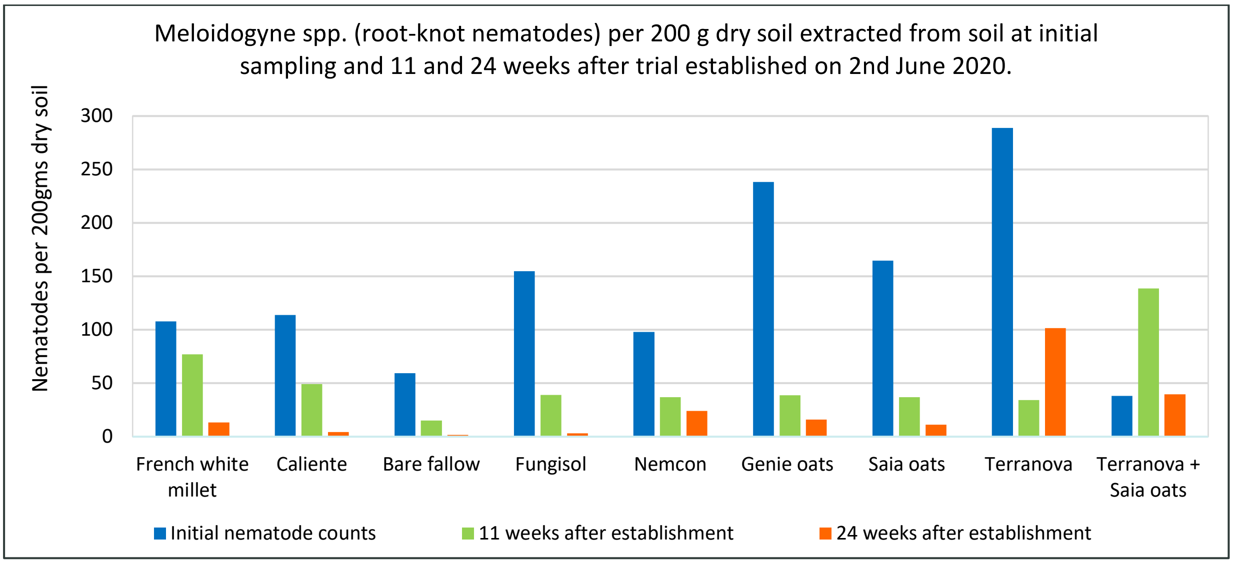

Figure 1. Cover crop trial RKN counts.

The Brassica cover crop species attracted large populations of various insect pests and required more water than other rotation crops making them less attractive for some growers. Considering the nematode reduction trend, a replicated field trial may be worth pursuing, however inclusion of Brassica species into the crop rotation would depend upon grower interest and the viability of growing this crop considering water availability and the requirement for pesticide application.

Five glucosinolates (GSLs) were tested with key differences showing up between the Caliente and the other biofumigant types. Sinigrin was the most pronounced within Caliente, whilst other biofumigant types had very little Sinigrin present. Glucoraphanin and Gluconapin were abundant in the Terranova radish, Nemsol and Fungisol. Different brassica biofumigants and therefore GSLs, have been shown to perform differently against different soilborne pathogens (Kirkegaard, 2009, Matthiessen and Kirkegaard, 2006).

Glucosinolate profiles

Four brassica biofumigants were trialed, 3 of which contained either a radish as the sole species (Terranova radish) or as part of a mixture (Nemsol and Fungisol). Caliente was the only Indian mustard type trialed. Five glucosinolates were tested, with key differences showing up between the Caliente and the other biofumigant types. Glucosinolate Sinigrin was the most pronounced in the variety Caliente. Glucoraphanin and Gluconapin were abundant in the Terranova radish, Nemsol and Fungisol. Different brassica biofumigants and therefore glucosinolates (GSLs), have been shown to perform differently against different soilborne pathogens (Kirkegaard, 2009, Matthiessen and Kirkegaard, 2006).

Biofumigants grown at different times of the year have also been shown to produce different levels of GSLs making the selection of one brassica biofumigant over another difficult. As most brassica biofumigants have been shown to be good hosts of RKN, selection of suitable cover crops becomes very important. Even though they may be hosts of nematodes that attack the root, what happens once the tops are macerated and incorporated into the ground (Kirkegaard and Sarwar, 1998) have shown that different parts of the plant have different GSL profiles which could in turn affect the various soilborne pathogens, including nematodes, to differing degrees.

Pot trials were undertaken in an attempt to determine the effect of each of the 5 glucosinolate compounds on RKN or whether total glucosinolate levels are effective for RKN control.

Table 1. Glucosinolate analysis.

Sample ID	Glucoberin (µmole/g) DW	Progoitrin (µmole/g) DW	Sinigrin (µmole/g) DW	Glucoraphanin (µmole/g) DW	Gluconapin (µmole/g) DW	Total GSL (µmole/g) DW
Terranova radish *Raphanus sativus*	1.64	0.55	0.09	2.69	3.13	8.10
Nemsol *Raphanus sativus + Eruca sativa*	1.66	0.22	0.09	7.55	4.70	14.22
Fungisol *Raphanus sativus + Brassica carinata*	0.38	0.25	0.36	5.04	2.66	8.68
Caliente B2 *Brassica juncea*	0.50	0.51	15.50	0.00	0.56	17.08

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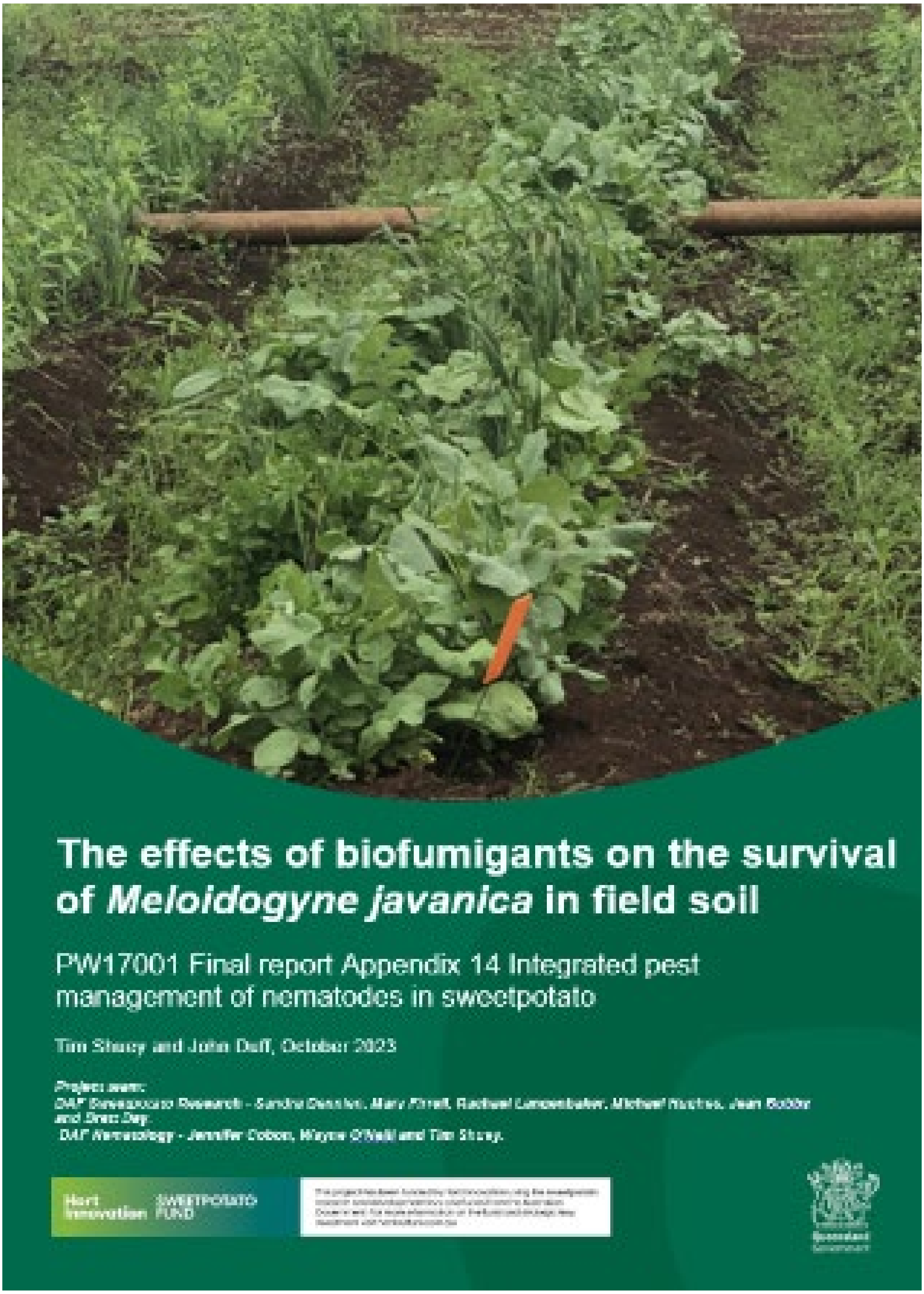
Appendix 14.

The effects of biofumigants on the survival of *Meloidogyne javanica* in field soil



The effects of biofumigants on the survival of *Meloidogyne javanica* in field soil

PW17001 Final report Appendix 14 Integrated pest management of nematodes in sweetpotato

Tim Shuey and John Duff, October 2023

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

Introduction

The management of soil-borne pathogens and pests remains a critical challenge to the Australian sweetpotato industry. Among these, a root-knot nematode (RKN) species (*Meloidogyne javanica*) stands out as a formidable adversary, inflicting substantial yield losses with negative economic implications for sweetpotato growers. Traditional control methods, such as chemical nematicides, have shown efficacy, but concerns about environmental impact, residue buildup, development of nematode resistance and biodegradation have prompted a search for sustainable alternatives. This pursuit has led to the exploration of biofumigants, a group of naturally occurring compounds with soil-borne pest and pathogen suppressive properties.

Biofumigation involves the incorporation of brassica plants, particularly members of the mustard family (*Brassicaceae*), into soil. These plants contain glucosinolates, sulphur-containing compounds, which, when hydrolysed by enzymes upon tissue disruption, release isothiocyanates and other volatile compounds with proven pesticidal and nematicidal properties. The ability of biofumigants to suppress soil-borne pests and pathogens, including nematodes, shows promise as a potential alternative for conventional nematicides.

This small study aims to evaluate the impact of biofumigants on nematode survival in a tightly controlled environment, to ascertain the efficacy of certain biofumigants for further expanded study.

Methodology

Red ferrosol soil was collected from a stockpile located at Redland Research Station in Brisbane, sieved to approximately 5 mm, and mixed to ensure a homogeneous soil. 200 g was oven dried at 70°C to determine moisture content (18.25%). A subsample was processed for nematode extraction. No RKN was detected, although very low numbers of other plant parasites were present.

Cultures of *Meloidogyne javanica* maintained in a glasshouse on tomato (cv. Tiny Tim) and eggs were obtained for use as inoculum by soaking roots in NaOCl (0.5% available chlorine) for five minutes, retrieving eggs on a 38 µm sieve by washing thoroughly with water. Eggs were placed in a hatching tray for three days, then juvenile RKN numbers were quantified. Inoculum density was quantified to 2420 juveniles per ml. Low numbers of nematode eggs were also present.

Soil (2400 ml) was placed into multiple large ziplock bags (Figures 1 and 2). This was sufficient soil for five replicates of each biofumigant, and a sealed and non-sealed treatment to replicate recommended vs non-recommend post incorporation practice. No organic matter was added to the Nil control treatments.

Image 18 Left, ground vegetative matter. Right, ground vegetative matter mixed with soil.

Dried, ground vegetative matter was mixed in each bag in the following amounts, calculated on volume of the pot, and average dry weight in a field environment prior to incorporation (Table 1). Oats weights were calculated just prior to seed head development.

Table 1. Weight of biofumigants added, related to average dry weight in a field environment

Treatment	10 cm pot (g/pot)	Volume of soil (ml)	Biofumigant needed (g)	Average dry weight (t/ha)
Caliente (Indian mustard, *Brassica juncea*)	2.06	2400	24.69	12.4
Nemat (*Eruca sativa*)	1.73	2400	20.70	10.4
Terranova radish (*Raphanus sativus*)	1.48	2400	17.78	8.93
Cappucchino (Ethiopian mustard, *Brassica carinata*)	3.03	2400	36.37	18.27
Oats (*Avena sativa*)	2.2	2400	26.40	13.3
Nil	0	0	0	0

The biofumigants and organic matter were mixed thoroughly in the bags, then 200 ml of each mix was transferred into 250 ml screw-top containers (Figure 3). In the sealed treatments, the soil was lightly compressed. Conical holes were made in the soil at varied depths (Figure 4), a total of one millilitre (2420 RKN juveniles) of the nematode inoculum was added, and the holes were lightly covered by scratching over adjacent soil. The sealed treatments were misted with three sprays of water and the lids loosely placed on top of the containers. The unsealed treatments were not sprayed, and the lids were loosely placed on top of the containers (Figure 5). The experiment was incubated at room temperature (22°C – 24°C) for 72 hrs. After incubation, all soil was individually removed from each container and extracted over four days using a Whitehead tray (Whitehead AG *et al.,* 1965) - a modified Baermann funnel technique - after which the solution was poured over a 38 µm sieve. Root-knot nematodes and free-living nematodes (FLN) were quantified.

Image 19 Left, 200 ml of soil. Centre, Nematode inoculation. Right, Incubation.

Results

Table 2. Total root-knot and free-living nematodes recovered after treatments applied for 72 hours

Sealed Treatments		Total RKN	Total FLN
Ethiopian mustard	R1	1250	673
	R2	1080	565
	R3	910	750
	R4	675	655
	R5	1085	770
Indian mustard	R1	48	68

Not Sealed		Total RKN	Total FLN
Ethiopian mustard	R1	1480	452
	R2	805	530
	R3	535	350
	R4	428	565
	R5	81	440
Indian mustard	R1	43	97

	R2	90	78
	R3	34	36
	R4	51	49
	R5	52	39
Radish	R1	557	6620
	R2	477	9140
	R3	320	5420
	R4	687	7740
	R5	464	5020
Rocket	R1	858	515
	R2	850	353
	R3	484	545
	R4	825	650
	R5	660	408
Oats	R1	1030	640
	R2	1080	536
	R3	1165	610
	R4	1290	720
	R5	935	640
Nil	R1	1020	363
	R2	780	397
	R3	1140	780
	R4	775	404
	R5	1210	484

	R2	169	155
	R3	202	169
	R4	83	78
	R5	77	121
Radish	R1	1480	8000
	R2	1470	5520
	R3	1440	6160
	R4	1180	6720
	R5	1020	7520
Rocket	R1	1170	363
	R2	1110	512
	R3	1180	505
	R4	1190	224
	R5	1310	510
Oats	R1	1070	900
	R2	1350	960
	R3	1300	690
	R4	973	833
	R5	1070	990
Nil	R1	1230	1240
	R2	1280	730
	R3	1200	1100
	R4	1055	570
	R5	940	640

Preliminary analysis suggests that Indian Mustard (cv. Caliente) has a significant effect on the reduction of both RKN and total FLN numbers in both the sealed and non-sealed treatments. Very low numbers were observed in all Indian Mustard treatments. Radish and rocket sealed treatments, while not as effective, showed some effect (Figure 1).

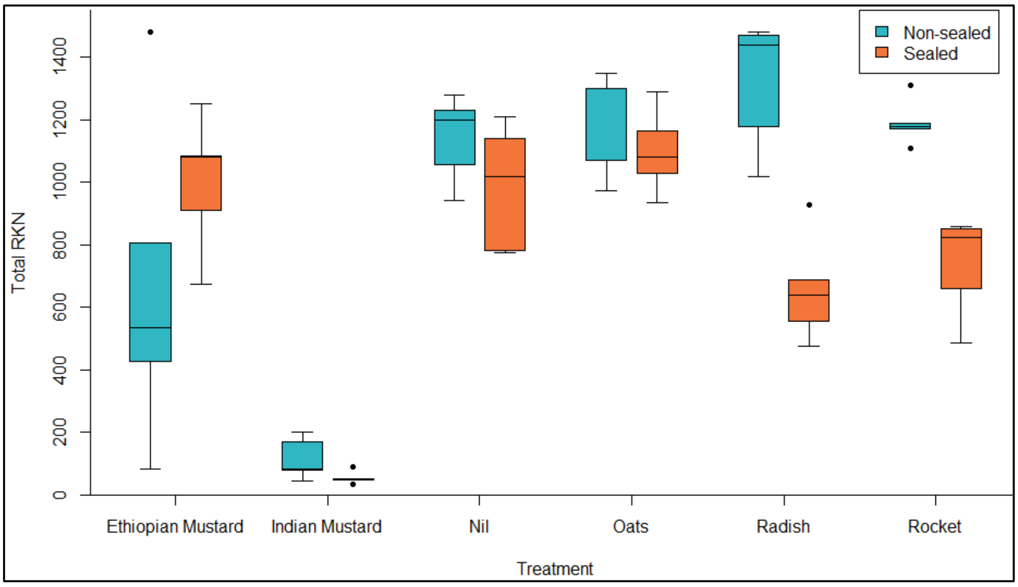


Figure 1. Total root-knot nematodes recovered after treatments applied for 72 hours.

All treatments had low numbers of total FLN, except for both radish treatments, in which total FLN numbers were elevated. While not segregated into trophic groups, the majority appeared to be bacterivores. The reason for this is unknown (Figure 2).

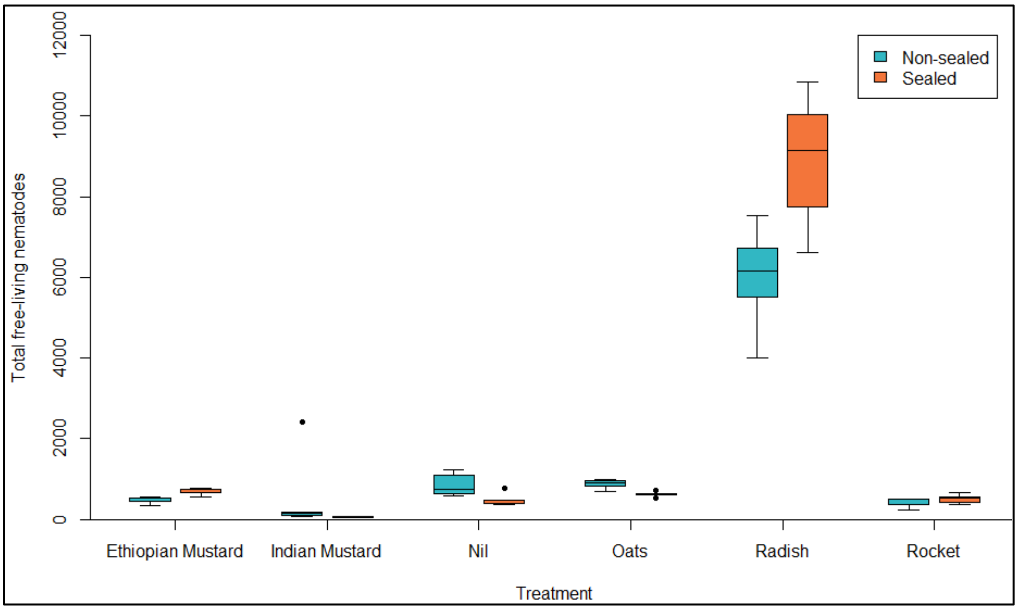


Figure 2. Total free-living nematodes recovered after treatments applied for 72 hours

Conclusion

While further analysis is required, results of this small study indicate that Indian Mustard has the potential to reduced RKN numbers significantly. Other brassica treatments may also have a similar if lesser affect when the vegetative matter is well sealed in the soil. Progress to pot and/or field trials are recommended to determine the feasibility and practical application of this process.

Appendix 15.

Sustainable farming systems trials - long term trials

Sustainable farming systems trials - Nematode population monitoring

PW17001 Final report Appendix 15 Integrated pest management of nematodes in sweetpotato

Wayne O'Neill August 2023

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

Hort Innovation SWEETPOTATO FUND

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Queensland Government

Sustainable farming systems trials nematode population monitoring

Summary

Two long-term field trials were conducted at Bundaberg Research Facility to test the feasibility of using integrated management tactics to minimise losses caused by root-knot nematode. An intensive trial (with 4 crops over 5 years) was managed close to grower best practice, and also included some treatments with high rates of organic amendments. The extensive trial was more experimental and included pre-formed beds to minimize tillage prior to planting, as well as a wider range of rotation crops. There were 3 crops over 5 years in this trial.

Statistically significant suppression of root-knot nematode was achieved for 3 consecutive harvests by the organic matter (chicken manure + sawdust) amendment treatment in the intensive trial. The compost amendment treatment also had significantly less root-knot than the nil and nematicide treatments at the 3rd and 4th harvests.

There were no significant differences in root-knot nematode counts between treatments at any harvest in the extensive trial, although there was a trend for lower root-knot numbers in treatments with organic amendments. The pre-formed bed system meant that most of the organic amendments had to be applied a long time prior to the sweetpotato crop, with an apparent drop in efficacy of those treatments. This was reflected by reductions in free-living nematode numbers and less organic carbon accumulation during the course of the crop, which contrasted with stable/increased free-living nematodes numbers and greater organic carbon gains in comparable treatments in the intensive trial.

The early bed formation system in the extensive trial was not successful at enhancing root-knot nematode suppression, and the v-furrow of amendment treatment (tested in both trials) also did not provide any significant benefits in terms of nematode suppression or crop yield/quality. Resistant rotation crops, including forage sorghum, sunn hemp, white French millet and pasture grasses were all successful in dramatically reducing root-knot nematode populations between sweetpotato crops. No treatment in either trial was successful in suppressing reniform nematode, another sweetpotato pest which became widespread in both trials during the 5 years of the field trials.

At most harvests, organic amendment treatments had the highest marketable yields or there was no difference compared with other treatments. Organic amendment treatments often had fewer nematode defects but sometimes had higher incidence of other defects.

Organic amendments have the potential for effective root-knot control as well as improved yield and long-term soil health benefits for growers willing to make them part of their system. The cost is comparable to nematicide treatment. On-farm evaluation of locally available materials would be recommended to determine if the practice will achieve consistency in results in a farming system.

Outputs

Farmer field days and grower updates on field trials

Project Reference Group Updates on field trials

ASPG annual general meeting updates on field trials

Conferences

O’Neill, W.T., Cobon, J.A., Shuey, T., Langenbaker, R., Dennien, S.E., 2022. Integrated management of Root-Knot nematode in sweetpotato. Oral presentation at the 11th Australasian Soilborne Disease Symposium, Cairns, August 2022.

Shuey, TA., O’Neill, W.O., Cobon, J.A., Langenbaker, R., B Day2, Bobby, J., Firrell, M., Hughes, M., Corner, R.D., Pattison, A.B., and Dennien, S.E. 2023. Suppression of Root-knot Nematode in Modified Commercial Sweetpotato Production Systems. Poster Presentation at the 24th Australasian Plant Pathology Society Conference, Adelaide, November 2023

Outcomes/ Take home message/key findings.

High rates of certain organic amendments have the potential for effective root-knot control as well as improved yield and long-term soil health benefits. Statistically significant root-knot nematode control was achieved by treatments comprising high rates of banded organic amendments (applied just prior to planting at bed formation), combined with a resistant rotation crop.

Ideally, these practices should be combined with other components - such as nematode monitoring, volunteer control and use of resistant sweetpotato cultivars where required - into an integrated nematode management program to deliver consistent crop yield and quality. Vigilance in on-farm biosecurity is critical to avoid introduction of new nematode pests which may be more difficult to manage.

Introduction

Long-term field trials were conducted over the course of the project to test the feasibility of using integrated management tactics to minimise losses caused by root-knot nematode (and potentially other plant-parasitic nematodes), while improving (rather than depleting) soil biological health. Longer term trials were required for these investigations as improvements in soil biological health and suppression of plant-parasitic nematodes may not be apparent in one crop cycle. Management practices included in the trials included:

- Inputs of organic matter from cover crops
- Use of diverse (largely root-knot resistant) rotation crops including legumes
- Minimum tillage, controlled traffic
- Organic amendments

Intensive Trial

Introduction

The intensive trial was designed to be similar to conventional best practice currently used by many sweetpotato growers. The aim was to assess the nematode control and soil health benefits provided by relatively high rates of organic amendments applied at bed formation, just prior to planting. A forage sorghum rotation was utilised in all plots between sweetpotato crops.

Methodology

The intensive sweetpotato trial had five replicates of 5 treatments laid out as a randomised complete block. Four harvests were completed in the 5 years of the trial. The five treatments were:

Treatment A	Organic Matter	band of sawdust + chicken manure
Treatment B	Compost	band of compost
Treatment C	V-furrow	Compost applied in a v-shaped furrow
Treatment D	Nil	no treatment control
Treatment E	Nematicide	Nimitz (fluensulfone)

Image 20. Double discs used to create v-furrow (right) and compost amendment in v-furrow (right)

Soil samples were collected by taking approximately 10 sub-sample along the length of each plot (5 – 15cm depth), which were well mixed by hand. To extract nematodes, two Whitehead trays per sample (approximately 200mL each) were set up for four days. The solutions from each tray were sieved twice through a 38µm sieve and then examined under a compound microscope for the presence of nematodes which were identified morphologically and quantified. Soil weights were recorded, and a subsample dried to calculate moisture content. Nematode counts were standardized and reported as the number per 200g dry weight equivalent soil.

Results and Discussion

In this trial, root-knot pressure was high in the first 3 crops but low for the 4th. There were no significant differences in root-knot numbers between the treatments at the first harvest (June 2020). However, at harvest 2 (June 2021), the organic matter amendment treatment (band of sawdust and chicken manure) had significantly less root-knot compared with all other treatments (a 109% reduction compared with the nil control treatment). At the third harvest (June 2022), both the organic matter treatment and the compost treatment had significantly less root-knot than the other three treatments (155% and 128% reduction respectively cf. nil). At the final harvest (May 2023), root-knot numbers were low across the trial, but the organic matter treatment still had significantly lower root-knot than all other treatments (166% reduction cf. nil). Figure 1 shows mean root-knot nematode counts for each treatment at the 4 harvests.

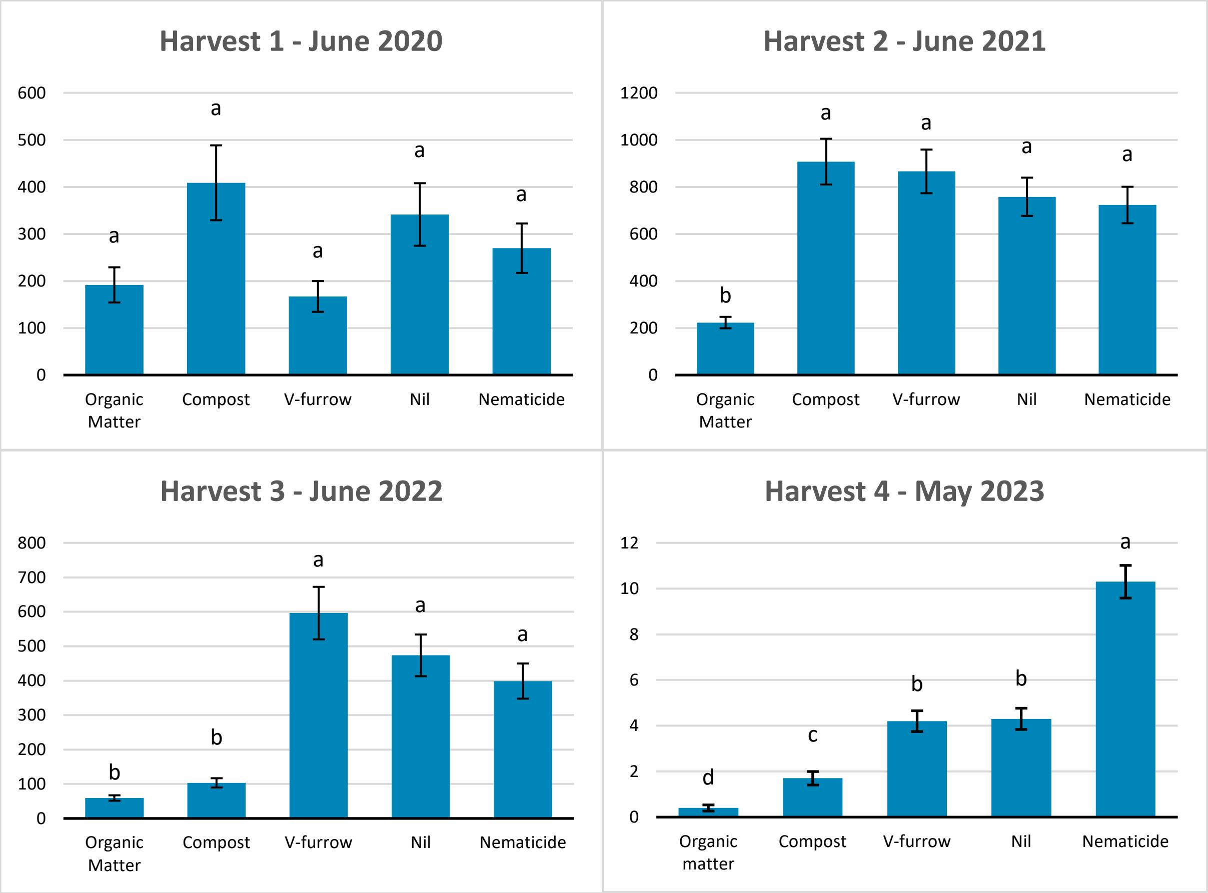

Figure 6. Mean root-knot nematode counts (per 200g dry soil) in the intensive field trial, at each of the four harvests.

This root-knot suppression in the organic matter treatment, which commenced at harvest 2, coincided with a boost in total free-living (TFL) nematode numbers which was first detected just prior to planting the second crop. At the January 2021, June 2021, January 2022 and June 2022 samplings, the organic matter treatment had a significantly higher mean count of TFL than all other treatments. Figure 2 illustrates the inverse relationship between root-knot nematode counts and TFL counts, in this case at harvest 2.

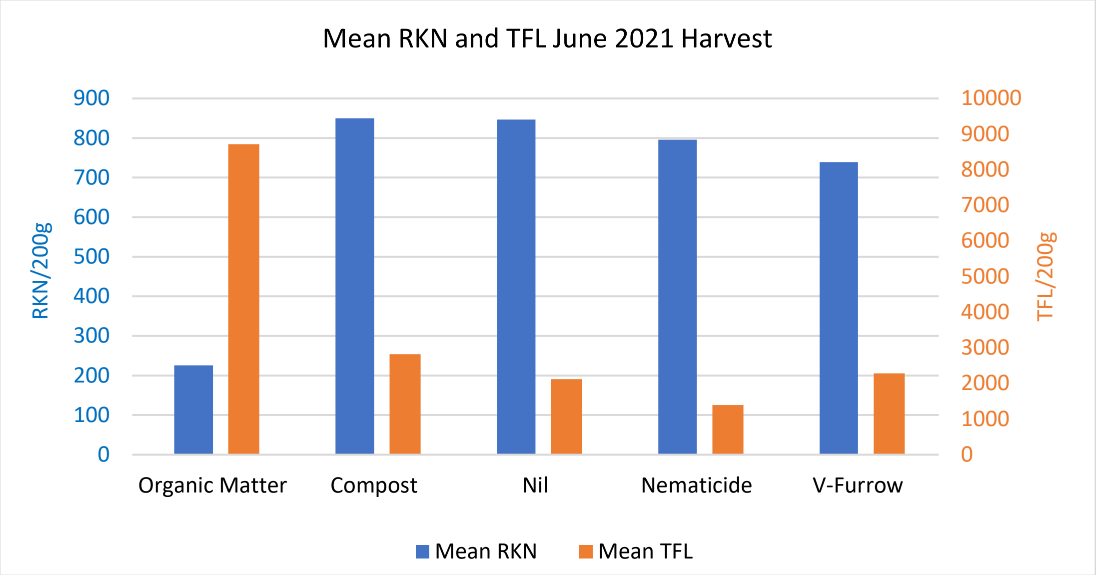

Figure 7.Mean root-knot and total free-living nematode counts (per 200g dry soil) at the second intensive trial harvest, June 2021. The organic matter treatment has significantly less root-knot and significantly more free-living nematodes than all other treatments

The banded compost treatment was variable in its performance; it was equivalent to the organic matter treatment at the June 2022 harvest and had significantly less root-knot than all other treatments (except organic matter) at the May 2023 harvest, but in the first two crops it was not as efficacious. Composts can be highly variable products and in some studies their application has increased numbers of plant-parasitic nematodes (see Thoden et al., 2011).

There was no significant difference for root-knot and TFL means between the nil and v-furrow treatments at any assessment (except for the final TFL count in May 2023), indicating that the v-furrow amendment application provided no appreciable advantage. The organic amendment used in the v-furrow treatment in this trial was compost.

Reniform nematode (Rotylenchulus reniformis) was detected in few plots at low numbers at the start of the field trial but was present in moderate to high numbers in all plots by the final sampling. There was no significant treatment effect at any assessment for reniform nematode in the intensive trial.

Extensive Trial

Introduction

The extensive trial was more experimental than the intensive trial in its design. The aim was to assess the nematode control and soil health benefits provided by farming systems that incorporate minimum tillage (pre-formed beds) as well as crop rotation and organic amendments.

Methodology

The trial had 4 replicates of 10 treatments made up as a factorial of 2 factors. The trial was laid out as a randomised complete block. Three harvests were completed in the 5 years of the trial. The 10 treatments were:

	Method		Rotation Crops
Treatment 1	Nematicide	Vydate (oxamyl)	Grass/Brassica
Treatment 2	Nil	no treatment control	Grass/Brassica
Treatment 3	V-furrow	sawdust + chicken manure in v-furrow	Grass/Brassica
Treatment 4	Incorporated	band of sugarcane mulch + chicken manure/compost	Grass/Brassica
Treatment 5	Double	incorporated + v-furrow treatments combined	Grass/Brassica
Treatment 6	Nematicide	Vydate (oxamyl)	Grass/Legume
Treatment 7	Nil	no treatment control	Grass/Legume
Treatment 8	V-furrow	sawdust + chicken manure in v-furrow	Grass/Legume
Treatment 9	Incorporated	band of sugarcane mulch + chicken manure/compost	Grass/Legume

Treatment 10	Double	incorporated + v-furrow treatments combined	Grass/Legume

Image 21. Banded amendments (sugarcane mulch + chicken manure) in the extensive trial at bed forming.

Results and Discussion

In this trial there were no significant differences in root-knot numbers between treatments at any of the three harvests, considering factors or individual treatments. However, there were significant differences in root-knot counts at some mid-rotation or pre-plant samplings, where the banded organic amendment treatments ("incorporated" or "double") had lower numbers. Total free-living nematode counts tended to be significantly higher for banded amendment treatments at mid-rotation or pre-plant samplings, but this effect didn't always persist through to harvest. For example, at the November 2022 pre-plant sampling, the incorporated and double amendment treatments had significantly higher TFL counts than all other treatments, but there was no difference between treatments at harvest.

No significant difference was found between the mean root-knot counts for the nematicide, nil and V-furrow treatments at any assessment, indicating that there was no advantage in implementing the V-furrow practice in this trial. The organic amendment used in the v-furrow treatment in this trial was sawdust + chicken manure.

Reniform nematode (*Rotylenchulus reniformis*) was initially absent or in low numbers throughout most of the extensive trial, although there were four plots at the northern end with moderate numbers. Like the intensive trial, reniform nematode became dominant over time and was present in moderate to high numbers in all plots by the final sampling. There was no significant treatment effect (considering factorial structure or just individual treatments) at any sampling date for this nematode.

A variety of rotation crops were tested in the extensive trial, with half of the treatments being a brassica/grass sequence and the other half legume/grass, in between sweetpotato crops. All rotations were selected on the basis of having moderate or better resistance to root-knot, so performed as expected in reducing populations between crops. The only significant difference between the brassica and legume crops detected during the course of the field trial was significantly less root-knot after the legume sunn hemp compared with the brassica blend Nemsol (178% reduction in comparison).

Discussion (both trials)

The intensive trial has demonstrated successful control of root-knot nematode through a farming system of a resistant rotation crop (in this case forage sorghum) plus the application of suitable organic amendments. Statistically significant control was achieved with the organic amendment treatment (a band of sawdust and chicken manure) by the second harvest and was maintained for all subsequent harvests. In contrast, the nematicide treatment (Nimitz) was no better than the nil control treatment at any of the four harvests, although nematicide trials have demonstrated that plant parasite numbers can rebound to high levels after initial chemical suppression in sweetpotato crops.

Suppression of root-knot nematode by the organic amendment treatment corresponded to a significantly higher mean count of free-living nematodes at almost all sampling dates from January 2021 onwards. Chicken litter (manure plus bedding material) is widely used as an amendment in agricultural soils (horticulture, pastures/turf, broadacre cropping) because it provides essential nutrients and benefits soil health due to its high organic carbon content (Wiedemann, 2015). Chicken litter or a chicken manure plus sawdust blend has successfully been trialled in the past for root-knot nematode control (e.g. Stirling 1989).

Sweetpotato yield and quality were enhanced by the organic amendment treatment at some harvests, but this effect was not consistent. For example, this treatment had a significantly higher total and marketable yield at harvest 1 and higher marketable yield at harvest 3. However, at harvest 2, total yield was not significantly different from other treatments and marketable yield was less than for the nematicide treatment. Full details of yield and quality results are given in appendix 18.

The root-knot control demonstrated in this trial was achieved with the susceptible variety Beauregard, which was used in both trials to better show differences between treatments. In a true integrated nematode management system, it would be preferable to utilise a more resistant variety, which would result in better control of root-knot numbers through the crop cycle, when combined with the other elements of the regime.

The banded amendment treatments were applied at a rate of 40 tonnes per hectare, calculated for the width of the band on top of the bed. This was approximately half of the row spacing, so the true per hectare rate for costing would be around 20t/ha. Sufficient hardwood sawdust and chicken manure for 20 tonnes of a 60/40 blend - the most successful treatment in the intensive trial - would cost approximately $1700 delivered, if the products are available in the local district (based on quotes from bulk suppliers: 12 tonnes hardwood sawdust @ $35/m3, 2.85 m3 per tonne; 8 tonnes chicken litter @ $30/m3, 2.2 m3 per tonne). This is comparable to the cost of some nematicides (others are less expensive) but the cost of organic amendments is also offset by additional benefits. So high rates of organic amendments can potentially offer superior root-knot nematode control, be cost competitive with nematicides, and have other advantages in terms of nutrient input and improvements to soil physical, chemical and biological soil health. However, organic amendments are variable in their availability, and transport may add considerably to cost if suitable products are not available in the local area. Some food safety schemes have withholding periods for untreated manures for some crops, so growers would need to check that the use of chicken manure is compliant with the relevant scheme. Composted/processed alternatives are available, although they may be more expensive than raw products.

The extensive trial was not as successful in suppressing root-knot nematode, despite the use of similar organic amendments. The sweetpotato system poses many challenges for implementing soil health practices, related to the marketable product being underground (e.g., major disturbance required for harvest, storage roots subject to direct effects of amendments/pests). The early bed formation utilised in the extensive trial was an attempt to introduce a minimize tillage practice into the system, by completing bed formation straight after the previous crop so no major soil disruption occurred just prior to planting. Unfortunately, this also meant that the banded organic amendments also had to be incorporated at bed formation, a long time prior to sweetpotato planting. The root-knot and TFL data indicate that the beneficial effects of the banded organic amendments were diminished by the time the sweetpotato crop was planted. The average time between amendment incorporation and planting in the intensive trial was only 12 days, whereas it was 317 days for the extensive trial. This delay inevitably meant that there was some depletion of carbon and other beneficial inputs from the amendments prior to planting and development of the sweetpotato crop. As a comparison, the incorporated treatment in this trial had a mean total organic carbon increase of 17% over the nil control at harvest, whereas the comparable organic matter treatment in the Intensive trial had a 30% mean increase at harvest.

The v-furrow treatment did not provide nematode control or yield/quality benefits in either trial. Other studies have demonstrated root-knot nematode control and yield benefits from similar practices in field and pot trials (Stirling 2020, Stirling et al 2020), with various amendments including sawdust, compost and sawdust/chicken manure blends. The objective is to provide a zone of high biological activity/suppression of plant-parasitic nematodes for developing roots. In our trials, compost was the amendment used in the intensive trial and sawdust/chicken manure in the extensive trial, but results were not encouraging. Stirling (2020) does caution that chicken manure can be detrimental to early root development and recommends delaying planting if high rates are used.

All rotation crops utilised in both trials were successful in reducing root-knot populations between sweetpotato crops. The legume sunn hemp performed especially well, reducing root-knot to extremely low numbers during its three-month rotation. Sunn hemp appears to be an excellent rotation option, quickly producing a large amount of biomass, fixing nitrogen, shading weeds and is a very poor host for root-knot.

Image 22 Dense stands of the rotation crops sunn hemp (left) and forage sorghum (right) in the extensive and intensive trials, respectively.

In both trials, there was no significant treatment effect at any assessment for reniform nematode. This nematode came to be the dominant plant parasite in both trials, even in treatments where root-knot nematode was suppressed. Initially, it was mainly confined to a few plots at the northern end of the extensive trial, with low numbers in a few other scattered plots. Despite machinery movements being along rows, across the short axis of the trials, reniform nematode became established throughout the full length of both trials and was present in high numbers in almost all plots by early to mid-2022 (see Figures 3 and 4, Heat Maps of Reniform Nematode). This demonstrates that management strategies that may work for one nematode pest won't necessarily control another. Compared with root-knot, reniform nematode is more difficult to control as it becomes metabolically inactive in dry conditions (enabling it to survive in soil for long periods of time) and it also can move very deep in the soil profile, avoiding the effects of nematicides and biological suppression near the soil surface. It can then reinvade a susceptible crop from the deeper soil layers. Competitive interactions between reniform and root-knot nematode has been reported in the literature, and one pest may dominate the other, depending on field conditions which interact with aspects of their differing life cycles. Thomas and Clark (1983) state that where root-knot is survival is reduced by fallowing (or resistant rotations in our field trials) between susceptible crops, the greater survival capacity of reniform will favour its predominance in a field.

In summary, the long-term field trials have successfully demonstrated most of the major components of an integrated nematode management program detailed below. Statistically significant root-knot nematode control was achieved by treatments comprising high rates of banded organic amendments (applied just prior to planting at bed formation) combined with a resistant rotation crop. In situations with high root-knot nematode pressure growers should also utilise a more resistant sweetpotato cultivar than was employed in these demonstration trials, as this would further suppress the pest and help to deliver consistent crop yield and quality. The rapid domination of reniform nematode in these trials, and the recent detection of guava root-knot nematode in Queensland, reinforce the importance of on-farm biosecurity for excluding pests not yet present on a farm.

Elements of an integrated nematode management program:

1. Monitoring – knowledge of plant parasite species present (therefore suitable resistant rotations), pre-plant levels, targeted use of "soft" nematicides
2. Organic amendments
3. Resistant cultivars
4. Minimising crop stress (irrigation, other pests, etc)
5. Crop rotation, volunteer & weed control
6. On-farm biosecurity (keep out what you don't have yet).

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Thomas RJ and Clark CA, 1983. Population dynamics of Meloidogyne incognita and Rotylenchulus reniformis alone and in combination and their effects on sweet potato. Journal of Nematology, Vol. 15(2), 204-211

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Heat Maps of Reniform Nematode

Heat maps illustrate the increasing dominance of *Rotylenchulus reniformis* in both field trials over time. From initial patchy distribution at low levels the nematode becomes widespread at high levels throughout both trials.

Extensive Trial

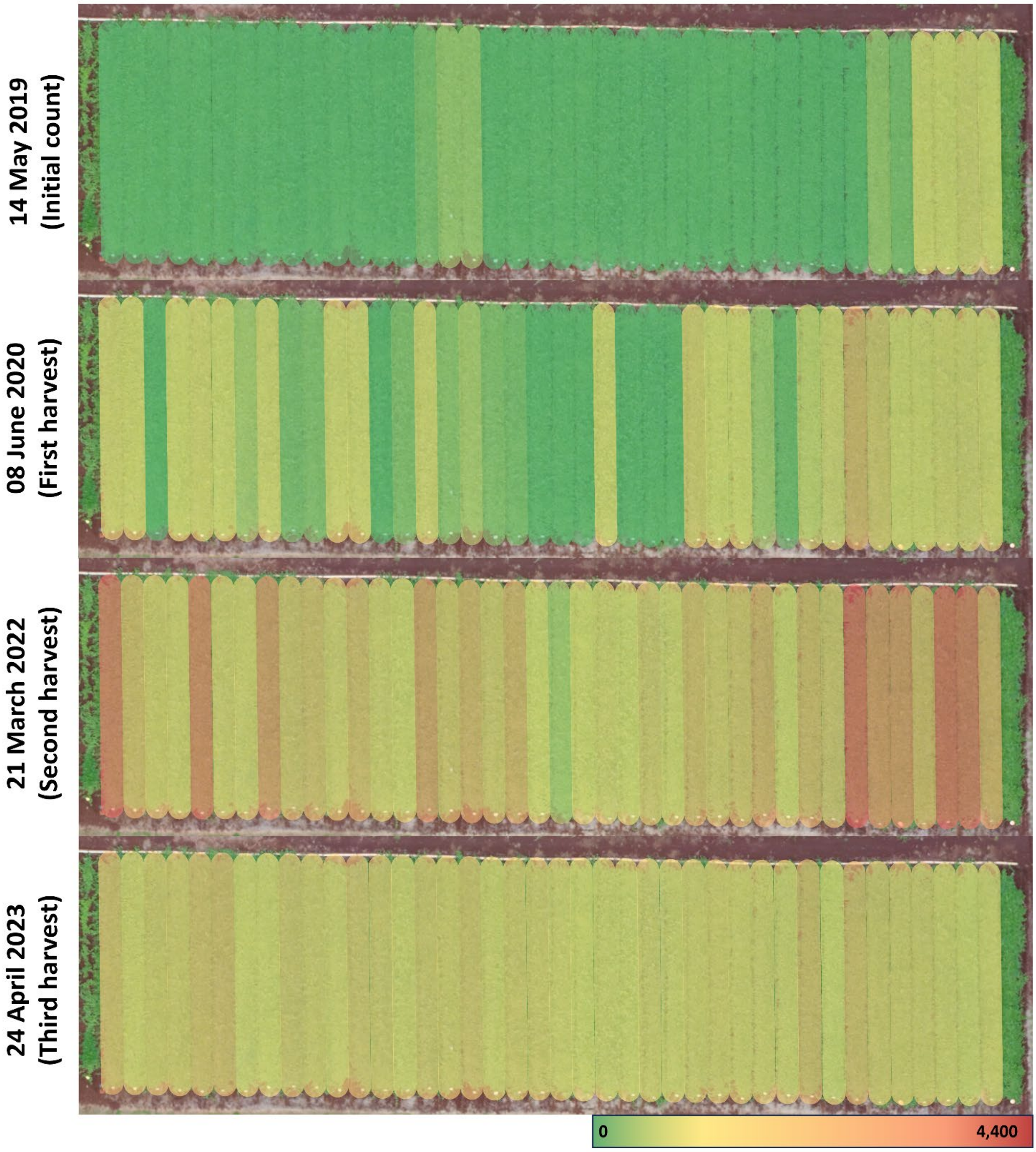

Figure 8. Mean reniform counts (per 200g dry soil) over the life of the Extensive trial.

Intensive Trial

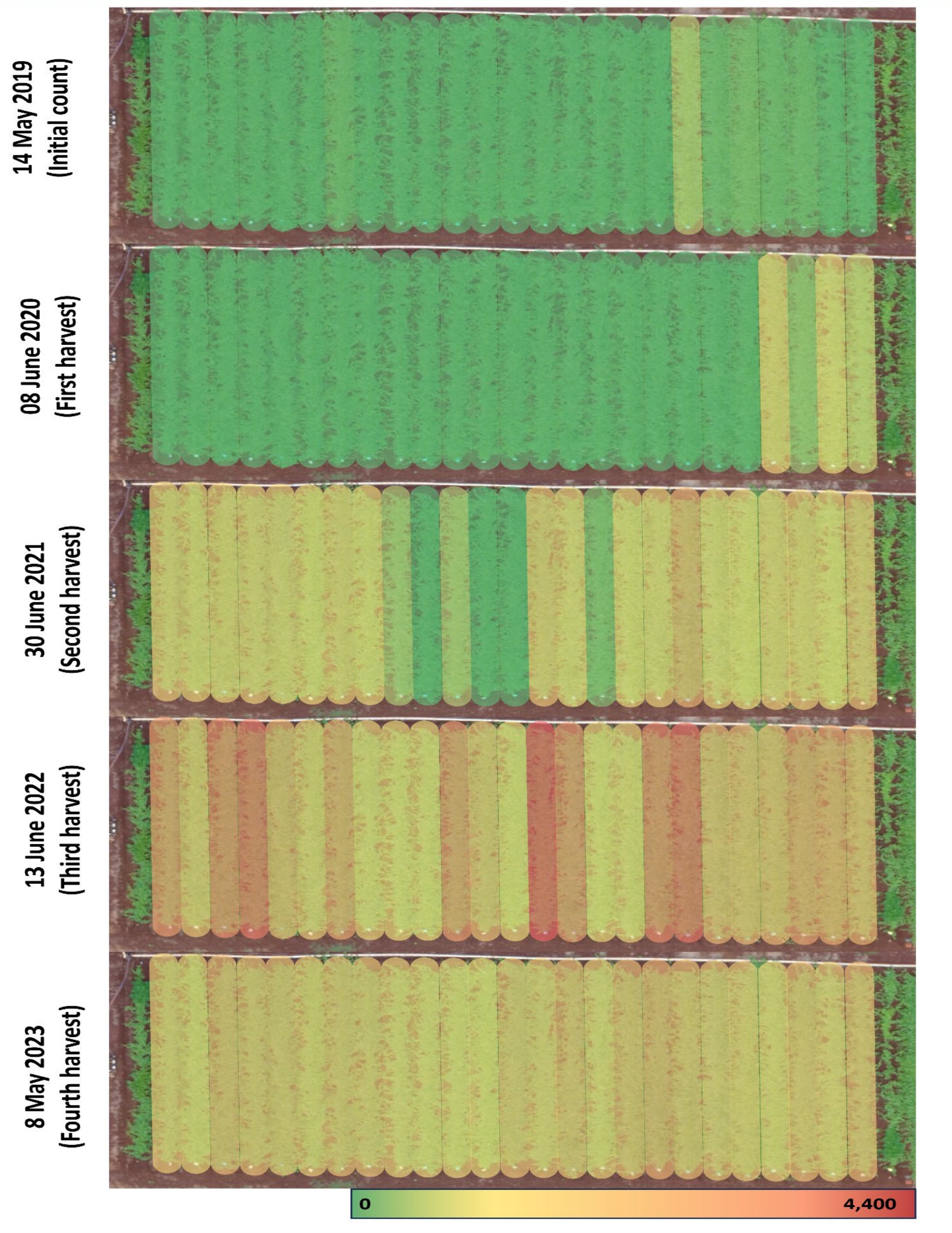

Figure 9. Mean reniform counts (per 200g dry soil) over the life of the Intensive trial.

Assays to Investigate Biological Suppression of Plant-parasitic Nematodes in Intensive Long-term Field Trial.

Introduction

General (non-specific) biological suppression of soilborne diseases (including plant-parasitic nematodes) is most commonly seen in soils with high levels of organic matter. This type of suppression results from many antagonistic organisms acting as predators, parasites, and competitors of the pest and disease organisms. Soils can also have specific suppression to certain nematode pests, resulting from a small number of antagonists (Stirling et al., 2016).

Following the addition of high rates of organic matter, some treatments in the intensive sweetpotato field trial demonstrated apparent suppression of root-knot nematode. Suppression assays were conducted to investigate the nature of this suppression.

Methodology

Soil samples were collected from the intensive trial at BRF on 17/04/23, just prior to harvest. Samples were collected in two ways for two different suppression assays:

Intact cores: PVC tubes (internal diameter 100 mm X 50 mm = 196 mL volume) were pushed into the soil until level with the surface in the centre of each plot. One soil core was collected per plot, and an extra core was collected from 5 plots (one for each treatment). The tubes were carefully withdrawn to retain all of the soil and were then bagged tightly to hold the soil core in place.

Composite samples for bioassays: 10 subsamples were collected and mixed to form one bulked sample per plot. Extra soil was collected from 5 plots (one for each treatment).

Intact Core Assays

The weight of each core was recorded. The 5 extra cores were heated at 80°C for one hour. After the heated cores had cooled to room temperature, all cores were inoculated with 1500 Pratylenchus zeae (mixture of adults, juveniles and eggs) in one mL of water. P. zeae was chosen as the test organism as it is rarely encountered in samples from the field site, so there is no background population to conflate results. The cores were then incubated at room temperature for 12 days. Soil was then removed from each core and set up in a Whitehead tray for extraction of nematodes over 3 days. Surviving P. zeae in each sample were identified and quantified using a compound microscope.

Image 23 Inoculated core assays incubating in the laboratory.

Pot Bioassays

The 5 extra soil samples were heated at 80°C for 2 hours. Pots (100 mm) were filled with the soil samples from each plot plus 5 extra pots of the heat-treated soils. Four days later a tomato seedling (cv. Tiny Tim) was planted into each pot. Eight days later each pot was inoculated with 6000 *Meloidogyne javanica* (root-knot nematode) eggs and the tomato plants were then grown for 7 weeks in the glasshouse. At the conclusion of the experiment, root systems were washed free of soil, galling was rated for each plant on a 1–5 scale, and root-knot nematode eggs were stripped from the roots by soaking in 0.1% NaOCl for 5 minutes and passing the solution through a 38 µm sieve. Egg numbers were then quantified by counting under a compound microscope.

Results and discussion

Intact Core Assays

Analysis of the P. zeae counts showed no significant difference between the trial treatments, but all treatments had significantly less surviving P. zeae than the heat-treated soils (Figure 1). This indicates that biological factors are suppressing nematodes, as the heat treatment regime is sufficient to kill most organisms in the soil. However, the suppression of P. zeae was either equal in all of the trial treatments, or this assay wasn't sensitive enough to show a difference between treatments. The organic matter treatment (which demonstrated the best root-knot nematode control) had the lowest mean P. zeae count (Table 1), but as previously mentioned, differences between trial treatments were not significant in this assay. Of the 2 predominant plant-parasitic species encountered in the field trial (root-knot and reniform nematodes), only root-knot nematode was being controlled by the trial treatments, so it could be that the biological suppression is of a more specific nature (controlling root-knot nematode) and not general to all plant parasite species.

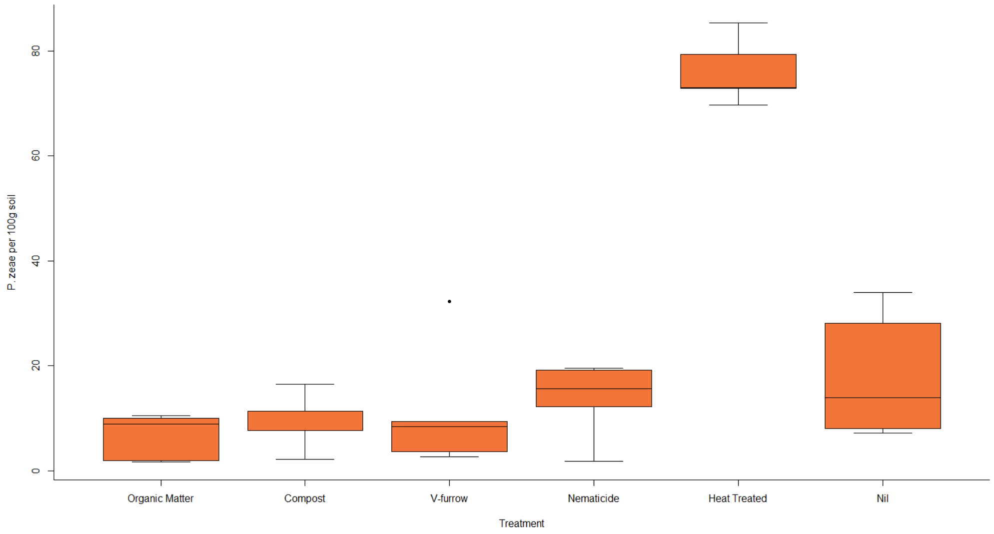

Figure 10. Box and whisker plot illustrating increased survival of P. zeae following heat treatment of soil.

Table 17. Mean numbers of *P. zeae* per 100g soil recovered from the cores after 12 days.

Treatment	**Mean *P. zeae* per 100g soil**
Organic Matter	6.6 b
Compost	9.1 b
V-furrow	11.3 b
Nil	18.2 b
Nematicide	14.4 b
Heat Treated	76.1 a

Means followed by the same letter are not significantly different (*P* ≤ 0.05)

Pot Bioassays

Analysis of the root-knot nematode egg numbers recovered from the root systems of the bioassay plants showed no significant difference between the heat-treated soils and the non-heated soils, nor between any of the field trial treatments. However, there was significantly greater root galling in the plants grown in heat-treated soil (Table 2), which supports a biological mechanism of root-knot nematode suppression at the trial site. It was hoped that the pot bioassay might show enhanced levels of suppression of root-knot nematode by some of the trial treatments, but like the core assays, the bioassay wasn't able to demonstrate any difference in the level of suppression between treatments. Root-knot nematode numbers were very low across the trial in this final crop compared with the previous three (numbers at the time of sampling were quantified to check for the likelihood of confounding effects in the bioassay). In specific suppression, populations of parasites that are adapted to using a specific pest as a food source fluctuate rapidly in response to pest numbers (Stirling et al., 2016). It may be that soil samples for this bioassay were collected at a time which coincided with low levels of specific suppression organisms in response to the low root-knot nematode population.

Table 18. Mean gall rating of bioassay plants (1–5 scale), 7 weeks after inoculation with Meloidogyne javanica

Treatment	**Mean Gall Rating**
Organic Matter	1.8 b
Compost	1.6 b
V-furrow	1.75 b
Nil	1.7 b
Nematicide	1.5 b
Heat Treated	3.2 a

Means followed by the same letter are not significantly different (*P* ≤ 0.05)

Reference

Stirling G, Hayden H, Pattison T & Stirling M. 2016. Soil Health, Soil Biology, Soilborne Diseases and Sustainable Agriculture: A Guide. CSIRO Publishing.

Summary Statistical Analysis of Nematode Counts from Long-Term Field Trials

Carole Wright

Intensive Trial

Counts of root-knot nematode (RKN), reniform nematode (Rr) and total free-living nematodes (TFL) were recorded at 6-month intervals from January 2020. The counts have been analysed using a generalised linear model (GLM). The replicate block is fitted as the first term in the model, followed by the treatment term. Initial analyses using a generalised linear mixed model (GLMM) often resulted in the random model being bound, therefore a GLM was fitted. The presence of over-dispersion was detected when a Poisson distribution was assumed (except May 2023) and therefore a Negative Binomial distribution is applied. Over-dispersion is not uncommon and occurs when there is more variation present than expected by the Poisson distribution. The dispersion parameter is estimated in all models. For RKN in May 2023, under-dispersion was detected. This suggests there is less variation than expected by the Poisson distribution. To account for this the dispersion parameter is fixed at 1. All significance testing is performed at the 0.05 level. Where a significant treatment effect is detected, the 95% least significant difference (lsd) is used to make pairwise comparisons.

Root-Knot Nematode (RKN)

Significant differences between the treatments were found for June 2021, January 2022, and June 2022.

- In June 2021, organic matter had a significantly lower mean RKN count than all other treatments.
- In January 2022, V-furrow had a significantly higher mean RKN count than compost and nil treatments. Nil had a significantly lower mean RKN count than nematicide and V-furrow.
- In June 2022, compost and organic matter had a significantly lower mean RKN count than the other three treatments.
- Significant differences between the treatments were found for May 2023 but not in December 2022. In May 2023 nematicide had a significantly higher mean count compared to all other treatments and treatment organic matter had a significantly lower mean count.

Below are the predicted means (pred), standard errors (s.e.), F-test, p-value and average 95% lsd.

January 2020	pred	s.e.
Treatment		
Compost	12.3	3.94
Nematicide	11.0	3.58
Nil	7.5	2.59
Organic Matter	11.3	3.66
V-furrow	22.0	6.63

$F_{(4,16)}$ = 1.46; p = 0.261; av 95% lsd = 12.50

June 2020	pred	s.e.
Treatment		
Compost	408.8	159.16
Nematicide	269.7	105.19
Nil	341.4	133.03
Organic Matter	191.7	74.90
V-furrow	167.1	65.36

$F_{(4,16)}$ = 0.87; p = 0.505; av 95% lsd = 329.45

January 2021	pred	s.e.
Treatment		
Compost	39.2	12.43
Nematicide	34.9	11.12
Nil	28.6	9.21
Organic Matter	36.5	11.61
V-furrow	34.6	11.02

$F_{(4,16)}$ = 0.13; p = 0.970; av 95% lsd = 33.11

June 2021	pred		s.e.
Treatment			
Compost	907.4	a	194.33
Nematicide	723.0	a	154.97
Nil	758.0	a	162.46
Organic Matter	223.2	b	48.36
V-furrow	865.9	a	185.47

$F_{(4,16)}$ = 5.68; p = **0.005;** av 95% lsd = 467.01

January 2022	pred		se
Treatment			
Compost	6.7	bc	2.29
Nematicide	19.7	ab	5.80
Nil	6.5	c	2.23
Organic Matter	10.6	abc	3.35
V-furrow	21.3	a	6.22

$F_{(4,16)}$ = 3.18; p = **0.042;** av 95% lsd = 12.54

June 2022	pred		se
Treatment			
Compost	103.4	b	27.01
Nematicide	398.9	a	102.20
Nil	473.5	a	121.17
Organic Matter	59.4	b	15.81
V-furrow	596.2	a	152.40

$F_{(4,16)}$ = 12.48; p**<0.001;** av 95% lsd = 279.32

December 2022	pred	se
Treatment		
Compost	1.9	1.17
Nematicide	3.6	1.90
Nil	3.5	1.83
Organic Matter	1.8	1.13
V-furrow	5.2	2.57

$F_{(4,16)}$ = 0.62; p = 0.658**;** av 95% lsd = 5.27

May 2023	pred		se
Treatment			
Compost	1.7	c	0.59
Nematicide	10.3	a	1.43
Nil	4.3	b	0.93
Organic Matter	0.4	d	0.27
V-furrow	4.2	b	0.91

$F_{(4,16)}$ = 17.45; p < 0.001**;** av 95% lsd = 2.65

Reniform Nematode (Rr)

Only 4 plots recorded Rr in June 2020 and therefore this data has not been analysed. The plots with Rr in June 2020 all occurred in replicate 5 and included treatments Compost, V-Furrow, Nil and Nematicide. No organic matter plots recorded Rr in June 2020. Over-dispersion was present in the counts for both December 2022 and May 2023. Therefore, a Negative Binomial distribution is assumed.

Results suggest there is no significant treatment effect at any assessment (p > 0.05). Below are the predicted means (pred), standard errors (s.e.), F-test, p-value and average 95% lsd.

January 2020	pred	se
Treatment		
Compost	1.35	0.713

Nematicide	1.22	0.675
Nil	0.74	0.515
Organic Matter	1.79	0.833
V-furrow	3.03	1.125

$F_{(4,16)}$ = 1.13; p = 0.375; av 95% lsd = 2.361

January 2021	pred	se
Treatment		
Compost	20.8	16.80
Nematicide	30.5	24.43
Nil	35.1	28.07
Organic Matter	11.1	9.10
V-furrow	9.6	7.94

$F_{(4,16)}$ = 0.40; p = 0.803; av 95% lsd = 53.20

June 2021	pred	se
Treatment		
Compost	304.8	260.27
Nematicide	513.5	438.17
Nil	435.3	371.51
Organic Matter	101.2	86.60
V-furrow	125.4	107.26

$F_{(4,16)}$ = 0.55; p = 0.702; av 95% lsd = 810.06

January 2022	pred	se
Treatment		
Compost	68.8	43.25
Nematicide	53.4	33.65
Nil	96.7	60.63
Organic Matter	39.0	24.70
V-furrow	30.9	19.65

$F_{(4,16)}$ = 0.46; p = 0.765; av 95% lsd = 112.09

June 2022	pred	se
Treatment		
Compost	1645.0	875.15
Nematicide	1200.8	638.96
Nil	3020.2	1606.45
Organic Matter	712.2	379.13
V-furrow	917.5	488.30

$F_{(4,16)}$ = 1.13; p = 0.378; av 95% lsd = 2533.98

December 2022	pred	se
Treatment		
Compost	81.5	39.00
Nematicide	39.8	19.27
Nil	142.1	67.63
Organic Matter	36.6	17.77
V-furrow	102.2	48.74

$F_{(4,16)}$ = 1.45; p = 0.265; av 95% lsd = 121.38

May 2023	pred	se
Treatment		
Compost	479.1	161.59
Nematicide	534.6	180.24
Nil	958.7	322.80
Organic Matter	764.4	257.49
V-furrow	463.5	156.33

$F_{(4,16)}$ = 0.85; p = 0.516; av 95% lsd = 657.04

Total Free-Living Nematodes (TFL)

Significant differences between the treatments were found for all assessments since January 2021 inclusive ($P < 0.05$), except December 2022. Over-dispersion was present in the counts for both December 2022 and May 2023. Therefore, a Negative Binomial distribution is assumed.

- In January 2021, June 2021, January 2022 and June 2022, organic matter had a significantly higher mean count of TFL than all other treatments.
- In June 2021, nematicide had a significantly lower mean count of TFL than all other treatments.
- In May 2023, treatment organic matter had a significantly higher mean count than all other treatments and nil and nematicide had significantly lower mean counts.
- There was no significant difference between the nil and V-furrow treatments at any assessment, except May 2023.

Below are the predicted means (pred), standard errors (s.e.), F-test, p-value and average 95% lsd.

January 2020	pred	se
Treatment		
Compost	3017	579.1
Nematicide	2621	503.2
Nil	2226	427.4
Organic Matter	2982	572.4
V-furrow	3309	634.9

$F_{(4,16)}$ = 0.62; p = 0.656; av 95% lsd = 1632.1

June 2020	pred	se
Treatment		
Compost	2338	377.9
Nematicide	1779	287.8
Nil	1572	254.4
Organic Matter	1930	312.2
V-furrow	1461	236.5

$F_{(4,16)}$ = 1.32; p = 0.304; av 95% lsd = 881.4

January 2021	pred		se
Treatment			
Compost	3812	b	355.2
Nematicide	3049	b	284.4
Nil	3404	b	317.3
Organic Matter	5325	a	495.5
V-furrow	3210	b	299.4

$F_{(4,16)}$ = 6.08; p = **0.004**; av 95% lsd = 1060.6

June 2021	pred		se
Treatment			
Compost	2826	b	259.0
Nematicide	1376	d	126.9
Nil	2131	c	195.7
Organic Matter	8835	a	805.9
V-furrow	2271	bc	208.4

$F_{(4,16)}$ = 66.38; p**<0.001**; av 95% lsd = 1066.5

January 2022	pred		se
Treatment			
Compost	1697	b	195.6
Nematicide	1729	b	199.3
Nil	1821	b	209.9
Organic Matter	2925	a	336.2
V-furrow	1744	b	201.0

$F_{(4,16)}$ = 4.42; p = **0.013**; av 95% lsd = 693.8

June 2022	pred		se
Treatment			
Compost	2032	b	346.6
Nematicide	618	c	106.0
Nil	910	c	155.7
Organic Matter	5305	a	903.3
V-furrow	1030	c	176.2

$F_{(4,16)}$ = 26.37; p**<0.001**; av 95% lsd = 1159.5

December 2022	pred	se
Treatment		
Compost	1951.8	397.70
Nematicide	947.9	193.55
Nil	1848.1	376.62
Organic Matter	1542.6	314.50
V-furrow	1375.1	280.44

$F_{(4,16)}$ = 1.79; p = 0.180; av 95% lsd = 949.61

May 2023	pred		se
Treatment			
Compost	776.4	b	165.21
Nematicide	333.9	c	71.56
Nil	326.7	c	70.04
Organic Matter	1951.6	a	413.91
V-furrow	714.5	b	152.11

$F_{(4,16)}$ = 12.28; **p < 0.001**; av 95% lsd = 573.26

Extensive Trial

Counts of root-knot nematode (RKN), and reniform nematode (Rr) were recorded at 9 occasions from May 2019 through to April 2023. Total free-living nematodes (TFL) were recorded on 8 occasions from August 2019 through to April 2023. For consistency with the analyses of the intensive trial, the counts have been analysed using a generalised linear model (GLM). The replicate block is fitted as the first term in the model, followed by the treatment terms. The treatment term has been fitted acknowledging the factorial treatment structure and also ignoring the factorial treatment structure. In the first analysis, the main effect of Method and Crop are fitted first, followed by the interaction of Method and Crop. If the interaction of Method and Crop is not significant, the term is dropped from the model and only the main effects are fitted. In the second analysis, a single treatment term with 10 levels is fitted ignoring the factorial structure. The presence of over-dispersion was detected when a Poisson distribution was assumed and therefore a Negative Binomial distribution is applied. Over-dispersion is not uncommon and occurs when there is more variation present than expected by the Poisson distribution. The dispersion parameter is estimated in all Negative Binomial models. There was no evidence of over-dispersion for RKN counts in September 2021 and therefore a Poisson distribution was assumed. All significance testing is performed at the 0.05 level. Where a significant treatment effect is detected, the 95% least significant difference (lsd) is used to make pairwise comparisons.

Root-Knot Nematode (RKN)

The counts observed in September 2021 were substantially lower than all other assessments. There was no evidence of over-dispersion and therefore a Poisson distribution was assumed for these counts. In fact, under-dispersion was observed and therefore the dispersion parameter was fixed at one.

A significant main effect of crop was detected in February 2021 and September 2021. A significant main effect of method was found in August 2019 and September 2021. The only significant interaction of method and crop was observed in January 2020.

- No significant difference was found between the mean RKN counts for the nematicide, nil and V-furrow treatments at any assessment. In August 2019, the mean RKN count for these three treatments was significantly higher than the double and incorporated treatments.
- In September 2021, the nematicide and nil treatments had significantly higher mean RKN counts than the double and incorporated treatments.
- In February 2021 and September 2021, the overall grass/brassica treatment mean RKN count was significantly higher than the mean for the grass/legume treatments.
- In January 2020, a significant interaction was found, but no significant difference was observed between the crops for each treatment. The only significant difference within the grass/brassica crop was incorporated had a significantly lower mean RKN count than the nil treatment. Within the grass/legume crop, the double and incorporated treatments had significantly lower mean RKN counts than the other treatments.

Below are the predicted means (pred), standard errors (s.e.), F-test, p-value and average 95% lsd.

May 2019	pred	se
Method		
Double	912.8	125.49
Incorporated	989.9	136.04
Nematicide	827.8	113.86
Nil	730.3	100.51
V-Furrow	819.8	112.76

$F_{(4,31)}$ = 0.71; p = 0.591; av 95% lsd = 340.03

May 2019	pred	se
Crop		
Grass/Brassica	858.6	75.10
Grass/Legume	853.6	74.66

$F_{(1,31)}$ = 0.00; p = 0.961; av 95% lsd = 214.36

August 2019	pred		se
Method			
Double	8.6	b	1.65

Incorporated	3.9	c	0.99
Nematicide	111.8	a	14.53
Nil	110.9	a	14.42
V-Furrow	89.0	a	11.71

$F_{(4,31)}$ = 76.31; p **< 0.001**; av 95% lsd = 28.81

August 2019	pred	se
Crop		
Grass/Brassica	70.9	7.01
Grass/Legume	58.8	5.88

$F_{(1,31)}$ = 1.90; p = 0.178; av 95% lsd = 17.92

January 2020	pred			
Crop	Grass/Brassica		Grass/Legume	
Method				
Double	37.7	cde	14.7	e
Incorporated	17.9	e	25.3	de
Nematicide	52.1	cde	108.5	abc
Nil	68.5	abcd	190.5	a
V-Furrow	53.6	bcde	186.0	ab

January 2020	se	
Crop	Grass/Brassica	Grass/Legume
Method		
Double	13.10	5.48
Incorporated	6.54	8.98
Nematicide	17.90	36.56
Nil	23.33	63.75
V-Furrow	18.39	62.24

$F_{(4,31)}$ = 2.79; p = **0.046**; av 95% lsd = 83.62

June 2020	pred	se
Method		
Double	269.6	70.97
Incorporated	431.6	113.42
Nematicide	564.4	148.21
Nil	600.5	157.65
V-Furrow	470.0	123.46

$F_{(4,31)}$ = 1.36; p = 0.271; av 95% lsd = 359.13

June 2020	pred	se
Crop		
Grass/Brassica	506.5	86.07
Grass/Legume	427.9	72.75

$F_{(1,31)}$ = 0.49; p = 0.490; av 95% lsd = 223.38

February 2021	pred	se
Method		
Double	9.4	6.62
Incorporated	21.0	14.33
Nematicide	80.1	53.53
Nil	42.1	28.30
V-Furrow	30.1	20.35

$F_{(4,31)}$ = 1.54; p = 0.215; av 95% lsd = 74.31

February 2021	pred		se
Crop			
Grass/Brassica	69.0	a	30.82
Grass/Legume	4.1	b	1.89

$F_{(1,31)}$ = 18.92; p **< 0.001**; av 95% lsd = 62.11

September 2021pred	se
Method	

Double	0.16	b	0.139
Incorporated	0.08	b	0.098
Nematicide	1.15	a	0.380
Nil	0.92	a	0.339
V-Furrow	0.39	ab	0.220

$F_{(4,31)}$ = 3.59; p = **0.006**; av 95% lsd = 0.722

September 2021	pred		se
Crop			
Grass/Brassica	0.95	a	0.214
Grass/Legume	0.12	b	0.078

$F_{(1,31)}$ = 14.54; p **< 0.001**; av 95% lsd = 0.473

March 2022	pred	se
Method		
Double	325.3	69.74
Incorporated	382.0	81.83
Nematicide	473.2	101.24
Nil	518.1	110.80
V-Furrow	522.3	111.69

$F_{(4,31)}$ = 0.92; p = 0.465; av 95% lsd = 272.64

March 2022	pred	se
Crop		
Grass/Brassica	433.0	60.41
Grass/Legume	455.3	63.51

$F_{(1,31)}$ = 0.06; p = 0.802; av 95% lsd = 170.74

November 2022	pred	se
Method		
Double	2.0	1.25
Incorporated	2.8	1.68
Nematicide	7.0	3.88
Nil	16.1	8.60
V-Furrow	8.1	4.48

$F_{(4,31)}$ = 2.32; p = 0.078; av 95% lsd = 11.99

November 2022	pred	se
Crop		
Grass/Brassica	4.4	1.86
Grass/Legume	10.0	4.16

$F_{(1,31)}$ = 2.70; p = 0.110; 95% lsd = 7.89

April 2023	pred	se
Method		
Double	93.4	47.59
Incorporated	97.5	49.65
Nematicide	132.1	67.19
Nil	99.9	50.86
V-Furrow	72.5	36.99

$F_{(4,31)}$ = 0.17; p = 0.953; av 95% lsd = 145.47

April 2023	pred	se
Crop		
Grass/Brassica	79.9	26.19
Grass/Legume	118.3	38.74

$F_{(1,31)}$ = 0.64; p = 0.432; 95% lsd = 92.84

When the factorial treatment structure is ignored, a significant treatment effect is found for August 2019, January 2020, February 2021 and September 2021. Significant effects were also found in the analysis above for these months.

- In August 2019, treatments 4, 5, 9 and 10 have significantly lower mean RKN counts than the other treatments. These are the incorporated and double treatments.
- Although a significant F-test was obtained in February 2021, no significant differences were detected using the 95% lsd. This is a reasonably rare event, although has previously occurred with nematode data. The overall F-test and the pairwise comparisons are independent tests and addressing slightly different questions. It is recommended to state that the overall F-test was significant, but no pairwise contrasts were found to be significant.
- In September 2021, treatments 1 and 2 had significantly higher mean RKN counts than treatments 4 to 10.

Below are the predicted means (pred), standard errors (s.e.), F-test, p-value and average 95% lsd.

May 2019	pred	se
Treatment		
1	726.8	139.02
2	599.0	114.75
3	943.8	180.21
4	1009.0	192.60
5	1045.9	199.61
6	929.6	177.53
7	863.1	164.90
8	694.9	132.96
9	972.6	185.70
10	782.4	149.58

$F_{(9,27)}$ = 0.89; p = 0.547; av 95% lsd = 478.15

August 2019	pred		se
Treatment			
1	125.0	a	22.15
2	118.3	ab	21.02
3	112.2	ab	20.00
4	2.9	d	1.20
5	8.3	c	2.32
6	98.8	ab	17.75
7	102.7	ab	18.41
8	68.1	b	12.58
9	5.0	cd	1.66
10	8.8	c	2.41

$F_{(9,27)}$ = 35.29; p **<0.001**; av 95% lsd = 39.47

January 2020	pred		se
Treatment			
1	52.1	cde	17.90
2	68.5	abcd	23.33
3	53.6	bcde	18.39
4	17.9	e	6.54
5	37.7	cde	13.10
6	108.5	abc	36.56
7	190.5	a	63.75
8	186.0	ab	62.24
9	25.3	de	8.98
10	14.7	e	5.48

$F_{(9,27)}$ = 6.46; p **<0.001**; av 95% lsd = 83.62

June 2020	pred	se
Treatment		
1	522.3	195.24
2	871.6	325.43

3	607.2		226.88
4	411.0		153.75
5	230.1		86.33
6	607.7		227.07
7	368.8		138.00
8	352.0		131.75
9	449.0		167.92
10	304.0		113.86

$F_{(9,27)}$ = 1.03; p = 0.444; av 95% lsd = 582.17

February 2021	pred		se
Treatment			
1	176.3	a	157.19
2	94.5	a	84.44
3	48.3	a	43.29
4	22.7	a	20.53
5	21.5	a	19.17
6	5.2	a	4.98
7	4.0	a	3.90
8	3.8	a	3.67
9	3.4	a	3.33
10	0.7	a	0.85

$F_{(9,27)}$ = 2.57; p = **0.028**; av 95% lsd = 123.83

November 2022	pred		se
Treatment			
1	4.8		3.70
2	8.5		6.22
3	2.3		1.98
4	2.5		2.14
5	1.2		1.17
6	7.9		5.84
7	21.6		14.94
8	14.7		10.39
9	1.8		1.61
10	2.6		2.21

$F_{(9,27)}$ = 1.46; p = 0.211; av 95% lsd = 16.11

April 2023	pred		se
Treatment			
1	118.8		87.00
2	34.9		25.83
3	56.0		41.22
4	103.7		75.97
5	93.5		68.53
6	153.9		112.61
7	199.1		145.64
8	108.6		79.55
9	76.7		56.29
10	72.1		52.91

$F_{(9,27)}$ = 0.39; p = 0.931; av 95% lsd = 225.72

September 2021pred		se	
Treatment			
1	2.00	a	0.707
2	1.84	a	0.679
3	0.62	ab	0.394
4	0.00	b	0.002
5	0.31	b	0.279
6	0.31	b	0.277
7	0.00	b	0.002
8	0.15	b	0.196

9	0.16	b	0.199
10	0.00	b	0.002

$F_{(9,27)}$ = 3.77; p **<0.001**; av 95% lsd = 0.935

March 2022	pred	se
Treatment		
1	459.1	140.18
2	569.0	173.57
3	543.4	165.78
4	253.4	77.71
5	341.1	104.38
6	484.1	147.78
7	453.5	138.50
8	481.0	146.83
9	510.7	155.85
10	301.1	92.21

$F_{(9,27)}$ = 0.73; p = 0.682; av 95% lsd = 392.79

Reniform Nematode (Rr)

Insufficient non-zero data was obtained in May 2019 for counts of Rr and this data has not been analysed. Non-zero data was found in 3 plots in replicate 2 (treatments 1, 2, 10) and 6 plots in replicate 4 (treatments 1, 2, 3, 4, 8, 9). The raw means for each treatment are shown below.

	Mean
Treatment	
1	3.683
2	13.505
3	57.704
4	2.455
5	0.000
6	0.000
7	0.000
8	9.822
9	7.366
10	1.228

The models for June 2020 would not converge. It is unclear why this has occurred but may be due to the large variability within each treatment. The following table shows the minimum and maximum Rr counts within each treatment. Six of the 10 treatments recorded at least one plot with no Rr recorded. No results are presented for this assessment.

	Minimum	Maximum
Treatment		
1	0.000	301.9
2	8.221	186.8
3	0.000	339.3
4	4.583	782.4
5	0.000	212.5
6	0.000	1528.3
7	17.169	235.7
8	0.000	607.3
9	0.000	168.9
10	3.371	143.9

The interaction of crop and method was not significant for any assessment and therefore this term has been dropped from all models. Across all assessments, the only significant effect of method was in August 2019. Unfortunately, the pairwise comparisons of the method means did not detect any significant differences.

Again, it is recommended to state that the overall F-test was significant, but no pairwise contrasts were found to be significant. Arithmetically the nil treatment has a higher mean Rr count than the other treatments in August 2019. Over-dispersion was present for counts recorded in both November 2022 and April 2023. The GLM fitted therefore assumed a Negative Binomial distribution. Below are the predicted means (pred), standard errors (s.e.), F-test, p-value and average 95% lsd.

August 2019	pred		se
Method			
Double	5.3	a	2.97
Incorporated	0.7	a	0.55
Nematicide	7.1	a	3.92
Nil	24.6	a	12.85
V-furrow	6.9	a	3.81

$F_{(4,31)}$ = 4.12; p = **0.009**; av 95% lsd = 15.35

August 2019	pred	se
Crop		
Grass/Brassica	7.7	3.39
Grass/Legume	10.1	4.44

$F_{(1,31)}$ = 0.32; p = 0.575; av 95% lsd = 8.67

January 2020	pred	se
Method		
Double	13.7	5.92
Incorporated	9.1	4.01
Nematicide	16.3	7.02
Nil	21.0	8.98
V-furrow	27.8	11.77

$F_{(4,31)}$ = 0.84; p = 0.509; av 95% lsd = 22.11

January 2020	pred	se
Crop		
Grass/Brassica	13.0	3.73
Grass/Legume	22.1	6.26

$F_{(1,31)}$ = 1.56; p = 0.221; av 95% lsd = 14.04

February 2021	pred	se
Method		
Double	10.0	4.24
Incorporated	9.6	4.09
Nematicide	24.3	9.97
Nil	31.7	12.91
V-furrow	10.5	4.46

$F_{(4,31)}$ = 1.94; p = 0.129; av 95% lsd = 21.55

February 2021	pred	se
Crop		
Grass/Brassica	14.8	4.26
Grass/Legume	19.7	5.63

$F_{(1,31)}$ = 0.45; p = 0.508; av 95% lsd = 13.00

September 2021	pred	se
Method		
Double	14.8	7.99
Incorporated	8.8	4.84
Nematicide	44.3	23.31
Nil	42.8	22.51
V-furrow	35.1	18.53

$F_{(4,31)}$ = 1.55; p = 0.211; av 95% lsd = 46.83

September 2021	pred	se
Crop		

Grass/Brassica	30.57	11.31
Grass/Legume	27.74	10.27

$F_{(1,31)}$ = 0.05; p = 0.833; av 95% lsd = 27.52

March 2022	pred	se
Method		
Double	896.1	359.75
Incorporated	1352.6	542.85
Nematicide	1818.1	729.61
Nil	1463.5	587.34
V-furrow	1076.1	431.94

$F_{(4,31)}$ = 0.43; p = 0.784; av 95% lsd = 1523.75

March 2022	pred	se
Crop		
Grass/Brassica	1262.4	335.18
Grass/Legume	1380.2	366.45

$F_{(1,31)}$ = 0.06; p = 0.811; av 95% lsd = 946.69

November 2022	pred	se
Method		
Double	81.9	26.83
Incorporated	132.0	42.99
Nematicide	221.8	71.98
Nil	249.2	80.81
V-furrow	178.8	58.08

$F_{(4,31)}$ = 1.86; p = 0.143; av 95% lsd = 163.02

November 2022	pred	se
Crop		
Grass/Brassica	176.2	39.05
Grass/Legume	169.3	37.52

$F_{(1,31)}$ = 0.02; p = 0.886; 95% lsd = 98.91

April 2023	pred	se
Method		
Double	453.8	115.88
Incorporated	487.2	124.38
Nematicide	679.2	173.26
Nil	617.8	157.62
V-furrow	376.1	96.10

$F_{(4,31)}$ = 0.81; p = 0.527; av 95% lsd = 387.31

April 2023	pred	se
Crop		
Grass/Brassica	490.1	80.80
Grass/Legume	555.5	91.57

$F_{(1,31)}$ = 0.27; p = 0.607; 95% lsd = 242.14

When the factorial treatment structure is ignored, no significant differences between the treatments is detected ($p > 0.05$). Below are the predicted means (pred), standard errors (se), F-test, p-value and average 95% lsd.

August 2019	pred	se
Treatment		
1	9.4	6.99
2	35.1	24.26
3	6.1	4.76
4	0.3	0.38
5	2.2	1.99

6	5.8	4.54
7	20.3	14.37
8	8.3	6.25
9	1.2	1.23
10	11.5	8.40

$F_{(1,31)}$ = 2.15; p = 0.060; av 95% lsd = 23.81

January 2020	pred	se
Treatment		
1	13.8	8.08
2	25.6	14.68
3	17.6	10.22
4	4.0	2.64
5	6.9	4.24
6	17.5	10.16
7	9.1	5.48
8	40.9	23.16
9	16.1	9.39
10	21.4	12.36

$F_{(1,31)}$ = 1.14; p = 0.373; av 95% lsd = 31.01

February 2021	pred	se
Treatment		
1	22.0	13.21
2	23.7	14.16
3	6.6	4.24
4	11.8	7.27
5	8.7	5.46
6	25.7	15.35
7	42.3	24.94
8	15.7	9.57
9	7.6	4.83
10	11.6	7.18

$F_{(1,31)}$ = 0.96; p = 0.491; av 95% lsd = 32.69

September 2021pred	se	
Treatment		
1	51.6	39.94
2	57.5	44.51
3	37.9	29.48
4	7.9	6.54
5	11.9	9.62
6	38.8	30.18
7	33.2	25.92
8	32.4	25.27
9	9.6	7.83
10	18.2	14.40

$F_{(1,31)}$ = 0.67; p = 0.729; av 95% lsd = 72.06

March 2022	pred	se
Treatment		
1	1835.6	1057.01
2	1331.9	767.06
3	675.4	389.23
4	2106.9	1213.16
5	830.0	478.19
6	1762.5	1014.91
7	1777.1	1023.32
8	1597.5	919.91
9	749.1	431.61

10	1122.7	646.64

$F_{(1,31)}$ = 0.48; p = 0.875; av 95% lsd = 2353.60

November 2022	pred	se
Treatment		
1	241.9	105.43
2	291.1	126.72
3	153.8	67.31
4	237.4	103.50
5	50.7	22.68
6	223.2	97.33
7	254.2	110.74
8	225.0	98.14
9	60.5	26.94
10	117.9	51.80

$F_{(9,27)}$ = 1.458 p = 0.172; av 95% lsd = 243.87

April 2023	pred	se
Treatment		
1	713.3	258.59
2	483.2	175.37
3	296.3	107.76
4	621.6	225.43
5	366.4	133.13
6	638.6	231.58
7	771.7	279.73
8	466.2	169.20
9	334.2	121.45
10	549.8	199.43

$F_{(9,27)}$ = 0.77; p = 0.647; av 95% lsd = 562.84

Total Free-Living Nematode (TFL)

A significant effect of method was detected in August 2019, June 2020, February 2021, September 2021, and March 2022. There was no significant effect of crop at any assessment. A significant interaction was identified for the assessment in January 2020.

- In January 2020, there was a significant effect of crop on the nil treatment. The grass/brassica treatment had a significant higher mean count of TFL than the nil treatment with grass/legume. The double and incorporated treatments had the highest mean counts for both crops. For grass/brassica the nematicide treatment had a significantly lower mean count than double, incorporated, and nil treatments. For grass/legume the nil and V-furrow treatments had a significantly lower mean count than the double and incorporated treatments.
- In August 2019, double and incorporated treatments had significantly higher mean TFL counts than all other treatments.
- Double, incorporated and V-Furrow treatments consistently had the highest mean TFL for all assessments from June 2020 inclusive.
- In June 2020 and February 2021, the nil and nematicide treatments had significantly lower mean TFL counts than the other treatments.
- In September 2021 and March 2022, the nil treatment had a significantly lower mean TFL count, although it was not significantly lower than nematicide in March 2022.
- The main effect of method was significant for November 2022, but no significant main effects were detected in April 2023. In November 2022 the double and incorporated treatments had significantly higher mean counts of TFL compared to the other three treatments.

Below are the predicted means (pred), standard errors (s.e.), F-test, p-value and average 95% lsd.

August 2019	pred		se
Method			
Double	11364.3	a	833.81
Incorporated	9713.2	a	712.83
Nematicide	2487.0	b	183.34
Nil	2215.0	b	163.41
V-furrow	2040.9	b	150.65

$F_{(4,31)}$ = 134.54; p **< 0.001**; av 95% lsd = 1335.11

August 2019	pred	se
Crop		
Grass/Brassica	5640.2	295.73
Grass/Legume	5488.0	287.76

$F_{(1,31)}$ = 0.17; p = 0.681; av 95% lsd = 746.76

January 2020	pred			
Crop	Grass/Brassica		Grass/Legume	
Method				
Double	6988.7	a	5546.7	ab
Incorporated	7394.6	a	4975.6	abc
Nematicide	1453.6	de	2399.6	cde
Nil	4175.7	abc	1321.3	e
V-furrow	3014.9	bcd	1803.0	de

	se	
Crop	Grass/Brassica	Grass/Legume
Method		
Double	1619.57	1285.58
Incorporated	1713.59	1153.28
Nematicide	337.50	556.64
Nil	968.01	306.86
V-furrow	699.16	418.44

$F_{(4,27)}$ = 1.46; p = **0.030**; av 95% lsd = 2824.76

June 2020	pred		se
Method			
Double	5253.2	a	637.39
Incorporated	2432.5	c	295.52
Nematicide	893.8	d	109.01
Nil	1183.5	d	144.13
V-furrow	3572.1	b	433.64

$F_{(4,31)}$ = 35.31; p **< 0.001**; av 95% lsd = 1022.95

June 2020	pred	se
Crop		
Grass/Brassica	2510.2	210.29
Grass/Legume	2823.8	236.51

$F_{(1,31)}$ = 1.17; p = 0.288; av 95% lsd = 590.99

February 2021	pred		se
Method			
Double	2516.4	a	311.41
Incorporated	2646.1	a	327.42
Nematicide	812.0	c	100.94
Nil	786.2	c	97.75
V-furrow	1648.2	b	204.20

$F_{(4,31)}$ = 20.98; p **< 0.001**; av 95% lsd = 640.78

February 2021	pred	se
Crop		
Grass/Brassica	1722.6	142.43
Grass/Legume	1641.0	135.71

$F_{(1,31)}$ = 0.19; p = 0.668; av 95% lsd = 380.39

September 2021

pred

se

Method			
Double	2436.8	b	309.60
Incorporated	3970.0	a	503.97
Nematicide	1685.8	b	214.39
Nil	1073.3	c	136.74
V-furrow	1811.0	b	230.26

$F_{(4,31)}$ = 14.00; p **< 0.001**; av 95% lsd = 842.31

September 2021	pred	se
Crop		
Grass/Brassica	2006.8	170.48
Grass/Legume	2383.9	202.44

$F_{(1,31)}$ = 2.28; p = 0.142; av 95% lsd = 508.02

March 2022	pred		se
Method			
Double	1394.8	ab	208.24
Incorporated	1753.5	a	261.64
Nematicide	1104.1	bc	164.94
Nil	886.2	c	132.51
V-furrow	1493.3	ab	222.90

$F_{(4,31)}$ = 3.11; p = **0.029**; av 95% lsd = 579.86

March 2022	pred	se
Crop		
Grass/Brassica	1183.3	113.10
Grass/Legume	1469.5	140.37

$F_{(1,31)}$ = 2.58; p = 0.118; av 95% lsd = 363.07

November 2022	pred		se
Method			
Double	4064.7	a	433.17
Incorporated	4174.1	a	444.81
Nematicide	1724.6	b	184.23
Nil	2165.4	b	231.12
V-furrow	1762.0	b	188.20

$F_{(4,31)}$ = 17.24; **p < 0.001**; av 95% lsd = 891.76

November 2022	pred	se
Crop		
Grass/Brassica	2787.7	195.72
Grass/Legume	2768.6	194.38

$F_{(1,31)}$ = 0.01; p = 0.942; 95% lsd = 540.00

April 2023	pred	se
Method		
Double	1567.6	234.62
Incorporated	2150.5	321.65
Nematicide	1438.5	215.34
Nil	1575.4	235.78
V-furrow	1442.4	215.92

$F_{(4,31)}$ = 1.16; p = 0.348; av 95% lsd = 707.75

April 2023	pred	se
Crop		
Grass/Brassica	1757.2	168.24
Grass/Legume	1512.6	144.87

$F_{(1,31)}$ = 1.20; p = 0.283; 95% lsd = 445.65

When the factorial treatment structure is ignored, significant differences between treatments were detected at all assessments except March 2022.

- In August 2019, treatments 4, 5, 9 and 10 had significantly higher mean TFL counts than all other treatments. These are the incorporated and double treatments.
- In January 2020, treatments 4, 5 had significantly higher mean TFL counts than all treatments except 9 and 10. These are the incorporated and double treatments.
- In June 2020 and February 2021, treatments 1, 2, 6 and 7 had significantly lower means than all other treatments. These are the nematicide and nil treatments.
- In November 2022, treatments 4, 5 and 9 had significantly higher mean TFL counts than all other treatments except treatment 10. These are the incorporated and double amendment treatments for the two crops. In November 2022, treatments 1, 2, 3, 6, and 8 had significantly lower mean TFL counts than all other treatments except treatment 7. These are the nematicide, nil and V-furrow treatments for the two crops.

August 2019	pred		se
Treatment			
1	2561.2	b	265.27
2	2337.7	bc	242.28
3	2270.3	bc	235.35
4	9291.8	a	957.63
5	10422.1	a	1073.89
6	2413.0	bc	250.03
7	2095.2	bc	217.33
8	1819.1	c	188.93
9	10123.3	a	1043.15
10	12282.1	a	1265.23

$F_{(9,27)}$ = 61.08; p **<0.001**; av 95% lsd = 1862.12

January 2020	pred		se
Treatment			
1	1453.6	de	337.50
2	4175.7	abc	968.01
3	3014.9	bcd	699.16
4	7394.6	a	1713.59
5	6988.7	a	1619.57
6	2399.6	cde	556.64
7	1321.3	e	306.86
8	1803.0	de	418.44
9	4975.6	abc	1153.28
10	5546.7	ab	1285.58

$F_{(9,27)}$ = 7.06; p **<0.001**; av 95% lsd = 2823.76

June 2020	pred		se
Treatment			
1	876.0	e	155.16
2	1252.0	e	221.29
3	2905.5	bcd	512.11
4	2285.3	d	403.03
5	4830.2	ab	850.61
6	908.3	e	160.84
7	1101.7	e	194.85
8	4305.9	abc	758.41
9	2579.8	cd	454.81
10	5694.0	a	1002.54

$F_{(9,27)}$ = 15.23; p **<0.001**; av 95% lsd = 1488.46

February 2021	pred		se
Treatment			
1	919.3	c	167.53
2	742.6	c	135.53
3	1630.6	b	296.34
4	2918.3	a	529.55
5	2384.6	ab	432.89
6	708.0	c	129.25
7	824.2	c	150.30
8	1662.0	b	302.02
9	2385.0	ab	432.96
10	2641.1	ab	479.34

$F_{(9,27)}$ = 8.88; p **<0.001**; av 95% lsd = 940.23

September 2021pred		se	
Treatment			
1	1620	cde	281.3
2	898	f	156.5
3	1356	def	235.7
4	4410	a	764.0
5	2215	bcd	384.3

6	1730	cde	300.4
7	1258	ef	218.7
8	2317	bc	401.9
9	3385	ab	586.7
10	2657	abc	460.8

$F_{(9,27)}$ = 7.55; p **<0.001**; av 95% lsd = 1152.24

March 2022	pred	se
Treatment		
1	1057	229.3
2	719	156.3
3	1186	257.1
4	1500	324.9
5	1454	315.0
6	1137	246.6
7	1069	231.7
8	1833	396.9
9	2022	437.8
10	1285	278.4

$F_{(9,27)}$ = 1.84; p = 0.106; av 95% lsd = 850.73

November 2022	pred		se
Treatment			
1	1752.4	c	265.08
2	1871.9	c	283.07
3	1667.0	c	252.23
4	4339.1	a	654.52
5	4657.3	a	702.42
6	1694.3	c	256.34
7	2454.9	bc	370.84
8	1858.0	c	280.97
9	4001.4	a	603.67
10	3478.8	ab	524.99

$F_{(9,27)}$ = 8.07; **p < 0.001**; av 95% lsd = 1267.17

April 2023	pred	se
Treatment		
1	2032.1	400.57
2	1545.1	304.81
3	1464.8	289.02
4	1808.5	356.61
5	1766.9	348.41
6	916.5	181.21
7	1585.0	312.65
8	1409.3	278.10
9	2427.6	478.34
10	1378.8	272.10

$F_{(9,27)}$ = 1.69; p = 0.142; av 95% lsd = 947.29

Appendix 16

Sustainable farming systems trials - Soil testing as an indicator of soil health improvement

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, Michael Hughes, Jean Bobby and Brett Day.
DAF Nematology - Jennifer Cobon, Wayne O'Neill and Tim Shuey.

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Queensland Government

Soil testing as an indicator for soil health improvement

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 19 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 20 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 21 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 22 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 23 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 24 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.

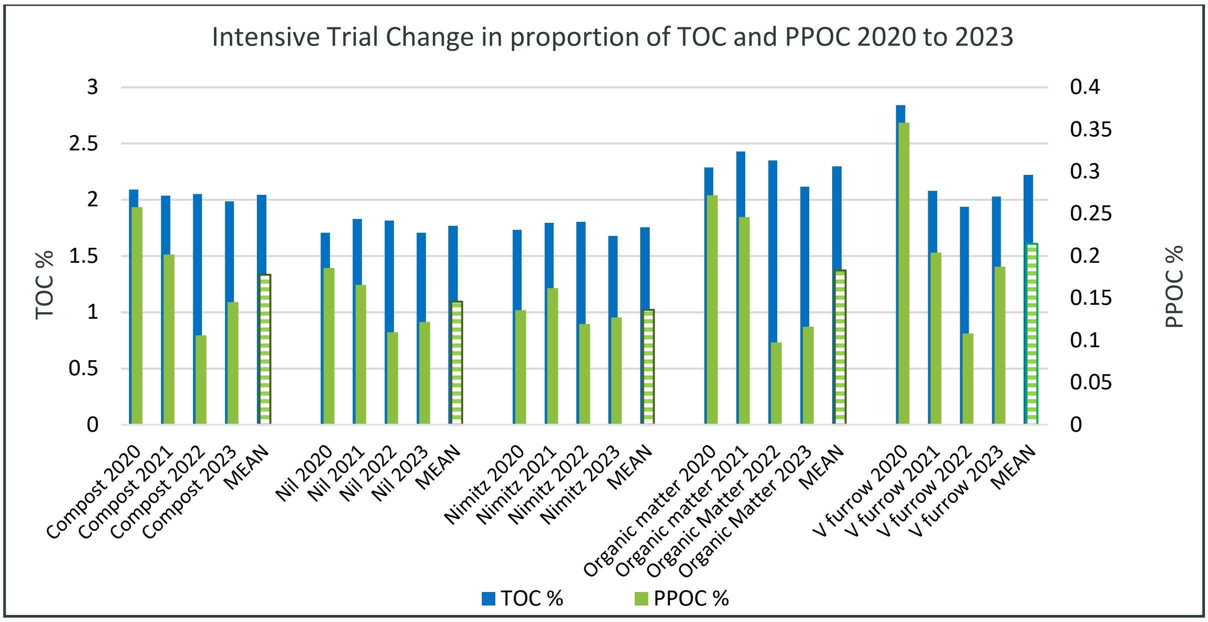

Figure 11 The relative proportion of PPOC to TOC at the four harvest sampling times. The PPOC scale is on the right hand side of the graph and is approximately 1/10 of the TOC scale.

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 25 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 26 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 27 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 28 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 29 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 30 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 31 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.

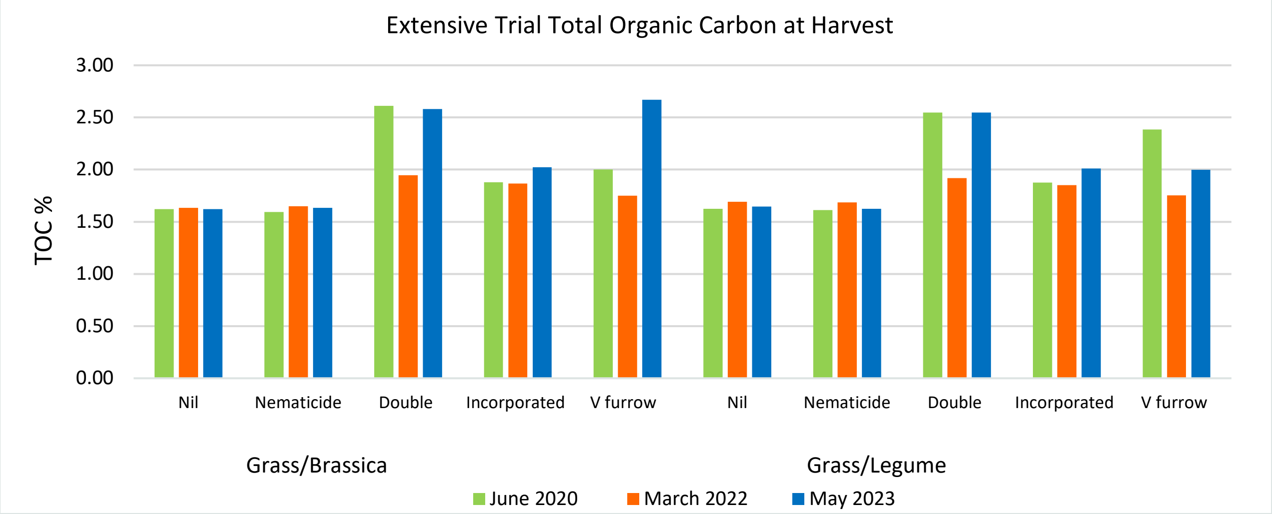

Figure 12 Comparison of TOC levels at the 3 harvest sampling events.

Table 32 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 33 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 34 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 35 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 36 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 37 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 38: 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 39 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.

	Means			
Treatments	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 40 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.

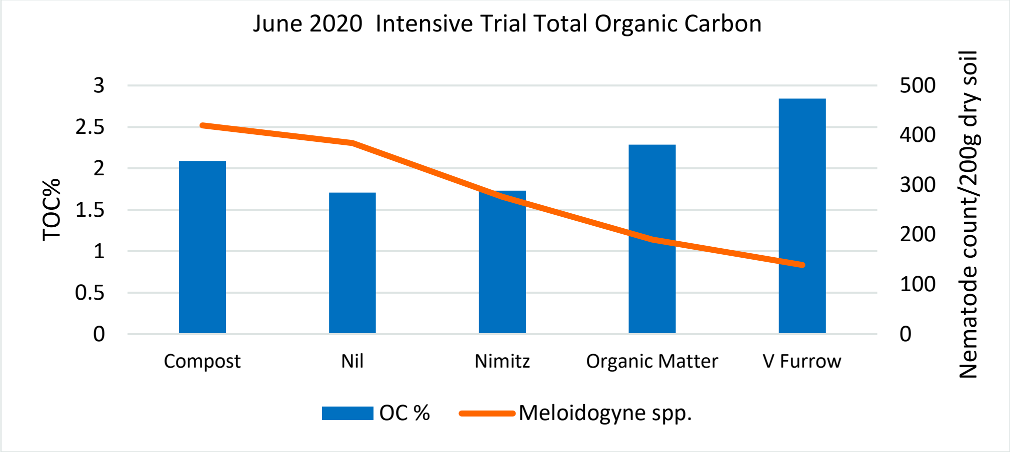

Figure 13 Comparison of TOC levels at the 3 harvest sampling events.

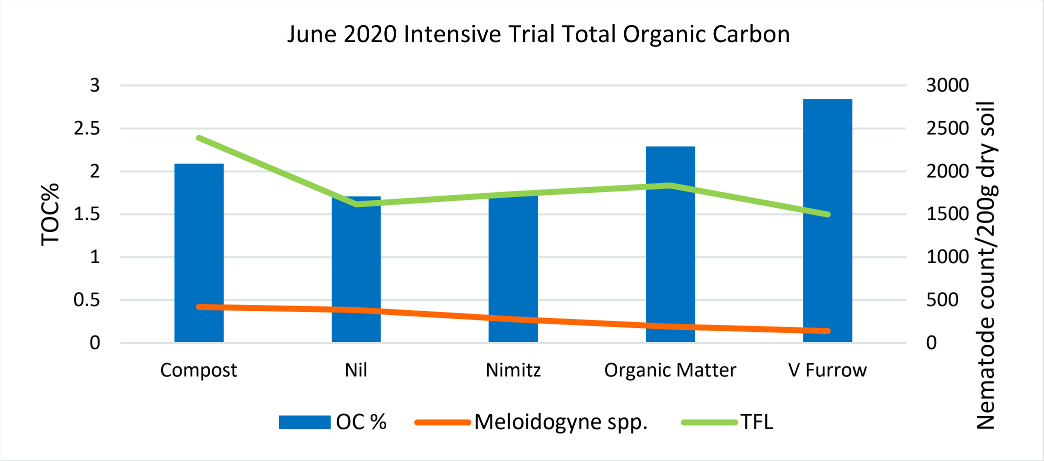

Figure 14 The relationship between Total Organic Carbon, Total Free Living nematodes and Root Knot Nematode counts

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.

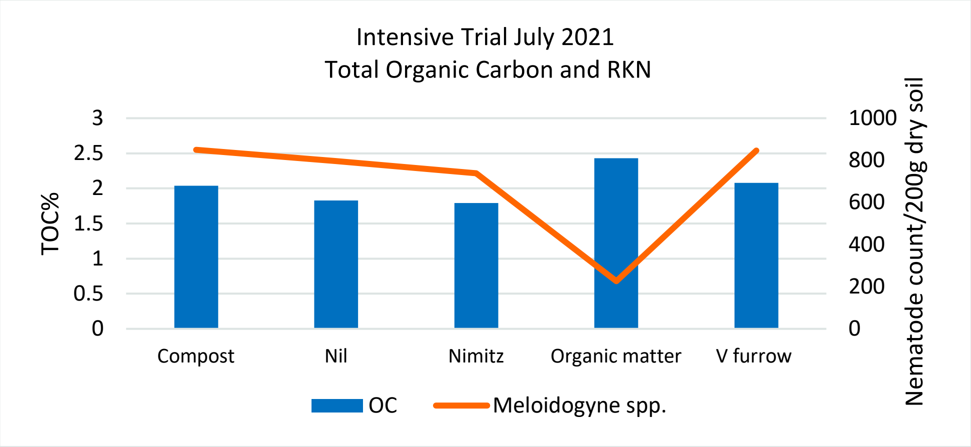

Figure 15 The relationship between Total Organic Carbon and RKN counts in July 2021

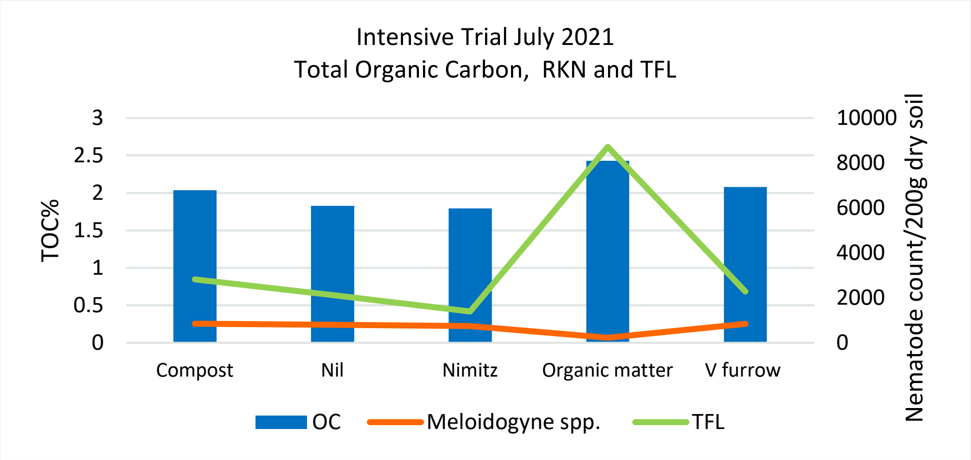

Figure 16 The relationship between Total Organic Carbon, Total Free Living nematodes and Root Knot Nematode counts in July 2021

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.

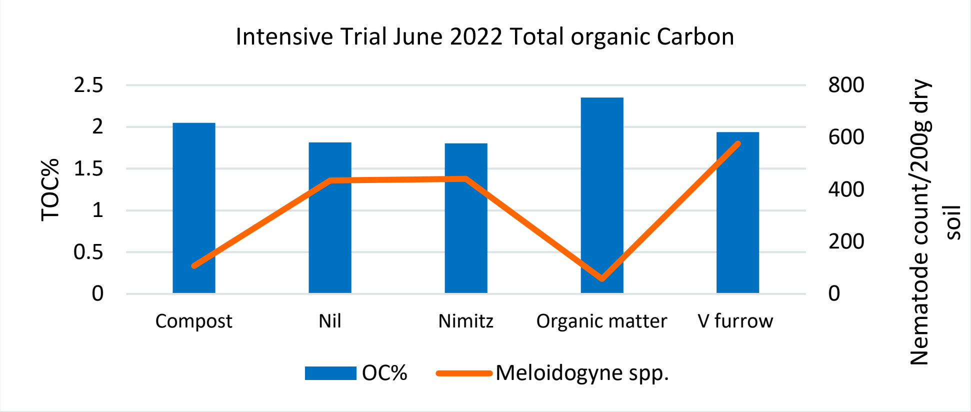

Figure 17 The relationship between Total Organic Carbon and Root Knot Nematode counts in June 2022.

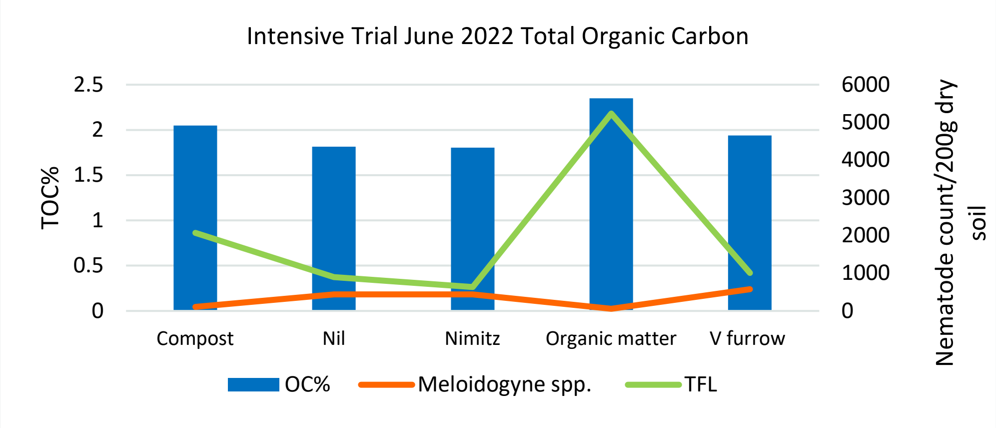

Figure 18 The relationship between Total Organic Carbon, Total Free Living nematodes and Root Knot Nematode counts in June 2022.

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.

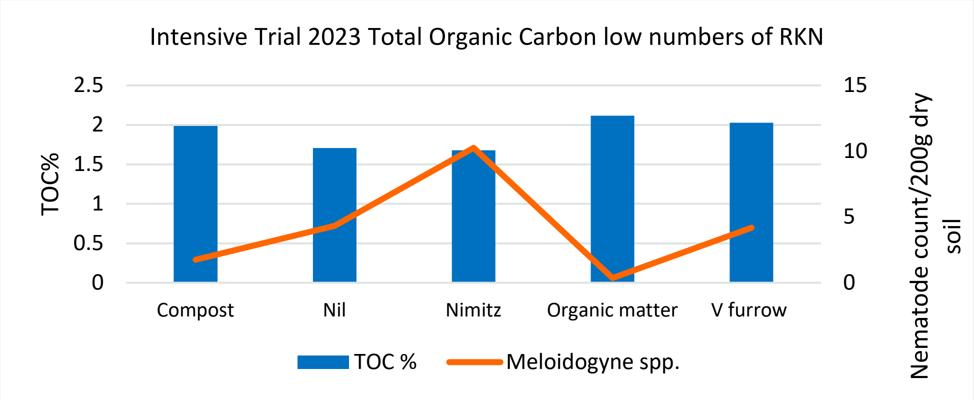

Figure 19 The relationship between Total Organic Carbon and Root Knot Nematode counts in May 2023. Note the very low counts of RKN.

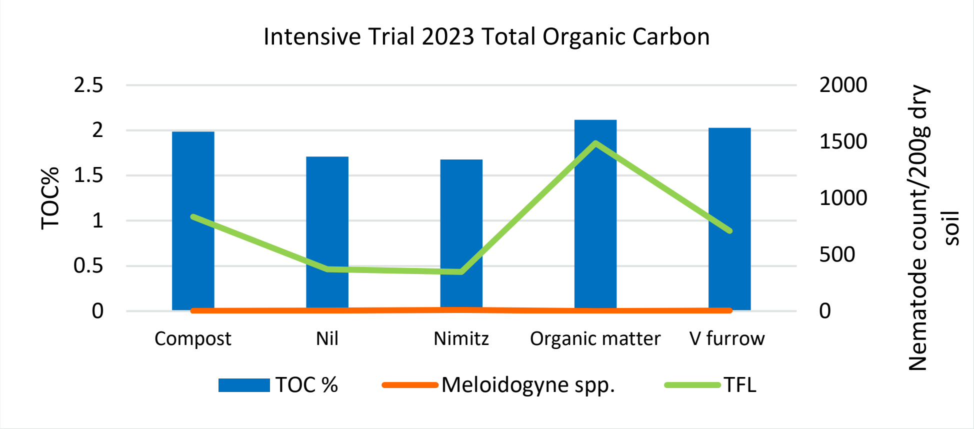

Figure 20 The relationship between Total Organic Carbon, Total Free Living nematodes and Root Knot Nematode counts. Note the very low counts of RKN.

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 Meloidogyne, negative correlations were found in each year that data was collected for EC, NO3N, TC%, TOC%, and PPOC%. This suggests that the count of Meloidogyne 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 41 Table of adjusted R² 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		

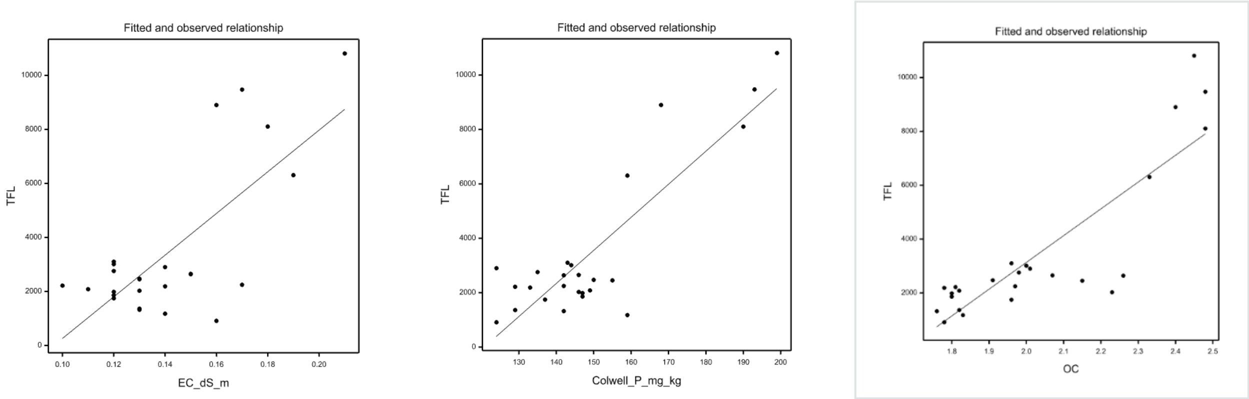

Figure 21 The fitted models for relationships with an adjusted R2 above 50%

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.

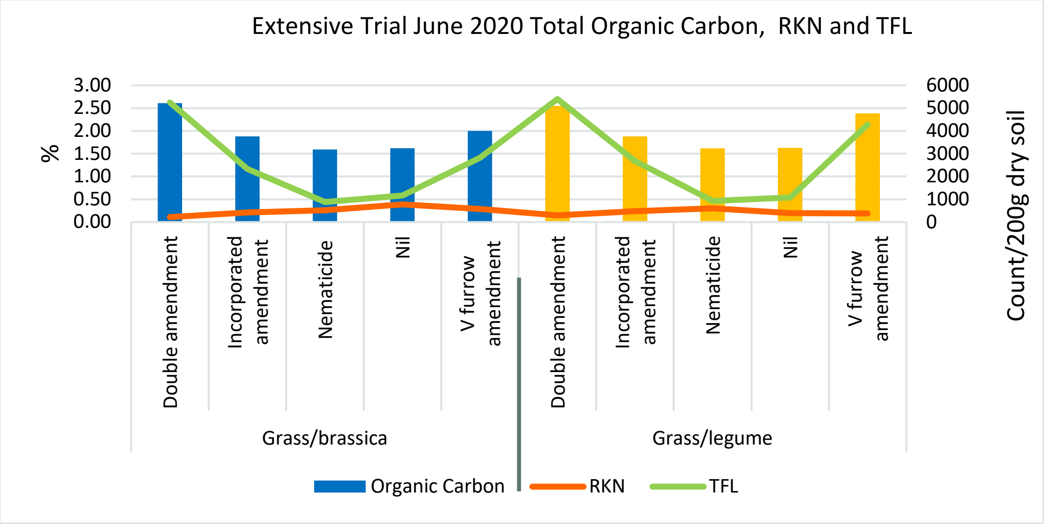

Figure 22 The relationship between Total Organic Carbon, Total Free Living nematodes and Root Knot Nematode counts in June 2020.

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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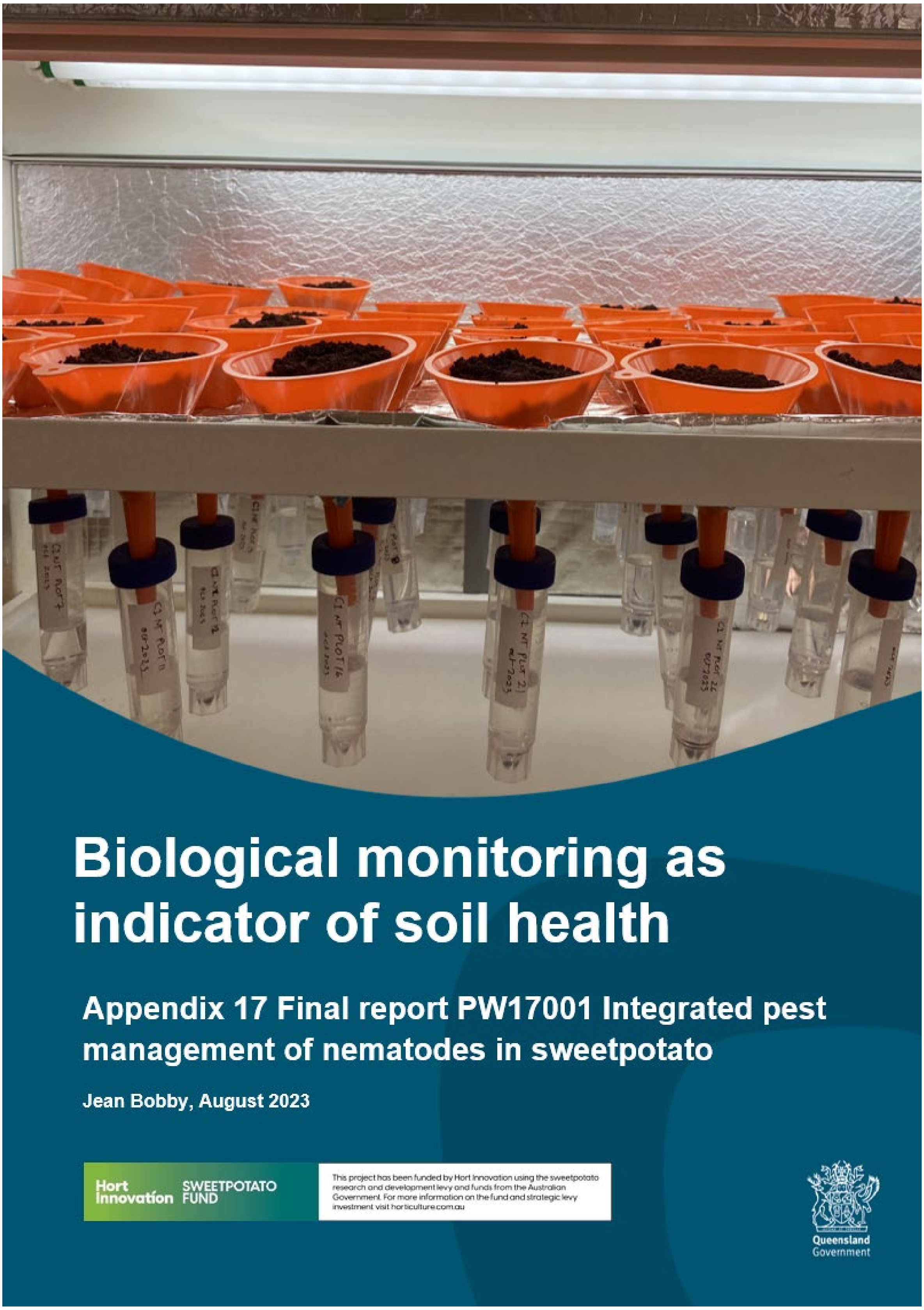
Appendix 17

Sustainable farming systems trials - Biological monitoring



Biological monitoring as indicator of soil health

Appendix 17 Final report PW17001 Integrated pest management of nematodes in sweetpotato

Jean Bobby, August 2023

Hort Innovation SWEETPOTATO FUND

This project has been funded by Hort Innovation using the sweetpotato research and development levy and funds from the Australian Government. For more information on the fund and strategic levy investment visit horticulture.com.au

Queensland Government

Intensive trial- biological monitoring as an indicator of soil health

Summary

Microarthropod population and presence of Nematode Trapping Fungi (NTF) as indicators of soil health were collected at pre-plant and pre-harvest stage of the crop including during cover crop or rotation crop for the life of the trial (see full report at Appendix 17).

Statistical analysis of the microarthropod data showed significant effects of collection date ($p<0.001$) and treatment ($p<0.001$). Mean microarthropods per plot fluctuate over time. The highest mean was recorded on the second collection date (4-Feb-2021) after which it declined but increased slightly on 6-Jun 2022 before declining again in later assessments. The high counts in February 2021 can be attributed to the build-up of litter from amendments and a rotation crop (White French Millet/Jumbo Sorghum) prior to planting of first commercial sweetpotato crop. The decline in mean microarthropod count on 28-Jun-2021 and further decline in 27-Jan-2022 can be attributed to high rainfall; chemicals from pesticide, herbicide, nematicide and fertilizer application.

Organic matter treatment had a significantly higher mean microarthropod count than all other treatments followed by V Furrow amendment, which was significantly better than the nematicide treatment but not the compost and nil treatments.

Nematode trapping fungi have a significant effect of collection date ($p<0.001$). Mean proportion of plates with NTF decreases significantly after the first assessment. This may be attributed to build-up of plant litter and organic matter in the soil prior to first planting, an environment favorable for NTF to be prevalent. However, the decline in preplant (04-Feb-21 & 27-Jan-22) may be related to tillage as well as environmental factors such as rainfall, heat, and agronomic practices such pesticide and herbicide application. NTF proportions increased again on 09-Dec-22 at preplant and reasonably high on 28-Apr-23 (pre-harvest) after a period of rotation crop. Mean proportion of plates with NTF is generally high for preharvest assessments (02-June-20, 28-Jun-21).

Presence of conidia was significant for collection date ($p<0.001$), higher at the first collection date (2-Jun-20) and the last two (9-Dec-22 & 28-Apr-23) collection dates. The decline in mean proportions on 4/02/2021 to 6/06/2021 may be a resulting effect of agronomic practices such as tillage, chemicals from pesticide, herbicide, nematicide and fertilizer application as well as soil environment.

Extensive Trial – biological monitoring as an indicator of soil health

Summary

Mean microarthropod count increased significantly over the first three collection dates before fluctuating over the rest of the collection dates, particularly for the double and incorporated amendment treatments. The increase can be attributed to build-up of plant litter and organic matter in the soil from application of amendments and cover crop (White French Millet followed by Soybean A6785 and Nemsol) prior to planting of first commercial sweetpotato crop.

Within treatment crops (grass/brassica and grass/legume), double and incorporated amendments have higher mean microarthropod count.

All treatments showed an increase in the overall mean microarthropod counts over the first three collection dates, before decreasing on 15/03/2022. The decrease can be attributed to March 2023's high rainfall (see appendix 17 for full report). All treatments except the nil and nematicide treatments then showed an increase followed by a decrease. Fluctuations in microarthropod population can be attributed to agronomic practices employed in the trial itself. For instance, tillage, application of chemicals as in pesticides, herbicides, nematicides and fertilisers (Winter et al 1990, Seymour 2006, Stirling 2016). Environmental factors such as temperature and rainfall (Winter et al 2006), acidity and Alkalinity of soil (measured as pH) also greatly influence population dynamics.

Nematode trapping fungi had significant effect of collection date ($p<0.001$). The proportion of NTF was highest on the first collection date. Mean proportion of plates with trapping decreases significantly over the first assessment before increasing and remaining reasonably stable. The interaction of treatment and collection date was significant (<0.001). The only sample with no significant difference was the collection on the 15-Mar-22. Only one plate has conidia. This collection date had high rainfall (see appendix 17 for full report).

When comparing treatments overtime, the only significant difference between the crops occurs for the double amendment on 14-Sep-21 and nematicide treatment on 29-Nov-22.

Outputs

1. Soil health Masterclass, grower updates and report.

Outcomes

The outcome of the biological monitoring as indicator as indicator for both trials (Intensive & Extensive) is that it increases grower knowledge on role of microarthropod and Nematode trapping fungi and their importance to soil health. It also increased grower knowledge on use of amendments and which amendments promotes soil health in a sweetpotato farming system (intensive and extensive)

Take home message/key findings

1. Cover cropping promotes buildup of microarthropod population and promotes NTF in the soil.
2. Organic matter and V furrow Amendments ass seen in this trial promotes soil health in terms of microarthropod population and NTF.
3. Agronomic practices such as application of pesticide, herbicide, fertilizer as well as well tillage affects microarthropod population and NTF

Intensive trial biological monitoring as an indicator of soil health

Introduction

Soil biota play major roles in the functioning of the soil and act as indicators of soil health. The two variables measured in the sustainable farming systems are: (1) Microarthropods (by count) & (2) Nematode Trapping Fungi (NTF) which is measured as presence of trapping (nematode is trapped by NTF) and presence of conidia. Conidia is produced by the *Arthrobotrys* species of nematode trapping fungi. Its presence is an indication of the presence of NTF as well as an identification key for the species of NTF present in the soil.

Methodology

Microarthropod extraction

Microarthropods were extracted using the Tullgren Funnel method. One hundred & twenty grams (120g) of soil from each plot (randomly sampled) was placed in a funnel attached to a collection tube containing 70% alcohol. Heat produced from lighting suspended in the Tullgren cabinet forced microarthropods to escape through the funnel. These microarthropods are trapped in the collection tubes containing 70% alcohol. The tubes are collected after 4-6 days and microarthropods counted under the microscope.

Image 24(a) Preparing soil for Tullgren (b) 120 g of soil in funnels with collection tubes attached (c) microarthropods under the microscope.

Identification of Nematode Trapping Fungi

To determine the nematode trapping fungi, 1g of soil from each plot is plated on quarter (1/4) strength cornmeal agar (CMA), incubated for 2-4 weeks to allow for fungal growth. The petri dish is observed under a bottom lit microscope. The two variables observed were trapping (actual trapping of nematodes by NTF) and the presence of conidia.

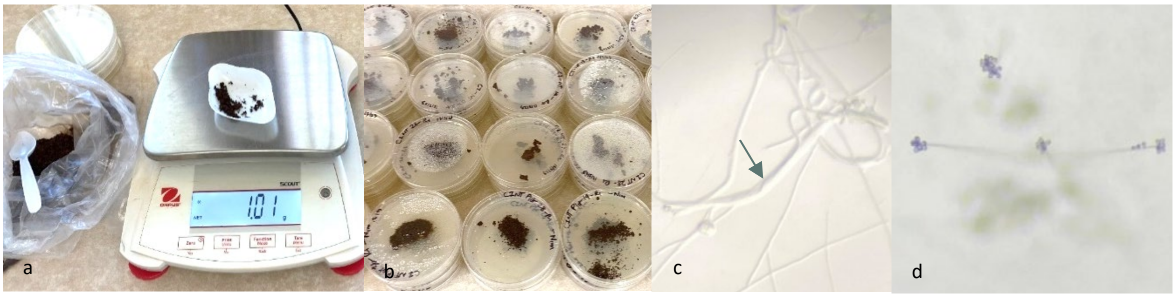


Image 25 (a) plating 1gm soil on ¼ strength CMA (b) incubating soil (c) trapped nematode (d) conidia under microscope.

The number of microarthropods per plot was counted. Count data for Nematode Trapping Fungi was based on presence and absence of trapping (actual trapping of nematode by NTF) & absence and presence of conidia. All data collected was analysed by the DAF biometrician. The counts of microarthropods were analysed using GLM/M and ANOVA and results for the model with the most appropriate fit is reported. All significance testing was performed at the 0.05 level and where a significant effect was found, the 95% least significant difference (lsd) was used to make pairwise comparisons.

Results & Discussion

Microarthropods

Microarthropods and Nematode trapping fungi data reported in detail in Appendix 17. Statistical analysis using GLM/M and ANOVA showed a significant effect of collection date ($p<0.001$) and a significant effect of treatment ($p<0.001$). Pairwise comparisons using the 95% lsd suggest that mean microarthropods per plot fluctuate over time. The highest mean was recorded on the second collection date (4-Feb-2021) (figure 1) after which it declined but increased slightly on 6-Jun 2022 before declining again in later assessments. The rise of microarthropod counts can be attributed to the build-up of litter from earlier amendments before the first commercial planting. After harvest, the block was planted with a rotation crop (White French millet/Jumbo sorghum) followed by another application of amendments before the second planting. The slight increase on the 6-Jun-22 was during a period of rotation crop. Findings by Winter et al 1990 confirmed increased microarthropods when bromegrass was planted for 3-4 years following 15 years of conventional tillage. Stirling et al 2020 reported increase in biological community with rotation crop and amendments in sweetpotato farming system. The decline on the later assessments may be attributed to high rainfall.

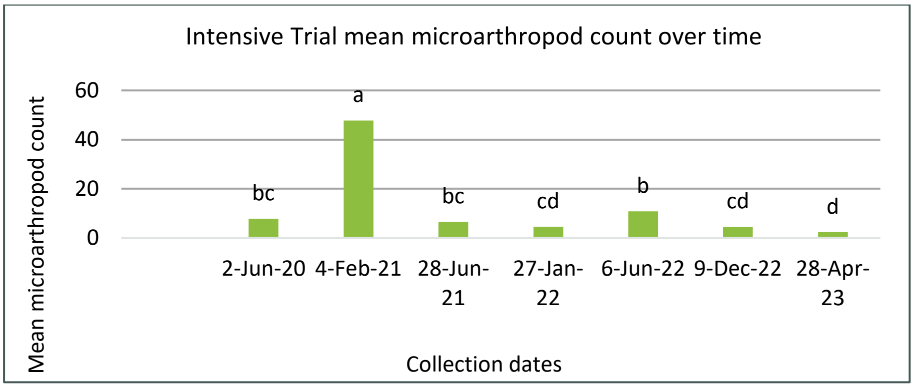


Figure 23 the mean microarthropod count at each collection date.

The organic matter treatments had a significantly higher mean microarthropod count than all other treatments followed by V Furrow amendment, which was significantly better than the nematicide treatment but not the compost and nil treatments. Microarthropods are decomposers of organic material, therefore the organic matter amendment provides a rich food source for them resulting in higher populations (Kautz 2006).

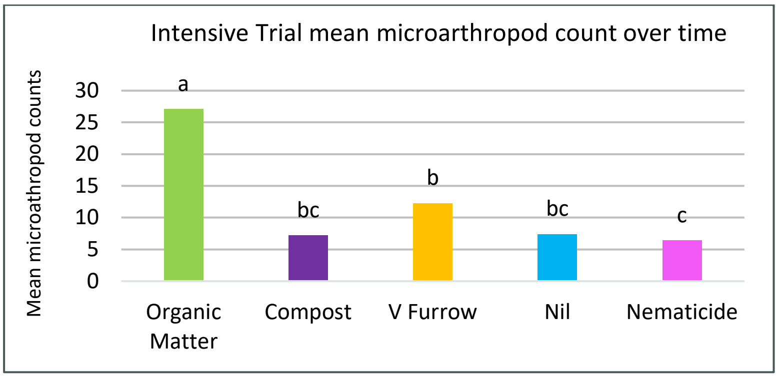


Figure 24 Mean microarthropod count per treatment over time.

Nematode Trapping Fungi

Trapping & Conidia

Data was collected on seven occasions. Count data for Nematode Trapping Fungi was based on presence of trapping (actual trapping of nematode by NTF) and conidia. The resulting main effects model found a significant effect of collection date ($p<0.001$). Pairwise comparisons using the 95% lsd shows the mean proportion of plates with NTF decreases significantly after the first assessment. Mean proportion of plates with NTF is high for preharvest assessments (02-June-20, 28-Jun-21). The high proportion reading for 02-Jun-20 may be attributed to a build-up of plant litter and organic matter in the soil prior to first planting, an environment favorable for NTF to be prevalent. However, the decline in preplant (04-Feb-21 & 27-Jan-22) may be related to tillage or environmental factors such as rainfall, heat as well as agronomic practices such pesticide and herbicide application. NTF proportions increased again on 09-Dec-22 at preplant and reasonably high on 28-Apr-23 (pre-harvest) after a period of rotation crop.

Presence of conidia was significant for collection date ($p<0.001$). Mean proportions of plates with conidia present is higher at the first (2-Jun-20) and the last two (9-Dec-22 & 28-Apr-23) collection dates. A similar pattern to NTF the trapping as conidia is produced by NTF (Arthrobotrys spp). The decline in mean proportions on 4/02/2021 to 6/06/2021 may be a resulting effect of agronomic practices such as tillage and herbicide application.

Table 42 Mean proportions of NTF and conidia.

Collection date	Cropping stage	Mean of NTF	Mean of Conidia
02-Jun-20	Pre-harvest	0.240 bc	0.324 b
04-Feb-21	Pre-plant	0.020 d	0.042 c
28-Jun-21	Pre-harvest	0.190 c	0.117 c
27-Jan-22	Pre-plant	0.120 cd	0.050 c
06-Jun-22	Rotation crop	0.110 cd	0.097 c
09-Dec-22	Pre-plant	0.493 a	0.774 a
28-Apr-23	Pre-harvest	0.360 ab	0.372 b

Extensive Trial – biological monitoring as an indicator of soil health

Introduction

Soil biota play a major role in the functioning of the soil and act as indicators of soil health. The two variables measured in the sustainable farming systems are: (1) Microarthropods (by count) & (2) Nematode Trapping Fungi (NTF) which is measured as presence of trapping (nematode is actually trapped by the hyphae of NTF) and presence of conidia. Conidia is produced by the Arthrobotrys species of nematode trapping fungi. Its presence is an indication of the presence of NTF as well as an identification key for the species of NTF present in the soil.

Methodology

Microarthropod extraction

Soil samples were collected on six occasions: At pre planting and pre-harvest stages of the sweetpotato crop and during a rotation or cover crop. Microarthropods counts were collected harvested from 120 grams of soil randomly collected from each plot and placed in the Tullgren funnel as previously described.

Nematode Trapping Fungi

To determine the nematode trapping fungi, 1 gm of soil from each plot is plated on quarter (1/4) strength cornmeal agar (CMA), incubated for 2-4 weeks to allow for fungal growth. The petri dish was observed under a bottom lit microscope. The two variables observed were trapping (actual trapping of nematodes by NTF) and the presence of conidia.

Results and Discussion

Microarthropods

Mean microarthropod counts increased significantly over the first three collection dates before fluctuating over the rest of the collection dates (see Appendix 17). Increase was more apparent for the double and incorporated amendments. The increase can be attributed to agronomic practices implemented prior to the first collection date. Amendments have been applied to double and incorporated treatment plots prior to the first planting of the commercial sweetpotato crop. The trial was also planted with a cover crop (White French Millet followed by Soybean A6785 and Nemsol). Amendments were then applied to the V furrows and double amendments before the first commercial planting. The soil had a build-up of plant litter and organic matter.

Table 43 Means for microarthropods overtime.

Date collected	Means	
2-Jun-2020	4.24	d
15-Feb-2021	11.12	b
14-Sep-2021	18.21	a
15-03-2022	5.55	cd
29-Nov-22	10.65	b
17-Apr-23	6.58	c

Within treatment crops (grass/brassica and grass/legume), the only significant difference was with nematicide and nil amendments of the grass/brassica treatments (figure 1) which have lower means than double and incorporated amendments.

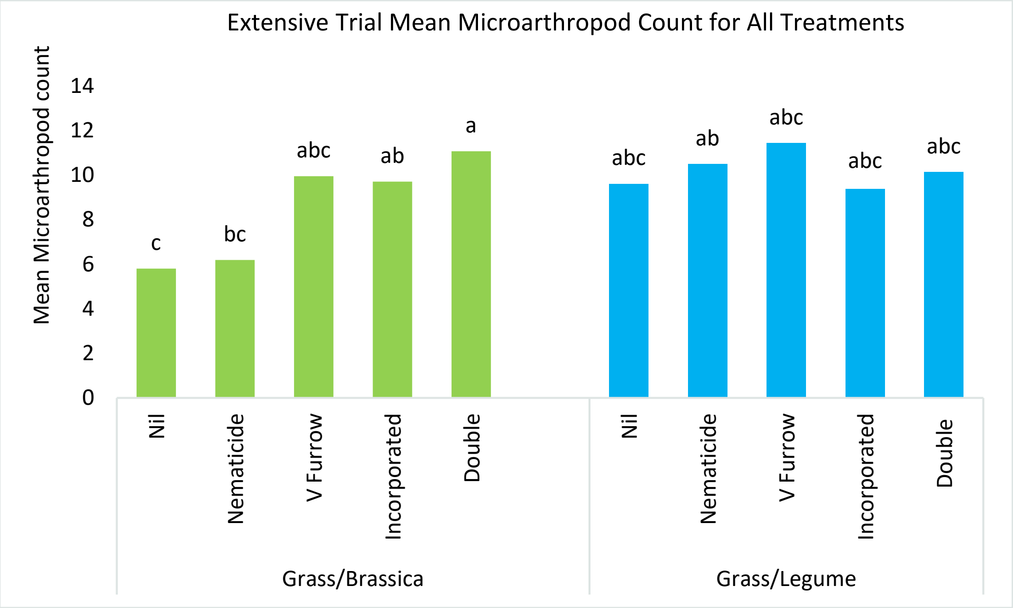


Figure 25 Graph of microarthropod means for treatment crops. No significant difference within Grass/Legume crop except for Nil & Nematicide in Grass Brassica treatment crop.

Table 44 Mean microarthropod count within each amendment over time. Letters of significance relate only to the column.

Date Collected	02-Jun-20	15-Feb-21	14-Sep-21	15-Mar-22	29-Nov-22	17-Apr-22
Double Amendment	4.40 ab	13.07 a	22.79 ab	5.30 ab	11.25 ab	8.33 ab
Incorporated	1.84 b	15.28 a	16.11 ab	4.21ab	18.16a	5.06 ab
Nematicide	3.08 b	8.46 a	27.71 a	4.97 ab	7.96 b	3.86 b
Nil	2.70 b	7.53a	11.94 b	8.93 a	7.30 b	5.49 ab
V Furrow	9.81 a	11.40 a	11.63 b	3.56 b	8.69 ab	10.72 a

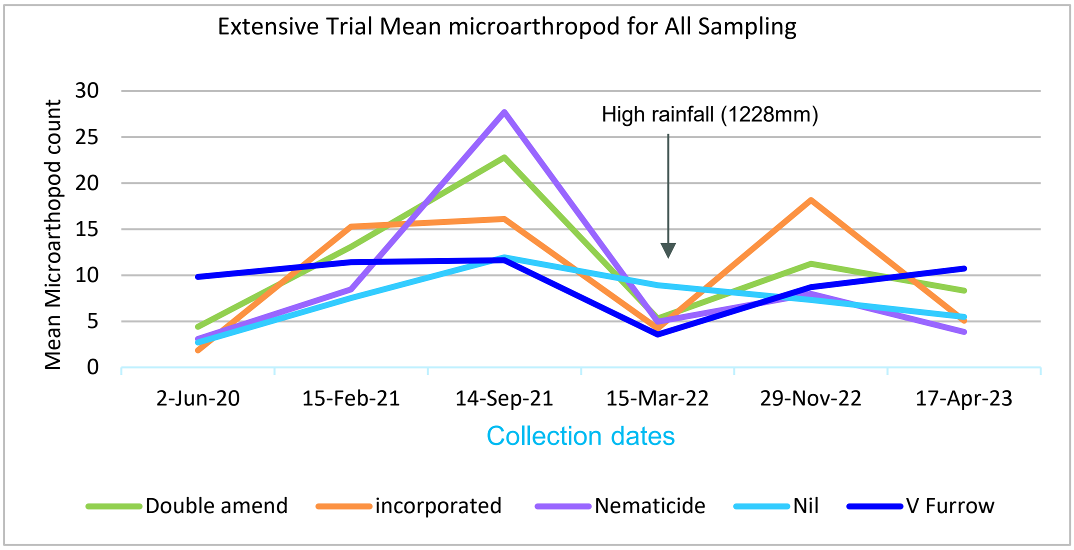


Figure 26 Graph of mean microarthropod count in each treatment over time.

All amendments showed an increase in the overall mean microarthropod counts over the first three collection dates, before decreasing on 15/03/2022. The decrease can be attributed to March 2023's high rainfall. All amendments except the nil and nematicide treatments then showed an increase followed by a decrease.

Microarthropod populations in the amendment treatments fluctuated. This is proven to be affected by agronomic practices such tillage, application of chemicals (as in pesticides, nematicides and even fertilisers) (Winter et al 1990, Seymour 2006, Stirling 2016). Population fluctuations can be caused by environmental factors such as temperature and rainfall (Winter et al 2006), acidity and alkalinity of soil (measured as pH) Figure 3 presents an observation on mean microarthropod versus pH. Microarthropod population is inversely proportion to pH for different treatments. As pH increases, microarthropod populations decreased and vice versa.

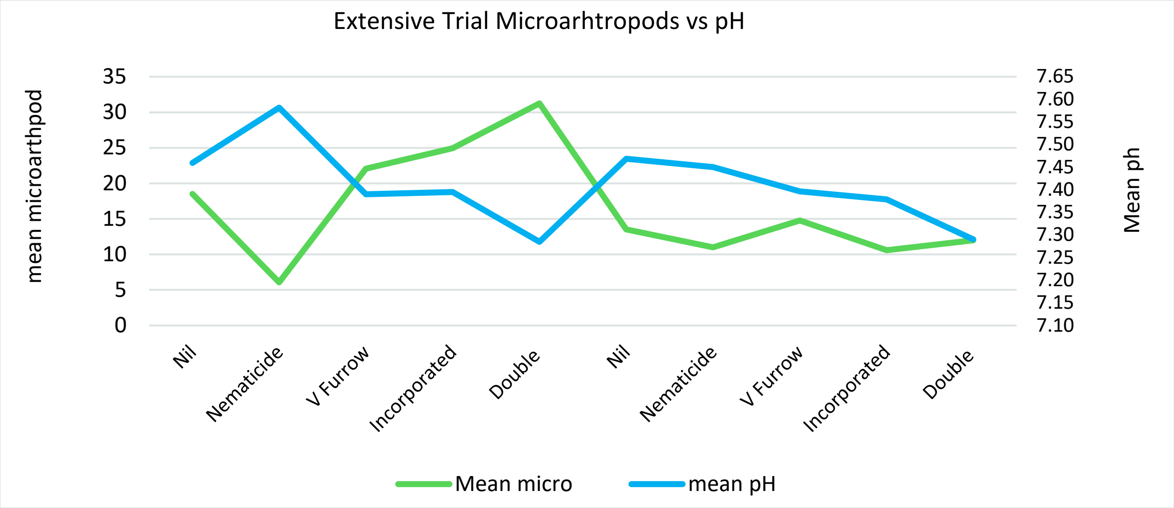


Figure 27 Graph of microarthropod vs pH for all treatments

Nematode trapping fungi

There was a significant effect of collection date ($p<0.001$) for NTF. The proportion of NTF was highest on the first collection date (01-Jun-20). The mean proportion of plates with trapping decreases significantly over the first assessment before increasing and remaining reasonably stable.

Table 45 Mean proportion for NTF for all collection date.

Date collected	Means	
1-Jun-2020	0.273	a
15-Feb-2021	0.000	d
14-Sep-2021	0.101	bc
15-Mar-2022	0.075	c
29-Nov-2022	0.131	bc
17-Apr-2023	0.159	b

The interaction of treatment and collection date was significant (<0.001). Table 6 presents a comparison between treatments within a date. The only sample with no significant difference was the collection on the 15-Mar-22. Only one plate has conidia. This could be attributed to high rainfall. Application of chemicals (herbicide, pesticide, nematicide and even fertilizer affects soil biology populations (Winter et al 1990, Seymour 2006, Stirling 2016).

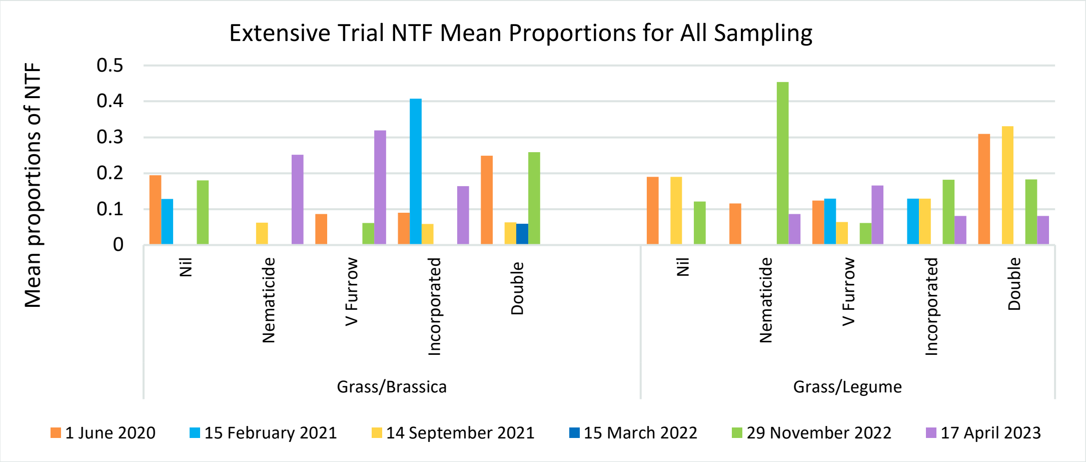


Figure 28 Graph of mean proportion of NTF for all sampling dates.

When comparing treatments overtime, the only significant difference between the crops occurs for the double amendment on 14-Sep-21 and nematicide treatment on 29-Nov-22.

Appendix 18.

Sustainable farming systems trials - Commercial crop yield and quality

Sustainable farming systems trials - Crop yield and quality

Final report PW17001 Integrated pest management of nematodes in sweetpotato

Sandra Dennien, Brett Day and Rach Langenbaker August 2023

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

Hort Innovation SWEETPOTATO FUND

This project has been funded by Hort Innovation using the sweetpotato research and development levy and funds from the Australian Government. For more information on the fund and strategic levy investment visit horticulture.com.au

Queensland Government

Summary

Two long-term field trials were conducted over the life of the project to test the feasibility of using integrated management options to minimise losses caused by Root-knot nematode (RKN) and potentially other plant-parasitic nematodes and improve soil biological health.

The Intensive trial, or Integrated nematode management long term trial following conventional sweetpotato best practice with relatively high rates of organic amendments at bed formation.

The Extensive trial or Sustainable farming systems long term trial. incorporating minimum tillage (pre-formed beds) with organic amendments and crop rotations of grasses, legumes and brassicas.

longer term trials were required for these investigations as improvements in soil biological health may not be seen immediately. Management practices included in the trials were:

- The use of diverse (largely root-knot resistant) rotation crops including legumes and inputs of organic matter from these crops.
- Application of organic amendments
- Minimum tillage and controlled traffic

A number of parameters were monitored throughout the life of the trial including populations of plant parasitic and free-living nematodes, microarthropods and nematode trapping fungi, as well as soil physical and chemical properties. Crop assessment parameters included yield, nematode damage and root defects.

Sustainable farming systems trials - Commercial crop yield and quality

Introduction

Research results (summarised by Stirling, 2014) have shown organic matter amendments are an effective strategy to improve a soil's nematode suppressiveness. Hay and Stirling (2014) and Stirling (2013) describe the value of integrated nematode management programs using crop rotations, organic amendments, minimum tillage and organic mulching farming systems. Composts are widely used (Thoden et al., 2011) and materials such as poultry manure, sugarcane trash, sawdust and mill mud have been effective in sugarcane soils (Stirling et al., 2003). These amendments provide benefits such as increased biological nutrient cycling, a source of nutrients for the crop and improved soil physical, chemical and biological fertility. Research findings on other crops need to be trialed and verified in the sweetpotato farming system given the sweetpotato plants responsiveness (positive or negative) to changes in physical and soil nutritional parameters.

Two long-term field trials were conducted over the life of the project to test the feasibility of using integrated management options to minimise losses caused by root-knot nematode (and potentially other plant-parasitic nematodes) and improve soil biological health.

The trials ran from November 2018 to June 2023. Longer term trials were required for these investigations as improvements in soil biological health may not be seen immediately. Management practices included in the trials were; The use of diverse, largely RKN resistant rotation crops including legumes and inputs of organic matter from these crops. Application of organic amendments. Minimum tillage and controlled traffic.

The Intensive trial or Integrated nematode management long term trial was conducted at Bundaberg Research Facility to assess the nematode control and soil health benefits provided by relatively high rates of organic amendments applied just prior to bed formation and planting. The intensive trial was designed to be similar to conventional best practice currently used by most sweetpotato growers. The trial incorporated five treatments, five replicates and four commercial crops from November 2018 to June 2023. A forage sorghum rotation was utilised in all plots between sweetpotato crops. Nematicide treatments (Nimitz-Fluensulfone) were included to determine if the organic amendments approach reduced RKN populations to an extent that a nematicide was no longer necessary.

The Extensive trial or Sustainable farming systems long term trial was also established at Bundaberg Research Facility to assess the nematode control and soil health benefits provided by farming systems that incorporate minimum tillage (pre-formed beds) as well as crop rotation and organic amendments. The extensive trial was more experimental than the intensive trial in its design with the use of pre-formed beds. The trial incorporated ten treatments including a nematicide treatment using Vydate (oxamyl), four replicates and three commercial crops in the five-year period.

Image 26. Aerial view of the Long term trials at Bundaberg Research Facility

Intensive trial - Integrated nematode management

A field trial was conducted at Bundaberg Research Facility to assess the nematode control and soil health benefits provided by relatively high rates of organic amendments applied just prior to bed formation and planting. Combinations of RKN resistant rotation crops and organic matter/compost amendments incorporated at bed formation or in a furrow prior to planting vs Nimitz vs no amendment. The intensive trial was designed to be similar to conventional best practice currently used by most sweetpotato growers. Amendments were chosen due to their availability and accessibility to growers in Bundaberg, poultry manure, sugarcane trash, sawdust and compost.

Materials and methods

The Intensive trial was established in November 2018 and ran until June 2023 when the fourth commercial crop was harvested. The trial incorporated five treatments and five replicates laid out as a randomised complete block (Table 1). Due to limited available land, one buffer row was installed at each end of the trial and a two-meter area at the end of each row was designated as buffer zone, leaving a 10m length of datum plants (50 plants).

Two rotation crops were chosen due to their high resistance ratings to RKN. Forage sorghum variety Jumbo was (used in spring and summer) and White french millet (used in autumn and winter). The nematicide treatment used Nimitz (Fluensulfone) to determine if the organic amendment approach reduced RKN populations to an extent that a nematicide was no longer necessary.

Table 46. Treatments in the intensive trial

Treatment	Amendment	Application method
Treatment A	Organic Matter	A band of sawdust + chicken manure applied to the centre of the bed
Treatment B	Compost	A band of compost applied to the centre of the bed
Treatment C	V-furrow	Compost applied in a V-shaped furrow
Treatment D	Nil	No treatment control
Treatment E	Nematicide	Nimitz (Fluensulfone)

RKN inoculation

To promote a uniform high RKN population across the trial block, a sacrificial sweetpotato crop (cv. Beauregard) was planted on the 22 November 2018. The RKN species Meloidogyne javanica, commonly detected in Bundaberg, was then introduced via transplanted infested tomato seedlings. Over 1000 Tiny Tim tomato seedlings were earlier propagated at Gatton Research Facility (GRF) and inoculated with root-knot nematode M. javanica. Over 800 inoculated tomato plants were then planted in between each of the sweetpotato cuttings. Inoculation bombs were made by cutting up the remaining M. javanica infested tomato roots and mixing them with 41 litres of washed sand. 50ml of the root/sand mix was then buried adjacent to each sweet potato plant.

The sacrificial sweetpotato crop was harvested in May 2019 and block was rotary hoed. Remaining crop material (potential volunteers) were removed mechanically and by hand. Soil samples were collected from each row (rows were also plots) previously marked with a tractor using GPS. The resultant nematode counts indicated that were was an even distribution of RKN across the block with an average count of 600 RKN juveniles per 200 grams of dry soil.

Rotation crops

The rotation component of the trial commenced on 27 May 2019 with sowing of White French Millet at rate of 40 kg/ha, (Table 2). At the conclusion of the millet rotation in August 2019, soil was again sampled from each plot for nematode analysis. The millet crop was then sprayed off and the block planted to Jumbo sorghum on September 3, 2019. A double rate was used to ensure good ground coverage and suppression of weeds and volunteers. The sorghum crop was sprayed out in December 2019 (Image 2), then mulched and incorporated using a rotary hoe. A Preplant soil samples were collected from each of the 25 rows on the 14 January 2020.

Details are listed in Table 1.

Image 27.Left to right, the intensive trial block was seeded with Jumbo Sorghum which was sprayed off prior to preparation for planting.

Table 47. Intensive trial treatments and application dates

Date	**Organic matter amendment** Incorporated and beds formed	**Compost amendment** Incorporated and beds formed	**V-furrow amendment** V furrow added after bed forming, prior to planting	**Nematicide treatment** Nimitz spray 8L/Ha, incorporated 7 days prior to planting as per label rate.	**Nil / control** No amendments or nematicides
21 Nov 18	Nematode inoculation to increase populations, sacrificial sweetpotato crop planted				
27 May 19	White french Millet				
3 Sep 19	Jumbo Sorghum				
14 Jan 2020	Poultry manure 22.4kg/row + Sawdust 33.6kg = 56kg/row. 40/60 blend	Compost 56kg/row	Compost 76L or 42.5kg/row	Nimitz applied before bed forming	No amendments or nematicides
20 Jan 20	Planted sweetpotato crop 1 cv. Beauregard				
8 Jun 20	Harvest and assess sweetpotatoes (140 DAP)				
29 Jun 20	White french millet				
20 Oct 20	Jumbo Sorghum				
19 Jan 21	Poultry manure 22.4kg/row + Sawdust 33.6kg = 56kg row. 40/60 blend.	Compost 56kg / row	Compost 42.5kg/row	Nimitz applied before bed forming	No amendments or nematicides
29 Jan 21	Planted sweetpotato crop 2 cv. Beauregard				
30 Jun 21	Harvest and assess sweetpotatoes (152 DAP)				
7 July 21	White french millet				
16 Sept 21	Jumbo Sorghum				
27 Jan 22	Poultry manure 22.4kg/row + Sawdust 33.6kg = 56kg row. 40/60 blend	Compost 56kg / row	Compost 42.5kg/row	Nimitz applied before bed forming	No amendments or nematicides
11 Feb 22	Planted sweetpotato crop 3 cv. Beauregard				
13 Jun 22	Harvest and assess sweetpotatoes (122 DAP)				
5 Jul 22	White french millet@ 40kg/Ha				
23 Aug 22	Jumbo sorghum @ 9.6Kg				
12 Dec 22	Poultry manure 22.4kg/row + Sawdust 33.6kg = 56kg/row. 40/60 blend	Compost @ 56Kg/ row	Compost 42.5kg/row	Nimitz applied before bed forming	No amendments or nematicides
15 Dec 22	Plant sweetpotato crop 4 cv. Beauregard				
8 May 23	Harvest and assess sweetpotatoes (145 DAP)				

Soil Monitoring

Soil samples were collected at critical points in the trials, such as pre plant, post-harvest and post rotation crops. Samples were sent to the project team nematologists for nematode extraction (Appendix 2 and 15), to the Department of Environment and Science (DES) for soil chemical and physical analysis (Appendix 16) and to GRF for extraction of soil biologicals (Appendix 17), microarthropods and Nematode trapping fungi (NTF). Results from these samples will allow investigation into correlation between soil characteristics, RKN populations and soil biology.

Amendments

Prior to bed formation a basal fertiliser was applied, following grower practice. PRG discussions resulted in the decision not to apply any preplant soil insect chemicals (as per current grower practice), so as not to interfere with biological soil populations at this stage. After rotary hoeing, the organic amendments were applied to the Organic matter and Compost treatments. Rates for banded amendments were based on those used in previous field trials demonstrating suppression of plant-parasitic nematodes; 56 kg/14m row or plot, is equivalent to 50 t/ha. The Organic matter amendments combined 22.4 kg/row of poultry manure plus 33.6 kg/row of sawdust (40/60 blend), providing a total of 56 kg of amendment per row (Table 2). The Compost plots were treated with 56 kg of compost per row. Amendments were hand placed on top of the rows in a 40 cm wide central band (based on GPS tracking) using buckets (image 3).

The amendments were incorporated during the bed forming process. The nematicide Nimitz was applied as per label rate at 8 L/Ha to the appropriate plots and incorporated during bed forming. The V furrow treatments were applied by opening a furrow on top of the respective beds with a double disc opener. Compost at the rate of 76 L or 42.5 kg/row applied directly into the ‘V’ shaped furrow on top of the formed beds. The furrows were then closed by shovel, using loose soil created during the furrow opening process. It is hypothesised that newly developed roots will potentially be protected from nematode attack due to increased suppressive activity in this zone enriched with organic matter.

Image 28. Amendments were weighed out and applied to the field by hand along the respective rows located by GPS.

Planting the commercial crop

The Intensive was planted with standardised hi spec vine tip cuttings (image 4), cultivar Beauregard at 20 cm plant spacing on the 20th of January 2020 (image 5). 2 January 2021, 11 February 2022 and 15 December 2022 (Table 2).

Image 29. Left to right, sweetpotato plant growth in the intensive trial. In 2020.

Image 30.the Intensive trial in 2023.

Trial maintenance

A maintenance schedule was developed for the trial blocks in conjunction with the PRG, following best practice. Regular soil and leaf tissue samples were collected for laboratory analysis to monitor critical nutrients such as nitrate analysis. Scheduled fertiliser applications were made based on the results of the analysis (image 6). Crop maintenance included irrigation scheduling, scuffling along with regular weeding until row closure. DAF designed weevil traps (VG 09052) containing pheromone attractant for sweetpotato weevil (Cylas formicarius) were installed at each corner of the block. Regular insecticide applications were carried out during the growth period based on weekly pest and disease monitoring. Selected Herbicides were used for in furrow grass control.

In 2021, sweetpotato weevil were a problem, with weekly pheromone traps collecting in excess of 200 weevils, despite regular chemical applications. Upon investigation, it was discovered that the spray equipment at Bundaberg Research Facility did not provide the coverage required for weevil control. A local grower then kindly provided machinery and an operator to ensure correct chemical application. Weekly weevil numbers in pheromone traps subsequently dropped to < 10 weevils.

Image 31. Left, Rachael Langenbaker (Bundaberg Research Facility),applying fertiliser to the sorghum cover crop. Right irrigation was applied to cover crops to ensure optimal growth.

Harvest

In Bundaberg, sweetpotatoes planted in January usually take 150 days to reach maturity. To monitor growth, three plants were dug up from the buffer rows at around 90 and 120 days after planting, to monitor root development. Prior to the harvest, the 2m buffer zones on the end of each row were hand dug and roots were removed. Rows were top chopped (pulversied) to remove the foliage and roots were left to harden for 3 weeks to prevent skinning during harvest. A potato harvester was used to lift the sweetpotato roots to the surface where they were manually hand-picked into hessian bags and placed into plastic half ton bins (image 7). Roots were freighted overnight to Gatton Research Facility (GRF) for assessment.

Image 32. Left rows were top chopped and roots were harvested.

Assessment

Harvested roots were washed in a chlorine solution using a standard butternut pumpkin washer. Once washed, roots were then sorted into eight size categories based on commercial packing sizes: extra-small, small, small-medium, medium, medium-large, large and jumbo (table 2). Roots were then graded based on marketability: first or premium grade, second grade and non-marketable (table 3). Root number and root weight were recorded in each plot.

Table 48. Shape and size grading for classifying sweetpotatoes.

Size	Weight gms	Length mm	Diameter mm
Extra small	60-150	100-180	25-50
Small	150-230	130--220	35-50
Small medium	230-350	200-300	35-50
Medium	350-550	180--300	45-70
Medium large	550-700	230-300	65-85
Large	700-1200	>300	70-90
Jumbo	>1200	>300	>90

Table 49. Quality grading for classifying sweetpotatoes.

Marketable roots	
Premium grade	Smooth skin, even elliptic shape, free from damage and defects.
Second grade	Smooth skin, slightly irregular shape or **one** of the following: shallow constriction, bump, bend, small (healed) growth crack or one area of slight damage.
Nonmarketable roots	
Too small	under 150g, 120mm or 40mm diameter
Defects	Irregular, uneven shape, constrictions, growth cracks, longitudinal grooves, alligator skin, veins
Damaged	Pests, mechanical
Long and thin	Long and thin roots

Raised pimples are commonly associated with RKN infection, however it is unknown if other skin lesions such as black pimples, are related to nematode infection, either directly or indirectly and what effects if any, the organic treatments may have on sweetpotato skin quality and incidence of soil insect damage. The teams 20 years of trial work and commercial sweetpotato production has led to the identification of 26 types of skin defects. A damage characterisation system was designed for the harvest assessments to capture skin lesions and defects and identify any possible associations (table 4, image 8).. Each root underwent close visual scrutiny and all lesions and defects were recorded. At the fourth harvest a severity rating system (high, medium or low) was incorporated. A large amount of data was collected at each yield and quality assessment. This was sent to a DAF biometrician for a complete analysis. Just under 25,000 roots were individually weighed and assessed over the four crops to determine yield and quality.

Table 50. Skin lesions and defects recorded during harvest assessments.

Categories	Lesions and defects recorded
Nematode related damage	Raised pimples, Black pimples, Nematode cracks, Barnacles.
Insect damage	Wire worm (*Agrypnus spp*.- true wireworm, *Pterohelaeus spp*., *Gonocephalum spp*. - false wireworm), White grub (various species), Sweetpotato weevil (*Cylas formicarius),* Flea beetle (various species), Symphylans (various species).
Breakdown (Bacterial and Fungal)	Soil Pox (*Streptomyces ipomoeae*), Geotrichum sour rot (*Geotrichum candidum*), Circular spot (*Sclerotium rolfsii*), Collar rot or mottle necrosis (xxxx), Other rots and breakdown.
Lenticel changes	Elongated lenticels, DLSR, Sunken lenticels.

Physiological defects	Misshapen, Veining, Longitudinal grooves, Constrictions, Concertina effects, Chimeras.
Physical defects	Sunburn, Broken, Animal damage,

Image 33 A range of skin lesions were recorded including nematode related damage, insect and animal damage., bacterial and fungal infections and physical defects.

Subsequent harvests

After harvest, the site was raked and deep ripped, to remove any visible sweetpotato material (vines or roots). The block was again sown with White french millet and the process was repeated as detailed in Table 2. Subsequent harvests were conducted in June 2021, June 2022 and May 2023.

Results and Discussion

Environmental factors

Bundaberg experienced higher than average rainfall events during 2021 and 2022.Rainfall data for Bundaberg from the Bureau of Meteorology is listed below. Darins were constructed at the sides of the trial block to allow water in flooded furrows to drain away.

Table 51. Rainfall during the 5 month growing period preceding crop harvest

Annual rainfall in Bundaberg 2018 to date	
Intensive Trial	rainfall (mms)

2018	743
2019	334
2020	654
2021	931
2022	1280
2023 to date	417

Image 34.Left and right, intermittent flooding in the long-term trial.

Each root underwent close visual scrutiny and all lesions and defects were recorded. After the 2020 harvest, several defects were consolidated into groups due to low incidence. For example, where all rots such as soil pox, Geotrichum. sour rot and circular spot which were previously recorded individually were recorded under the general defect of "rot". Misshapen, veins, longitudinal grooves and constriction were classified as "physiological defects". Animal damage, broken, sunburn and growth cracks were recorded as general physical defects. However, due to increased rainfall in 2021, and increased incidence of rots lesions and defects were recorded individually in 2022 and 2023. At the fourth harvest in 2023, a severity rating system (high, medium or low) was incorporated. Just under 25,000 roots were individually weighed and assessed over the four crops to determine yield and quality.

DAF biometricians Bill Mayer and Carole Wright conducted data analysis using a range of fir for purpose statistical methods. In 2023, Root weight was mostly analysed using analysis of variance (ANOVA)., Root numbers were analysed using a generalised linear model with a Poisson distribution and a log link. Incidence data has been analysed using a generalised linear model with a Binomial distribution and complementary log-log link. Terms fitted in the models were replicate + treatment. Results were reported as a percentage of non-marketable roots in that size class. Means, standard errors (se) and average 95% least significant differences are presented. Significance testing was performed at the 0.05 level. The 95% lsd is used to make pairwise comparisons where a significant effect is detected.

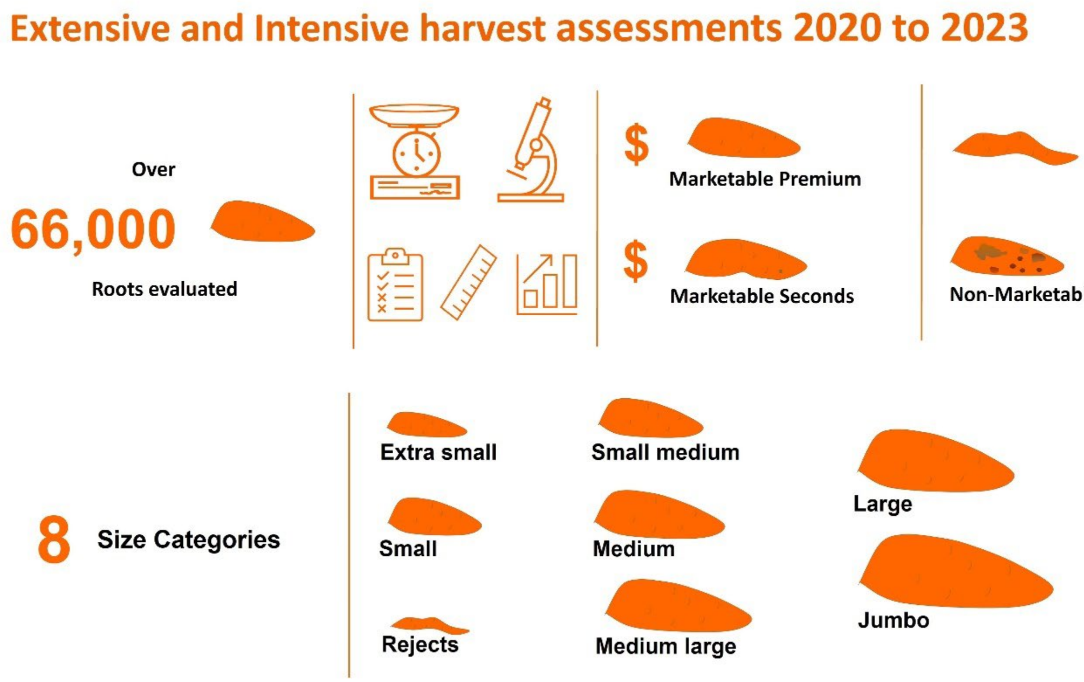


Image 35. Root grades and marketability.

Root weights

At the first harvest in 2020 the Organic matter treated plots produced a significantly higher weight of marketable roots than all other treatments (Figure 1). The Nil treatment plots produced the lowest weight of marketable roots. At the second harvest in 2021. The Nimitz plots produced a significantly higher weight of marketable roots than the organic matter and V Furrow plots but not significantly different form the Nil, and compost treatments. By the third harvest in 2022, the Organic matter treated plots again produced a significantly higher weight of marketable roots than all other treatments. There were no significant differences between the Nil, Nimitz, Compost and V furrow plots. There were no significant differences in the weight of marketable roots produced in all treatments in the last harvest in 2024.There were no significant differences in the weight of non-marketable roots produced in all treatments in any of the harvests.

In summary the Organic matter treatment had statistically higher meant root weight in two of the four years and yielded well in the other two years. In only one year (2020) were the other treatments significantly better than the nil treatment.

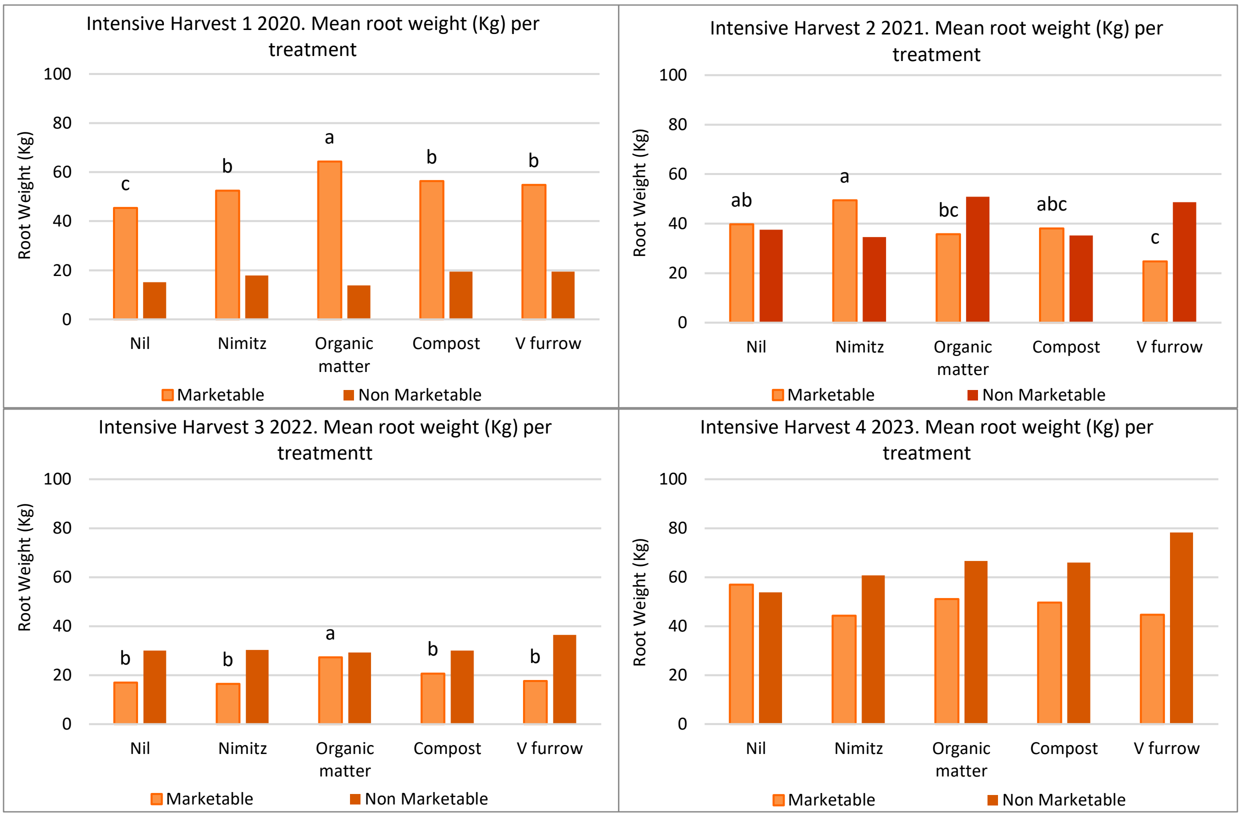
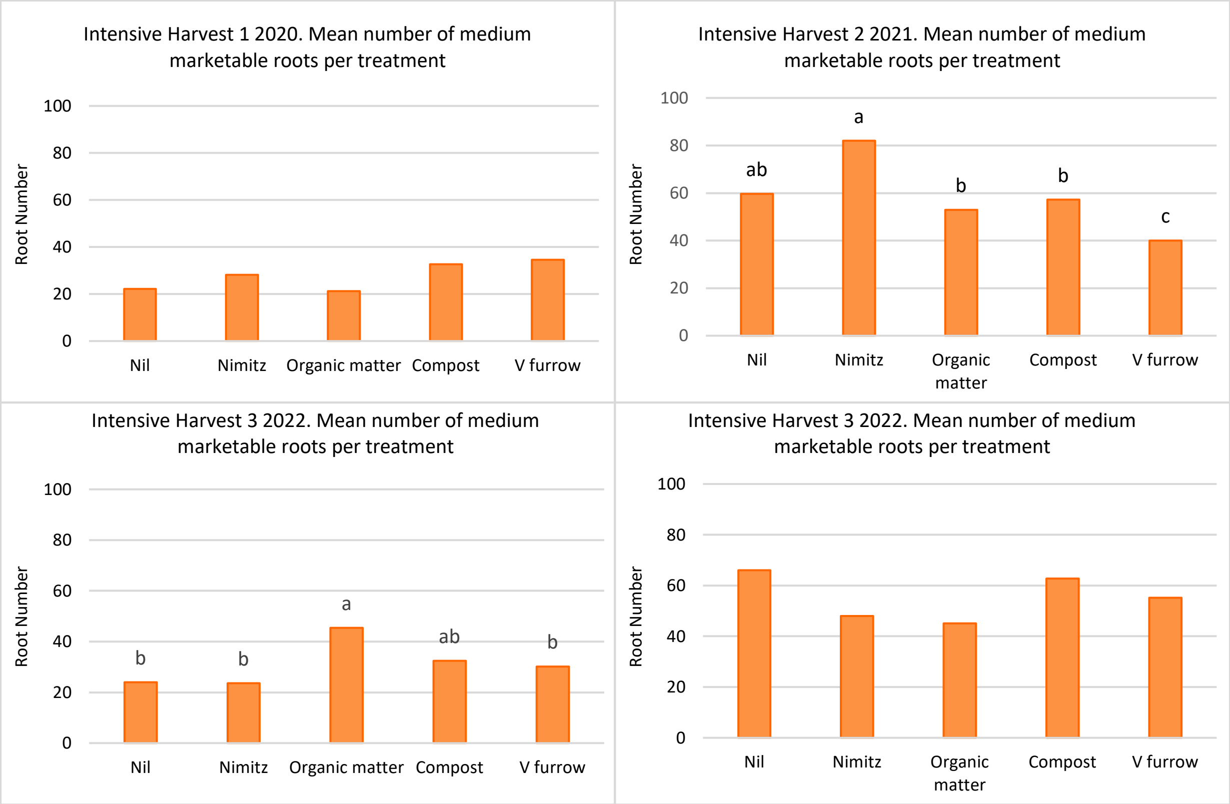


Figure 29. Intensive trial root weights across the four harvests, 2020 to 2023.

Root numbers

Analysed data from the first harvest in 2020 (figure 2), indicated that the Nil plots produced a significantly lower number of total medium roots than all other plots. The Organic matter and Compost plots produced a significantly higher number of total roots per plot, but this was not significantly different to the Nimitz, and V furrow plots. There was no significant difference in the mean number of marketable medium roots. The 2021 harvest Nimitz plots produced a significantly higher number of roots than the V furrow plots but this was not significantly higher than the Nil plots. By the third harvest, the organic matter plots produced a significantly higher number of roots than all other treatments except the Compost. The Compost numbers were not significantly different form the Nil, Nimitz, and V furrow lots. There were no significant differences in root numbers produced in 2023, though the Nil and Compost plots root numbers were higher.

Summarizing all years, plants in the Organic matter treatment produced a significantly higher number of medium marketable roots in one year (2022), as did plants in the Nimitz treatment (2021). Both treatments were similar to all others over the other years of the trial. The V furrow treatment produced good root number, although not statistically different in most years with the exception of 2021 when it produced a statistically lower number of roots.


Intensive Harvest 1 2020. Mean number of medium marketable roots per treatment

Intensive Harvest 2 2021. Mean number of medium marketable roots per treatment

Intensive Harvest 3 2022. Mean number of medium marketable roots per treatment

Intensive Harvest 3 2022. Mean number of medium marketable roots per treatment

Figure 30. Intensive trial root numbers across the four harvests, 2020 to 2023.

Nematode related lesions

Raised Pimples

In 2020 roots from the Organic matter treatment had significantly fewer raised pimples than Nil, Nimitz and V furrow treatments and a similar although lower percentage that the compost treatment (Figure 3) . A significantly higher percentage of raised pimples was recorded in roots form the V furrow treatments although this was not significantly different form the nil and nematicide treated plots. In 2021 the Nil treatment of small marketable, small non-marketable, all smalls, all marketable and all marketable + non-marketable roots category roots had a significantly higher mean of raised pimples comparted to the Compost, Nimitz, Organic matter and V furrow treatments. While there was no significant difference between Compost, Nimitz, Organic matter and V furrow, the Nimitz and Organic matter treatments tended have the lowest incidence of raised pimples across the categories. 2022 and saw no significant differences between any of the treatments. By 2023 the population of RKN had reduced dramatically and there were no raised pimples recorded form any treatments.

Although there a significant trend over the first two harvests in 2020 and 2021 between treatments and raised pimples, with lower levels of raised pimples in some size categories in the Organic amendment and Nimitz treatments, this trend did not continue in the last two harvests in 2022 and 2023.

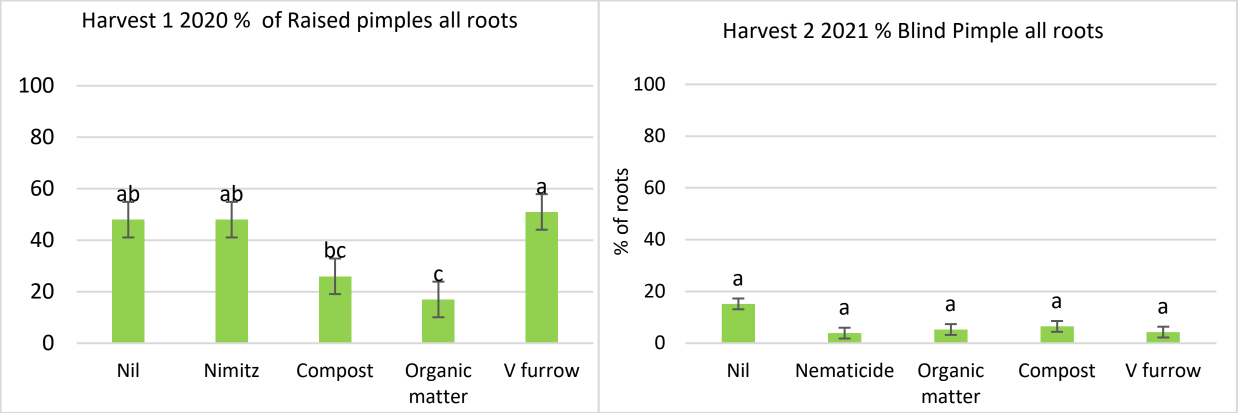


Figure 31 Intensive trial incidence of raised pimples per treatment in the First and second harvests.

Black Pimples

Organic matter treatment had the lowest level of Black pimples in 2020 non-marketable roots (figure 4). In 2021 the incidence of Black pimples in large unmarketable roots was lowest in the Organic matter treatment and highest in the Nil treatment although this was statistically similar to the Compost treatment. In the 2022 trial only medium roots showed any significant differences to level of Black pimples. The Organic matter treatment showed the lowest number of black pimples being similar to the V furrow treatment and significantly lower than the Nimitz, Compost and Nil treatments. The Nimitz treatment while similar to the Compost and V furrow treatments had significantly lower black pimples than the control treatment. There was a low incidence of Black pimples in 2023 and no differences were seen between treatments.

While treatment effects were only seen in a few root categories throughout the trial, the Organic matter treatment over all years had a lower level of black pimples.

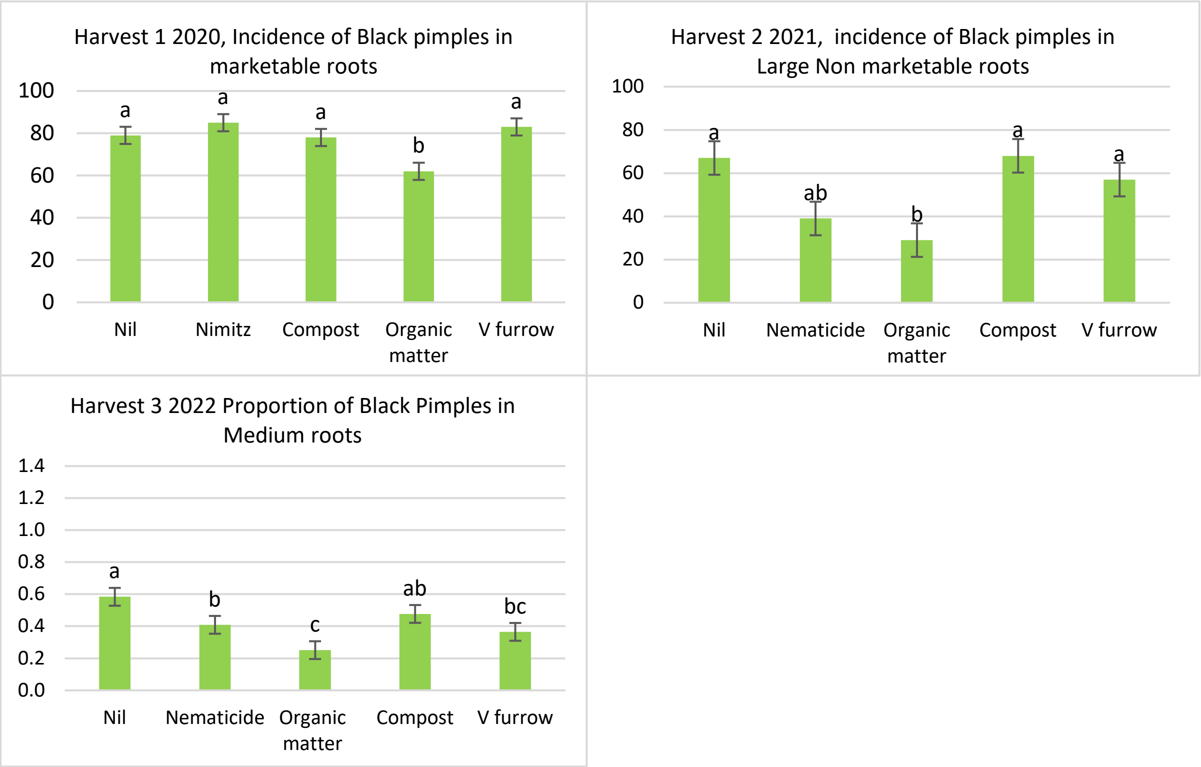


Figure 32. Incidence of black pimples in the intensive trial in 2020, 2021 and 2022.

Nematode cracks

There were few nematode cracks observed in 2020 and incidence decreased in subsequent harvests. There were no significant differences in incidence over the four harvests.

Barnacles

There were no significant differences in the incidence of Barnacles in 2020, 2021 and 2023. However, in 2022, small sized and total roots (small + medium + large) grown in the Organic matter plots had a significantly lower incidence of Barnacles than all other treatments but was not significantly different to the Compost treatment.

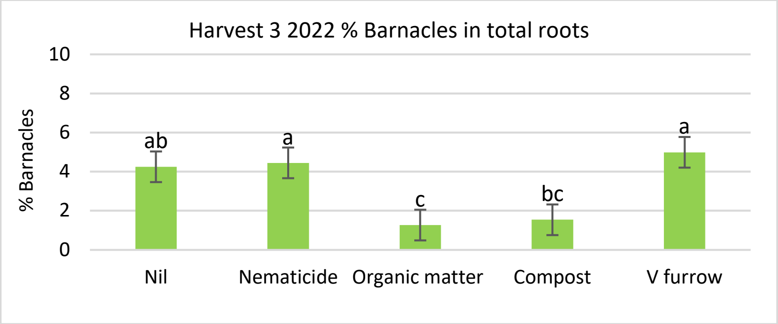


Figure 33.Incidence of Barnacles in harvest 3.

Insect damage

Wireworm

In 2020 wireworm presence was low so was not analysed. Wireworms were a problem during 2021 (figure 8). The Organic matter treatment. 2021 saw a high incidence of wireworm damage across all categories of roots (small marketable, small non-marketable, small all, medium marketable, medium unmarketable, medium all, large marketable, large unmarketable, large all and all). In all of these categories roots in the Organic matter treatment significantly showed most damage. The Compost and V furrow treatments also showed a higher level of damage. Nimitz showed least damage in all categories often significantly so. The next treatment for least damage was the nil treatment. In 2022 and plantings wireworm was present, but damage levels were not affected by treatments. At the fourth harvest in 2023 roots form the Organic matter and Compost treatments had a significantly higher incidence of damage by sweetpotato weevil than the Nimitz plot but this was not significantly different to roots from the Nil and V furrow treatments.

While significant differences in incidence were only observed in 2021 and 2023, it is noticeable that the wireworm damage was more prevalent in all treatments containing organic matter. Whether this was a once off occurrence due to the sudden increase of organic matter into the soil or could be an issue to contend with if using Compost, Organic matter or V furrow treatments cannot be confirmed.

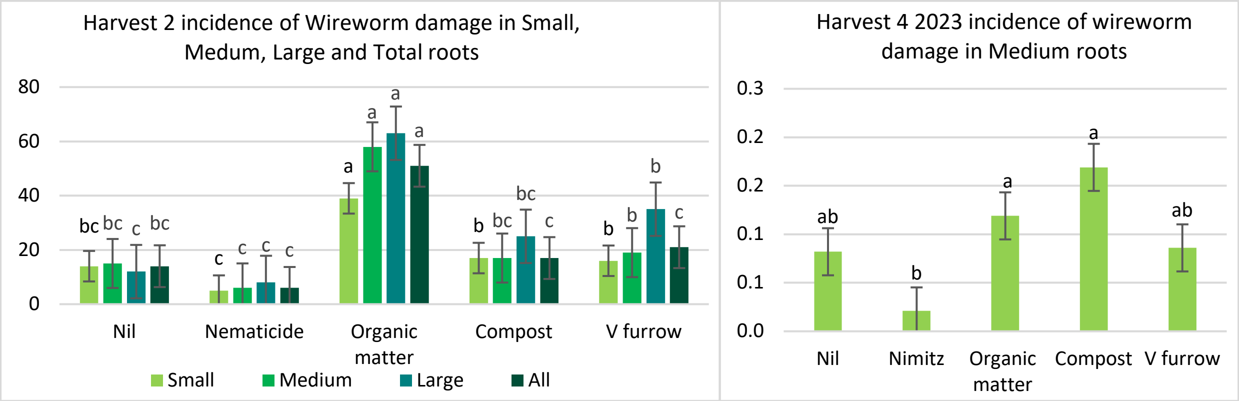


Figure 34. Incidence of Wireworm damage at Harvest 2 and Harvest 4.

White grub

As there was not a high level of white grub in 2020 so data was not analysed for any effects of this pest. In 2021 the large unmarketable category did show treatment effects for white grub damage. The Organic matter treatment showed significantly less damage than Nimitz and V furrow but was not dissimilar to Compost or Nil treatments. There were no significant differences between treatments in 2022. In 2023 the Organic matter treatment suffered significantly more damage than the Nil, Nimitz and marketable roots of the V furrow treatment.

Similar to wireworms, when white grub did occur it tended to cause more damage in treatments with higher levels of organic matter.

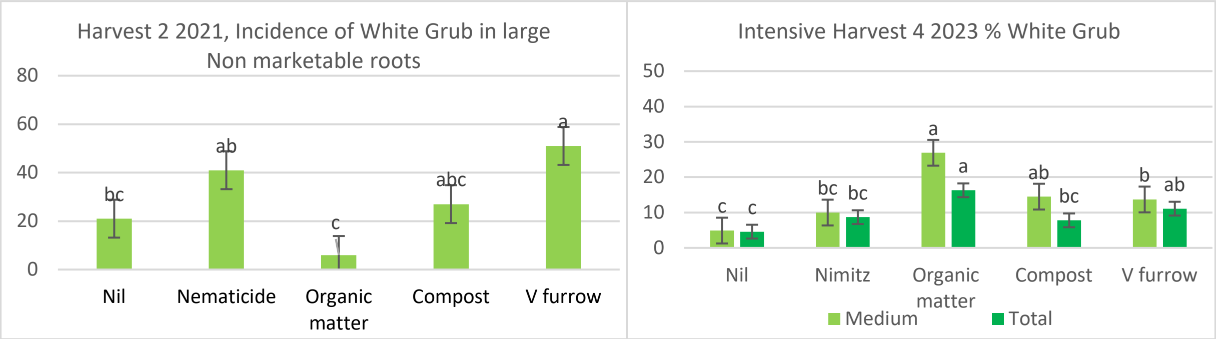


Figure 35. Incidence of White grub by treatment in the intensive trial in 2021 (left, and 2023 (right).

Symphilids

Symphilids were only recorded in 2023 and there were no significant differences in occurrence between the treatments.

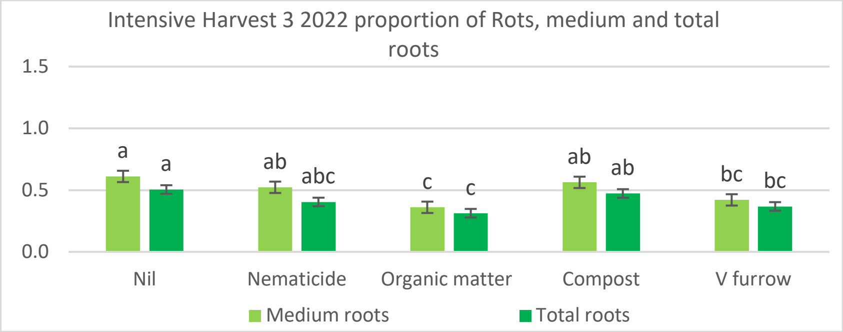


Figure 36. Proportion of rots in medium sized and total roots by treatment in the intensive trial in 2022.

Bacterial and fungal defects

Geotrichum sour rot

Due to the low level of Geotrichum sour rot in 2020, 2021 and 2022 there was no analysis done for treatment effects. In 2023 some treatment effects were seen for Geotrichum sour rot. In both Medium and Total root categories the Compost treatment was significantly more effected than Nil, Nimitz and V furrow treatments, and was similar to the Organic matter treatment. This indicates that higher levels of Organic matter may be an issue for sweetpotato roots being infected with Geotrichum sour rot, should environmental conditions favor its development.

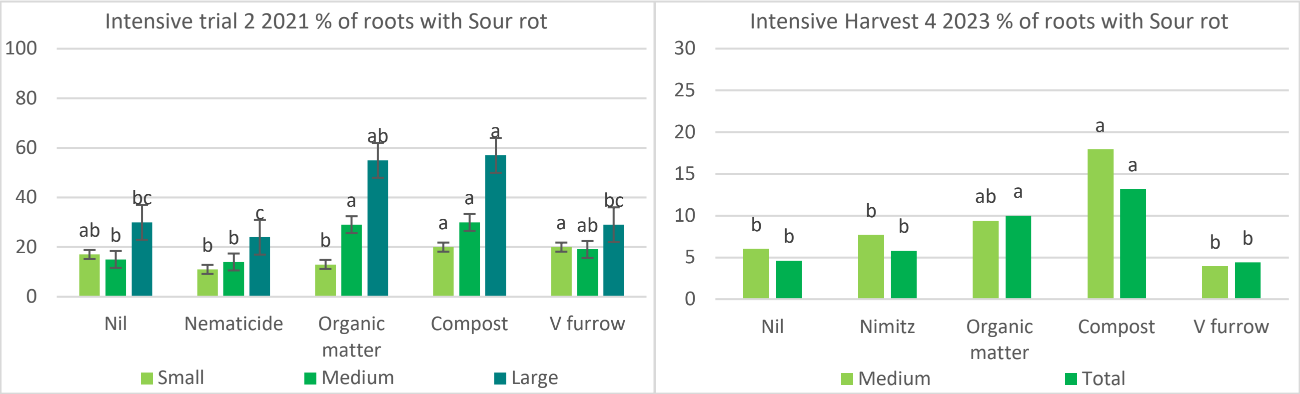


Figure 37. Proportion of Sour rot by treatment in the intensive trial in 2021 and 2023.

Streptomyces Soil Rot (Pox), Streptomyces ipomoeae

Soil pox was not an issue in 2020 and 2022. In 2021 the Nimitz treatment had significantly lower soil pox than all other treatments, followed by the nil and compost treatments. The Organic matter and V furrow treatments were significantly worse than the other treatments this was also a significant trend for roots in the in the small, medium and large sizes. In 2023 soil pox was present at a low level of infection across all root sizes. Again, the Nimitz treatment has lowest infection along with the nil and V furrow treatment.

While not clear the data does suggest that Nimitz treated blocks may have a lower level of soil pox.

Other rots and breakdown

In 2020 and 2021 seasons there was low level of root rots, so their incidence was not analysed. 2022 saw a higher level of root rots. The Organic matter treatment had significantly lower rots than nil and compost treatments. For medium roots, the size category where most of the rots occurred the Organic matter treatment also had significantly fewer rots than the Nimitz treatment. While analysis of rots was conducted in 2023 there was no significant differences between treatments. There is not enough evidence to state whether the treatments influenced the incidence of root rots.

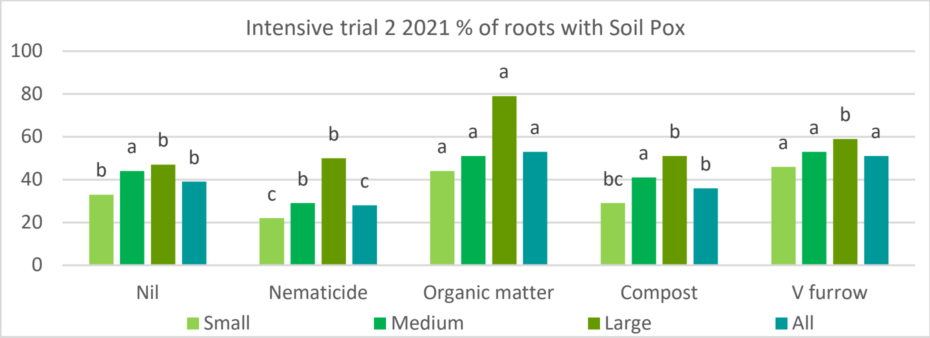


Figure 38. Proportion of Soil pox by treatment in the intensive trial in 2021.

Other defects

Darkened lateral feeder root scars (DLRS)

Darkened lateral feeder root scars (DLRS) occur when the lateral feeder roots are damaged, and a wound response is initiated. The result is an indent on the root surface filled with a darkened scab-like layer on the periderm. Cause is unknown.

There was no significant treatment effect for the level of DLRS in the 2020 planting. In 2021 only large roots showed treatment effects. In all categories of large roots, the Organic matter treatment showed significantly less DLRS than the Nil treatment (figure 6). In 2022 there was no significant differences between treatments. 2023 saw treatment effects in the medium root category, but the effects were contradictory to the 2022 results. Nimitz in 2023 had significantly lower incidence of DLRS than any treatments with added organic matter (Compost, Organic matter and V furrow treatments) and was similar to the Nil treatments.

Over the trial life the treatment results for DLRS incidence are confusing. This confusion may relate to some years having a low incidence of DLRS and trial variation being too great to identify treatment differences.

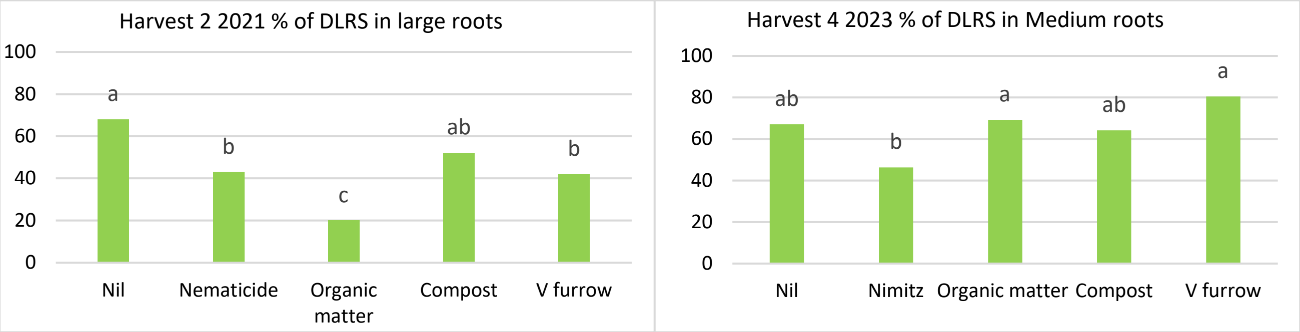


Figure 39.Incidence of DLSR at Harvest 2, left and Harvest 4, right.

Elongated Lenticels

In 2020, no treatment affected the level of Elongated lenticels. In 2021 there were some significant differences in small roots and in large unmarketable roots (figure 7). In all the small roots the Organic matter treatment had significantly more Elongated lenticels than all other treatments, while in the small roots the Organic matter treatment again had the highest percentage of Elongated lenticels although this was similar to Compost, Nematicide and Nil treatments, and only significantly different to the V furrow treatment. The large nonmarketable roots also saw some significant differences, although in this case it the Organic matter treatment was significantly lower than all treatments accept Compost. 2022, saw some treatment differences in the small sized roots with the Compost treatment having more elongated lenticels than Organic matter or V furrow treatments, but was similar to Nimitz and Nil treatments. The planting in 2023 saw no differences in the level of Elongated lenticels in any of the treatments.

Overall, the treatments did not show much effect on the level of Elongated lenticels. The occurrence of Elongated lenticels may be more related to environment and stage of growth factors.

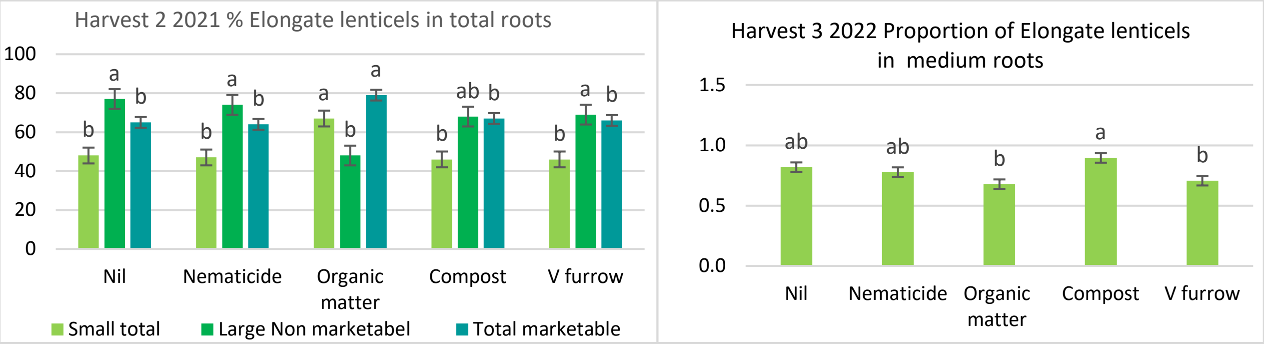


Figure 40 Incidence of Elongated lenticels at Harvest 2, left and Harvest 3, right.

Miscellaneous defects

In 2020 there was minimal occurrence of sunken lenticels in the trial. The numbers of sunken lenticels had increased in 2021, 2022 and 2023 there was not treatment affecting their occurrence. As over three years there was no treatment effect on the occurrence of sunken lenticels, their formation may be due to other factors.

Sunburn (Table 7) was not analysed 2020 and 2022 due to low numbers. In 2023 while analysed there were no significant differences between treatments and in 2021 the only treatment difference seen was in large unmarketable root category where the organic matter had significantly less sunburn than all other treatments. Overall, the level of sunburn does not appear to be affected by treatments. Concertina skin effect was not analysed in 2020, 2022 and 2023 due to low numbers of roots being affected. In 2021 only the large marketable roots showed any significant treatment differences in level of root concertina. The Organic matter and V furrow treatments had significantly less concertina than the Compost treatment. Given the lack of data, concertina would not appear to be a problem caused by any of the treatments.

There was a significantly lower incidence of broken roots in the nematicide treatments in 2021 and 2023. *In* the fourth harvest in 2023 there were significantly higher incidence of animal damage in Nimitz plots than all other plots except the V-furrow plots. Root constrictions were not analysed in 2020 and 2022 due to their low number. Although analysed in 2021 there was no difference between treatments. In 2023 the organic matter treatment showed significantly more root constrictions in medium sized roots than the Nil and Nimitz treatments but similar to Compost or V furrow which in turn were similar to nil and Nimitz treatments. Possibly the organic matter treatments may be more susceptible to root constrictions but there would need to be further research to prove this.

A significantly lower incidence of Longitudinal grooves was recorded in large roots grown in the Organic matter and Compost treatments in Harvest 4. There were no significant differences in previous harvests. As the 2020 and 2022 trials only had a low number of misshapen roots the data was not analysed. The level was higher in 2021 but no significant differences were seen between treatments. In 2023 there only differences seen between treatments was in the medium size roots. In this category the Nimitz treatment had significantly fewer misshapen roots than the Compost, Organic matter or V furrow treatments. Nimitz and Nil treatments were similar. There is not enough evidence to determine if the treatments have an effect on root shape.

Table 52. Other defects with significant treatments differences in 2021 and 2023.

Year	2021		2023						
Defect	Sunburn	Concertina	Broken	Broken	Animal Damage	Constrictions	Longitudinal Grooves	Longitudinal Grooves	Misshapen
Size	*Large Non-Mkt*	*Large Mkt*	*Small*	*All roots*	*Medium*	*Medium*	*Small*	*Large Non-Mkt*	*Medium*
Nil	24.6 a	4.0 ab	0.066 a	0.046 a	0.105 b	0.115 ab	0.077 b	76.4 a	0.866 ab
Nematicide	27.9 a	2.4 ab	0.014 b	0.02 b	0.094 b	0.072 b	0.178 a	72.4 a	0.789 bc
Organic matter	7.0 b*	0.0 b*	0.048 a	0.037 ab	0.163 a	0.069 b	0.075 b	43.2 b	0.761 c
Compost	29.7 a	5.7 a	0.074 a	0.057 a	0.103 b	0.171 a	0.072 b	75.0 a	0.867 ab
V furrow	23.8 a	0.0 b	0.057 a	0.039 ab	0.129 ab	0.114 ab	0.116 ab	56.6 b	0.892 a
F(4,16)	6.6	1.2	5.010	3.620	3.45	3.85	4.74	7.20	3.51
P	CR	RB	0.008	0.028	0.033	0.022	0.010	0.002	0.031
Average 95% lsd	0.03	0.02	0.0338	0.0217	0.0427	0.0609	0.0582	15.06	0.0893

** Means followed by a similar letter do not differ significantly (p>0.05)*

Extensive trial -Sustainable farming systems long term trial

Introduction

This trial was established simultaneously with the Intensive trial in November 2018 at Bundaberg Research Facility. The aim was to assess the nematode control and soil health benefits provided by farming systems that incorporate minimum tillage (pre-formed beds) as well as crop rotation and organic amendments. The extensive trial was more experimental than the intensive trial in its design with the use of pre-formed beds. The main components of this trial incorporate controlled traffic, minimum tillage, organic amendments, cover cropping with a grass legume rotation or a grass brassica rotation and mulching. The trial ran from November 2018 to June 2023.

The experimental trial design followed the process outlined below:

- Apply organic amendments, form beds, grow a cover crop on the beds, mulch or spray the above-ground biomass.
- Plant sweetpotato with minimum tillage and controlled traffic.
- Harvest the sweetpotato crop ensuring that all traffic was controlled during the harvesting operation.
- Re-form the beds and repeat the process.

Materials and methods

The trial followed these steps: Apply organic amendments, form beds, grow a cover crop on the beds, mulch or spray the above-ground biomass. Plant sweetpotato with minimum tillage and controlled traffic. Harvest the sweetpotato crop ensuring that all traffic was controlled during the harvesting operation. Re-form the beds and repeat the process.

The extensive trial comprised ten treatment combinations with a factorial treatment structure. There were two crop treatments (Grass/Brassica and Grass/Legume) and five amendment treatments (Double, Incorporated, Nematicide, Nil and V furrow). Each treatment was replicated four times, and the trial was designed as a randomised complete block. Nematicide treatments (Vydate) were included to determine if the sustainable farming system approach reduced RKN populations to an extent that a nematicide was no longer necessary. In the five-year trial period three commercial crops were grown and harvested

Table 53. Treatments in the Extensive trial.

	Method		Rotation Crops
Treatment 1	Nematicide	Vydate (oxamyl)	Grass/Brassica
Treatment 2	Nil	No treatment	Grass/Brassica
Treatment 3	V-furrow	Sawdust + chicken manure	Grass/Brassica
Treatment 4	Incorporated	Sugarcane mulch + chicken manure/compost	Grass/Brassica
Treatment 5	Double	Incorporated + v-furrow treatments	Grass/Brassica
Treatment 6	Nematicide	Vydate (oxamyl)	Grass/Legume
Treatment 7	Nil	No treatment	Grass/Legume
Treatment 8	V-furrow	Sawdust + chicken manure	Grass/Legume
Treatment 9	Incorporated	Sugarcane mulch + chicken manure/compost	Grass/Legume
Treatment 10	Double	Incorporated + v-furrow treatments	Grass/Legume

The same procedures used in the Intensive trial for RKN inoculation of the block, soil monitoring, planting of the commercial crop, trial maintenance, harvest and assessment were also carried out in the Extensive trial.

Amendments

After harvest of the sacrificial sweetpotato crop, the block was rotary hoed. Organic amendments were applied to the Double amendment and Incorporated amendment treatments band prior to incorporation during bed forming. Amendments were hand placed on top of the rows in a 40 cm wide central band (based on GPS tracking) using buckets (image 10). Rates for banded amendments were based on those used in previous field trials demonstrating suppression of plant-parasitic nematodes; 56 kg/14m row or plot, is equivalent to 50 t/ha. The amendments combined 22.4 kg/row of poultry manure plus 33.6 kg/row of sawdust (40/60 blend), or sugar cane mulch 25 t/ha (= 50 t/ha total). Prior to bed formation a basal fertiliser was applied, following grower practice. PRG discussions resulted in the decision not to apply any preplant soil insect chemicals (as per current grower practice), so as not to interfere with biological soil populations. After bed formation cover crops were planted, either a grass followed by a legume (20 plots), or a grass followed by a brassica species (20 plots).

Image 36 Amendments were weighed into buckets and had applied to the respective plots.

At the end of the cover crop phase a V-furrow was opened on top of the beds with a double disc opener and organic matter (poultry manure + sawdust 40/60 blend @76 L/row = 28.65 kg/row), was placed into the furrow in each of the 16 Double amendment treatments. The nematicide Vydate was applied as per label rate to the appropriate plots. The furrows were then closed by shovel, using loose soil created during the furrow opening process. It is hypothesised that newly developed roots will potentially be protected from nematode attack due to increased suppressive activity in this zone enriched with organic matter. The planting schedule can be viewed at table 7.

Image 37 Cover crops

Table 54 Extensive trial treatments and application dates

Treatment	**Incorporated amendment** Incorporated and beds formed		**Double amendment** (Incorporated + V-furrow amendment)		**V-furrow amendment** V furrow added prior to planting		**Vydate Nematicide** As per label, 18 L/ha within 7 days of planting, followed by four applications @ 2 L/ha at 14-day intervals.		**Nil/ control** No amendments or nematicides	
Rotation	Grass/Brassica	Grass/Legume	Grass/Brassica	Grass/Legume	Grass/Brassica	Grass/Legume	Grass/Brassica	Grass/Legume	Grass/Brassica	Grass/Legume
Date										
21 Nov 18	Nematode inoculation to increase populations, sacrificial sweetpotato crop planted									
14 May 19	Poultry manure + Sugarcane mulch.		**Incorporated:** Poultry manure + Sugarcane mulch.							
14 May 19	Rotary hoe and form beds									
27 May 19	White French millet									
3 Sep 19	Nemsol	Soybean A6785	Nemsol	Soybean A6785	Nemsol	Soybean A6785	Nemsol	Soybean A6785	Nemsol	Soybean A6785
15 Jan 2020			**V furrow:** Poultry manure + Sawdust		Poultry manure + Sawdust					
20 Jan 20	Planted sweetpotato crop 1 cv. Beauregard									
8 Jun 20	Harvest and assess sweetpotatoes 140 DAP									
29 Jun 20	Poultry manure + Sugarcane mulch.		**Incorporated:** Poultry manure + Sugarcane mulch.							
7 Jul 20	White French millet									
30 Nov 20	Nemsol	Sunn Hemp	Nemsol	Sunn Hemp	Nemsol	Sunn Hemp	Nemsol	Sunn Hemp	Nemsol	Sunn Hemp
25 Feb 21	Signal grass									
20 May 21	Swan oats									
21 Sept 21			**V furrow:** Poultry manure + Sawdust		Poultry manure + Sawdust					
23 Sept 21	Planted sweetpotato crop 2 cv. Beauregard									
21 March 22	Harvest and assess sweetpotatoes 179 DAP									
23 Mar 22	Poultry manure + Sugarcane mulch.		**Incorporated:** Poultry manure + Sugarcane mulch.							
23 Mar 22	Rotary hoe and form beds									
5 Apr 22	Swan oats									
28 Sept 22	Nemsol	Sunn Hemp	Nemsol	Sunn Hemp	Nemsol	Sunn Hemp	Nemsol	Sunn Hemp	Nemsol	Sunn Hemp
2 Dec 22			**V furrow:** Poultry manure + Sawdust		Poultry manure + Sawdust					
6 Dec 22	Planted sweetpotato crop 3 cv. Beauregard									
24 Apr 23	Harvest and assess sweetpotatoes 139 DAP									

Soil Monitoring

Soil samples were collected at critical points in the trials, such as pre plant, post-harvest and post rotation crop. Samples were sent to the project team nematologists for nematode extraction, to the Department of Environment and Science (DES) for soil chemical and physical analysis and to GRF for extraction of soil biologicals, microarthropods and Nematode trapping fungi (NTF). Results from these samples will allow investigation into correlation between soil characteristics, RKN populations and soil biology.

Planting the commercial crop

The Intensive was planted with standardised hi spec vine tip cuttings (image 22), cultivar Beauregard at 20 cm plant spacing on the 20th of January 2020. 2 January 2021, 11 February 2022 and 15 December 2022 (Table 7).

Image 41.The Extensive trial preformed beds showing the White french millet cover crop sprayed off in preparation for planting of the commercial crop.

Image 42.Left to right, planting into the preformed beds in the Extensive trial.

Image 43.The commercial crop in the Extensive trial showing a sorghum rotation in the Intensive trial to the right.

Harvests

Harvests were conducted in June 2020 March 2022 and April 2023. After harvest, amendments were again applied to the Double and Incorporated treatments, beds were re-formed, and the next cover crop was planted as per table 7.

Results

Roots were harvested from each plot and individually graded by size (small, medium, large) and marketability (premium marketable, second marketable and non-marketable). The data form the premium and second grade marketable roots was combined into a single marketable class. Each individual root was assessed for defects and the proportion of roots in each plot affected by damage was calculated.

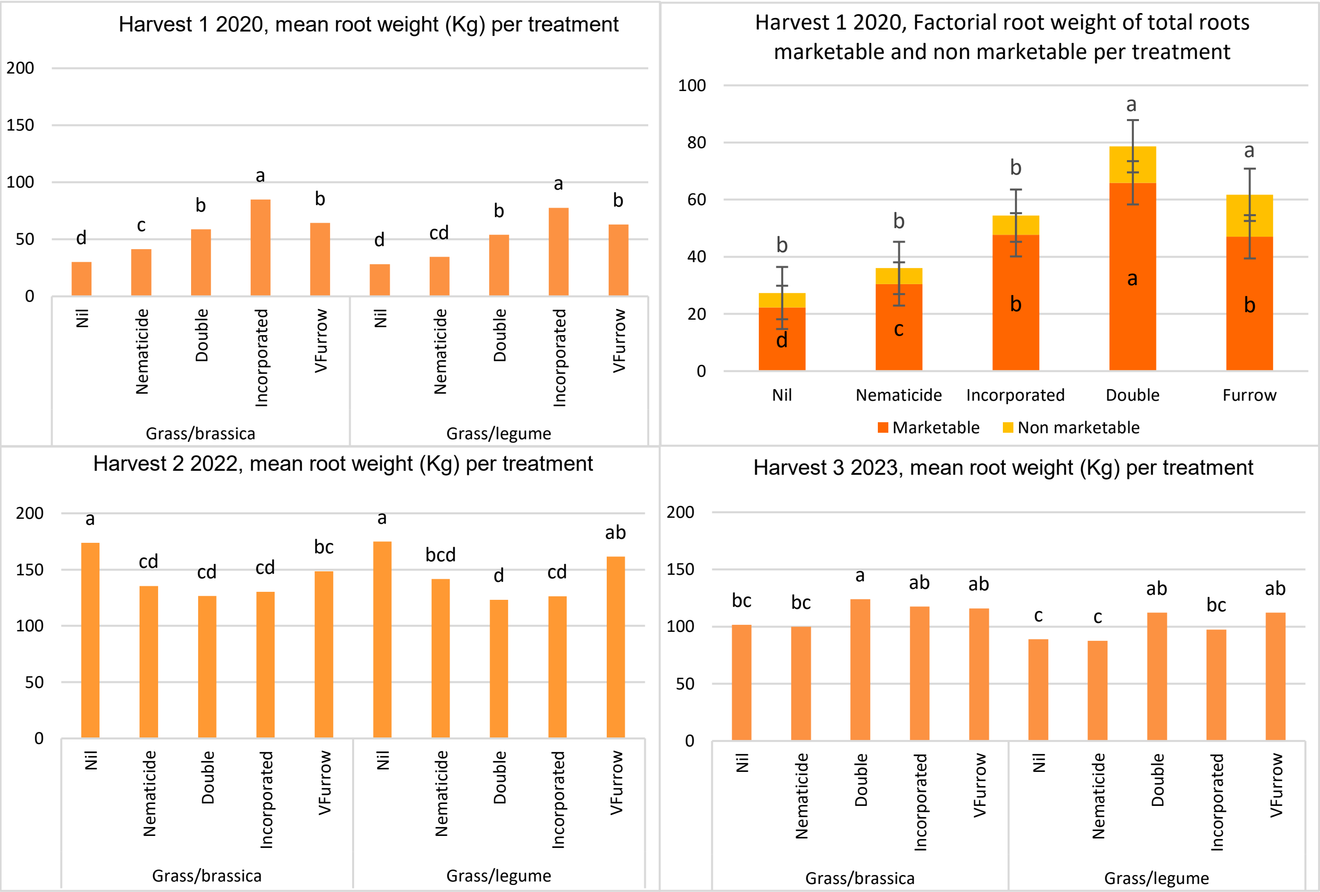
The plot proportions were initially analysed using a generalised linear mixed model (GLMM) assuming a binomial distribution and complementary log-log link function. However, the models often did not converge and therefore a generalised linear model (GLM) was fitted. The replicate effect was fitted as the first term in the model followed by a single treatment factor representing the 10 treatments. Each combination of size and marketability was analysed independently. This does not allow for any differences between size classes to be determined but allows for a simpler interpretation of the treatment effects. A simple contrast was also fitted to investigate an overall effect of crop. This was investigated further by fitting the factorial treatment structure in the model. Data from extra small and small roots was combined to form the small category, small medium-, medium- and medium-large root data was combined into the medium category and large and jumbo roots were combined to form the large category.

Root weights

In 2020 in both the grass/brassica and grass/legume treatments in the Incorporated plots produced significantly higher yields than all other treatments. In the grass/brassica plantings the Double and V furrow treatments were similar in yield although lower than the Incorporated treatment. In both plantings the Nil treatment produced the lowest yield, significantly so in the grass/brassica planting and similar to the nematicide treatment in the grass/legume planting.

In 2022 results were reversed in that the highest yielding treatment was the Nil treatment, significantly better in the grass/brassica plantings and equal to the V furrow and significantly better than the other treatments in the grass/legume plantings. In both the grass/brassica and grass/legume plantings the Nematicide, Double and Incorporated treatments were significantly lower. In 2023 another reverse occurred with Double, Incorporated and V furrow treatments being the best yielding treatments in both plantings. Nil and nematicide treatments were the lowest yielding treatments.

The yield results are variable over time. Given the complex nature of soils and soil biology there may well be need for extended trial periods to see the true benefits of these treatments. At this early stage it is only possible to say that the Incorporated, Double and V furrow treatments performed best in two out of three plantings.


Harvest 1 2020, mean root weight (Kg) per treatment

Harvest 1 2020, Factorial root weight of total roots marketable and non marketable per treatment

Harvest 2 2022, mean root weight (Kg) per treatment

Harvest 3 2023, mean root weight (Kg) per treatment

Figure 44 Extensive trial root weights across all harvest.

Root numbers

The root count data was analysed using a GLM but assumes a Poisson distribution and a log link function. In 2020, the Incorporated and V furrow treatments in the grass/brassica & grass/legume treatments had the highest root numbers. In the factorial analysis, the Double amendment produced the highest number of roots with the Nil treatment plots producing the lowest number of roots.

In 2022, the Nil treatment produced the highest number of roots in the grass/brassica plots and the double, Incorporated and V furrow plots in the grass/legume treatments produced the most roots High counts were recorded for double, incorporated and V furrow in the Grass/legume treatment crop. A somewhat similar trend was seen in 2023, however there were no significant differences between treatments in the number of total roots produced.

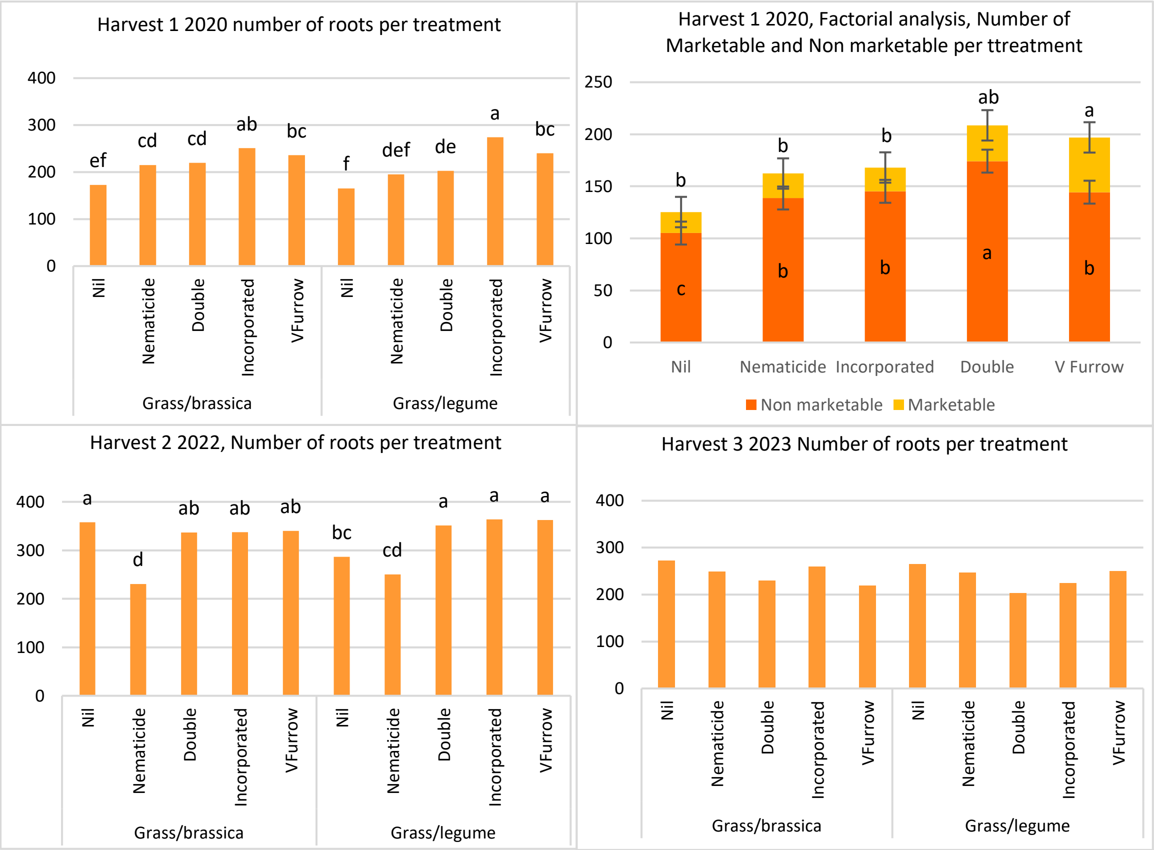


Figure 45 Extensive trial total no of roots per treatment for all harvest.

Nematode related lesions

Results are reported as a percentage of all roots (marketable and non-marketable) on the overall incidence for each size class and the sizes combined (Total roots). Incidence data was been analysed using a generalised linear model with a Binomial distribution and complementary log-log link with means, standard errors (se) and average 95% least significant differences shown.

Raised Pimples

In 2022 there were significant differences between treatments in the marketable second roots across all size grades. The mean incidence of raised pimples was highest in the Nil and Vydate treatments, in both cover crop planting regimes along with the Incorporated treatment with the grass/legume rotation.

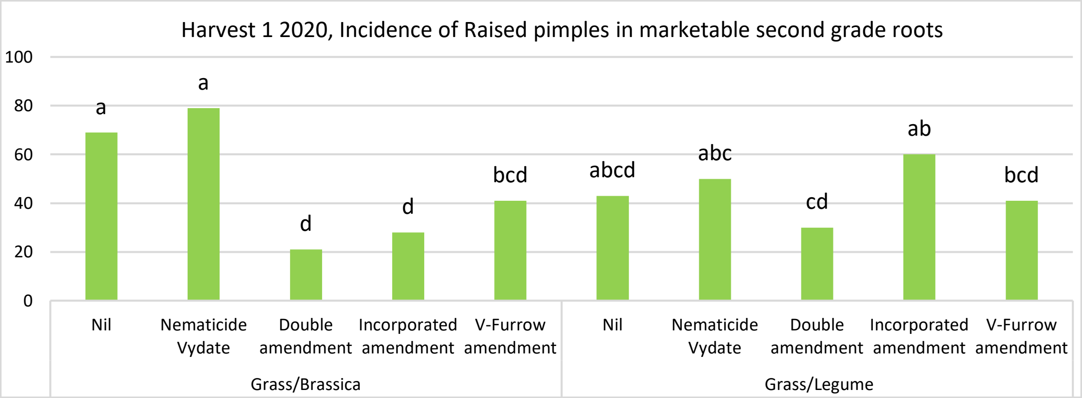


Figure 46. Occurrence of Raised pimples in marketable second grade roots in harvest 1.

A similar trend to that observed in 2020 was apparent in the second harvest in 2022 with significant differences in the incidence of raised pimples in both marketable and non-marketable medium sized roots. The proportion of raised pimples was highest in both marketable and unmarketable roots in the Nematicide and Vydate treatments followed by unmarketable roots in Nil treatment of the Grass/brassica treatment.

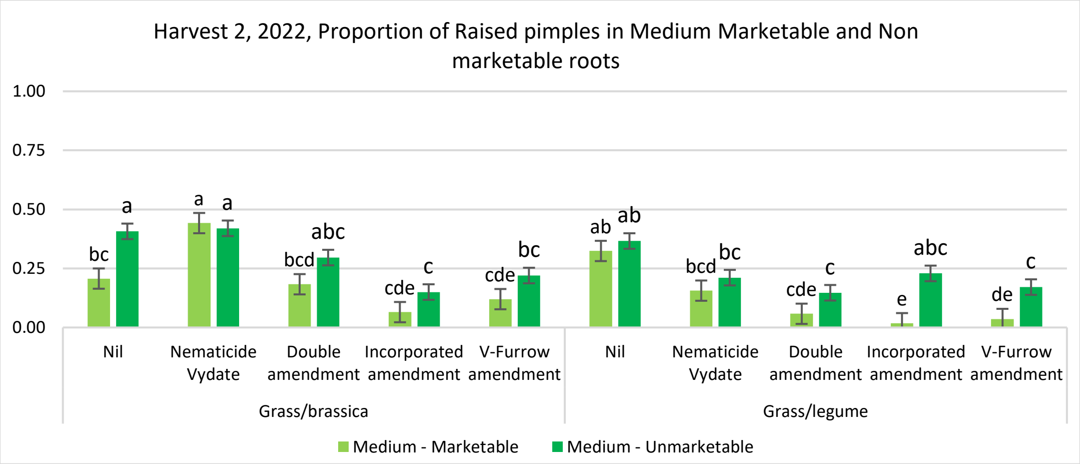


Figure 47. Proportion of Raised pimples in Medium marketable and Nonmarketable roots in harvest 2.

At the third harvest in 2023, the grass/legume Nil treatment produced roots with the highest incidence of raised pimples (Total roots) followed by nematicide treatment. The V Furrow and double amendments with Grass/brassica cover crops had the lowest incidences. The same significant differences were observed in the Medium sized category (data not shown).

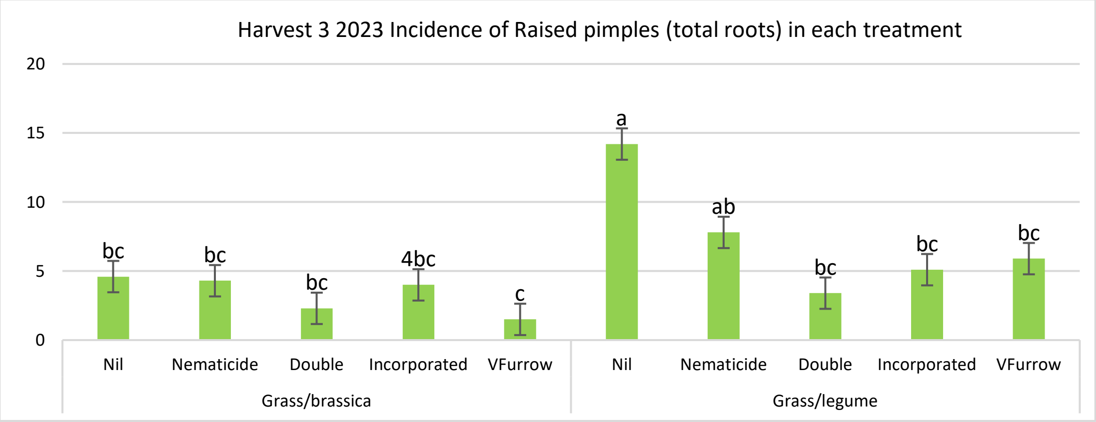


Figure 48.Incidence of Raised pimples in each treatment in Harvest 3.

Black Pimples

In 2020 roots in the grass/legume Nematicide treatments had the highest mean proportion of black pimples followed by the Nil treatment (also grass/legume) and the Nematicide and Incorporated grass/brassica treatments. All treatments generally had a high incidence of black pimples. The V furrow in both treatment crops recorded the lowest incidence.

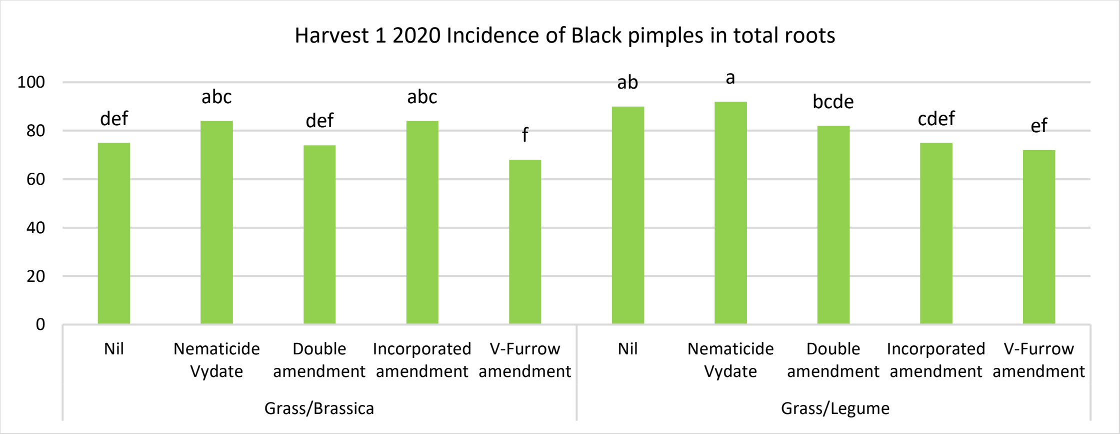


Figure 49. Incidence of Black pimples in total roots in first harvest in 2020.

In 2022, the highest mean incidence of black pimples occurred in the grass/brassica Nematicide and Double amendments and the Nematicide and Nil treatments with grass/legume cover crops.

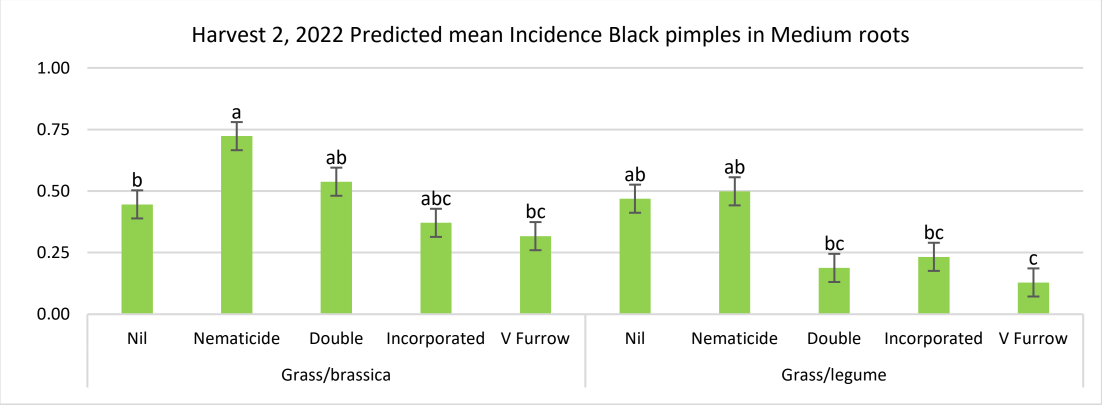


Figure 50. Predicted mean incidence of black pimples in Medium sized roots in harvest 2.

Conversely in 2023 as nematode numbers diminished across the trial, , there were significant differences in the severity rating for black pimples observed on roots with the double amendments in the grass/legume plots producing the most severe occurrences. However, this was not significantly different to the V furrow (grass/legume) and both the Double and Incorporated grass/brassica treatments.

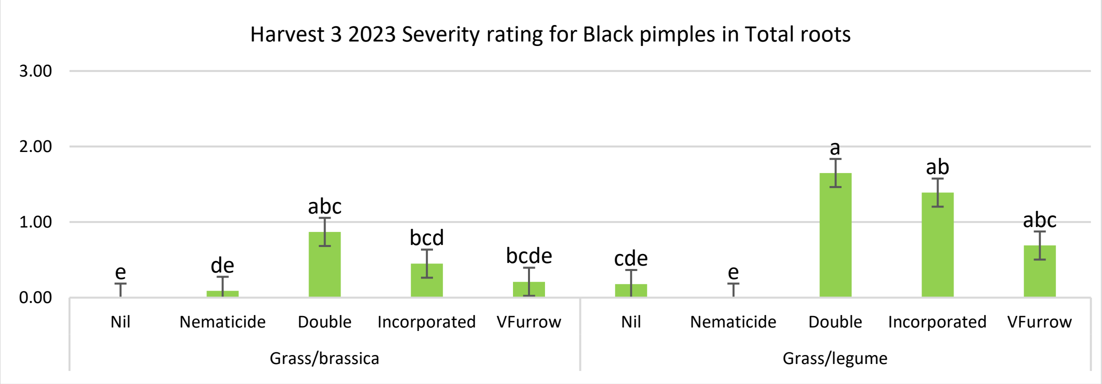


Figure 51. Severity analysis, mean count of Black pimples in each treatment in 2023.

Barnacles

There were no significant differences in the first harvest. In 2022, the highest incidence of Barnacles was recorded in the Nil grass/legume treatments, followed by Nematicide treatments in both cover crop treatments (grass/brassica and grass/legume).

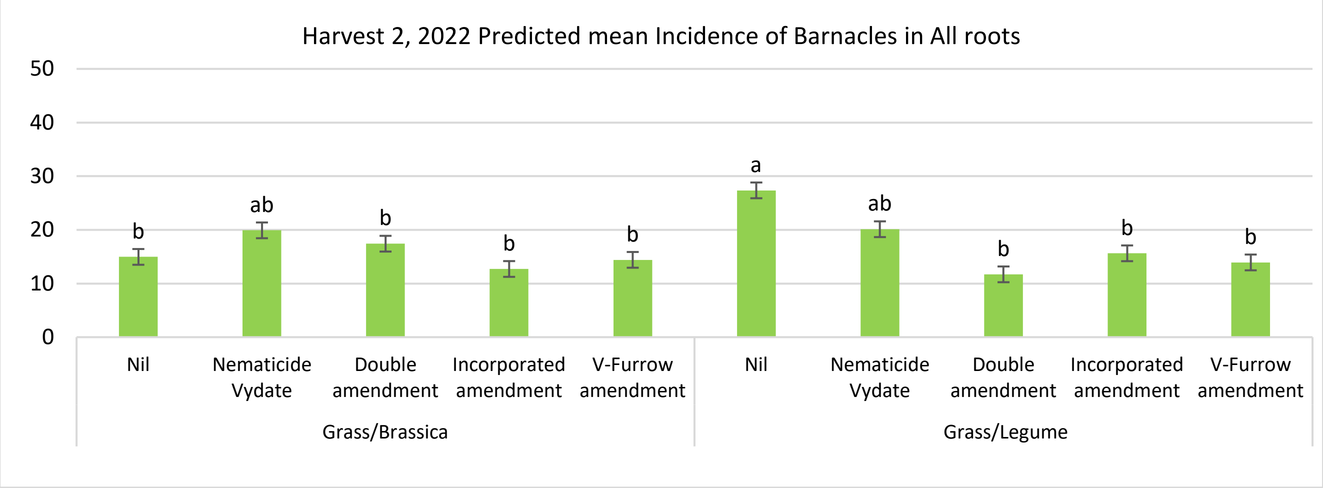


Figure 52 Incidence of Barnacles in the second harvest in 2022.

In 2023, roots grown in the grass/brassica Double amendment and Incorporated grass/legume treatments were the most severely affected by Barnacles.

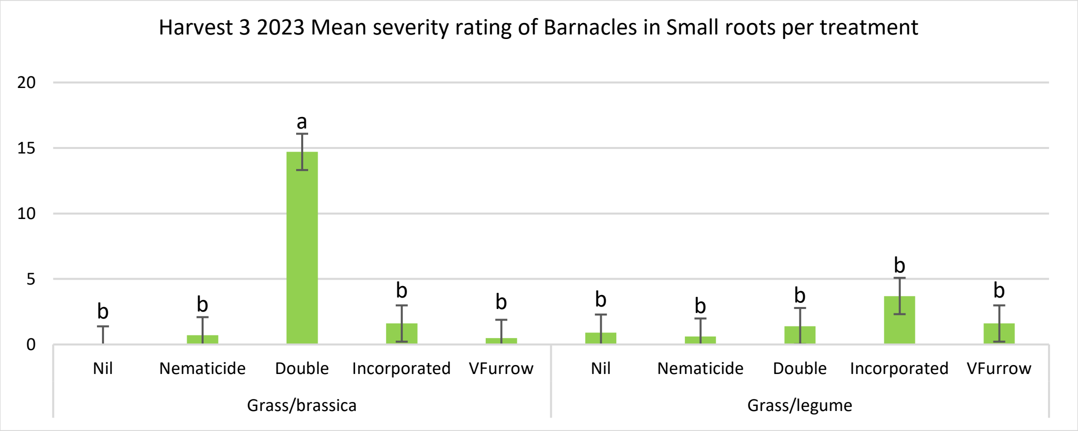


Figure 53. Severity rating of Barnacles in the third harvest in 2023.

Insect damage

Insect Damage (wire worm, white grub and weevil). There were no significant differences between the treatments for the proportions of roots with insect damage in 2020, therefore roots were considered to have insect damage if they were affected by either wire worm, white grub or weevil at the 2022 assessment. The contrasts between the two crops were all non-significant and the GLM found no significant differences between the amendments.

Wireworm

At the third harvest in 2023, the most severe wireworm damage occurred in the Incorporated and Double amended plots across total roots and in all size grades, (Small, Medium and Large).

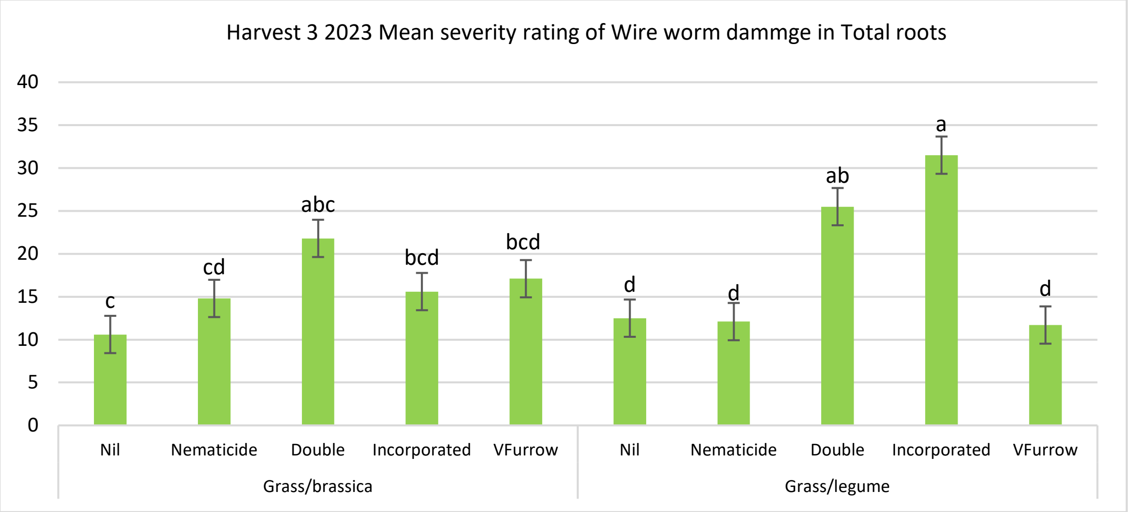


Figure 54. Mean severity of wireworm damage in Harvest 3, 2023.

White grub

The presence of white grub in total roots was highest in the Nil and V furrow treatment in both the grass/brassica and grass/legume treatments and lowest in the Incorporated amendments in both cover crop treatments.

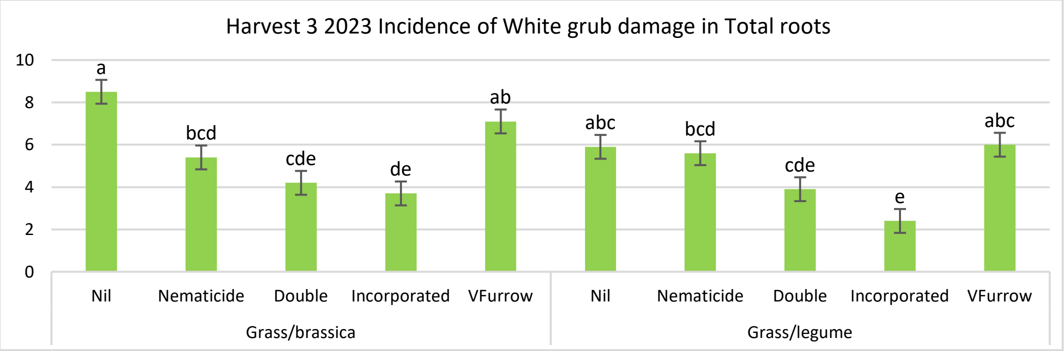


Figure 55 White grub damage in total roots, Harvest 3, 2023.

Sweetpotato weevil

A high incidence of weevil damage was observed in the Nil, Double and Incorporated amendments in the grass/brassica treatments as well as the Double, Incorporated and V furrow amendments in the grass/legume treatments. The Nil and Nematicide treatment in the grass/legume plots had the lowest incidence of weevil damage.

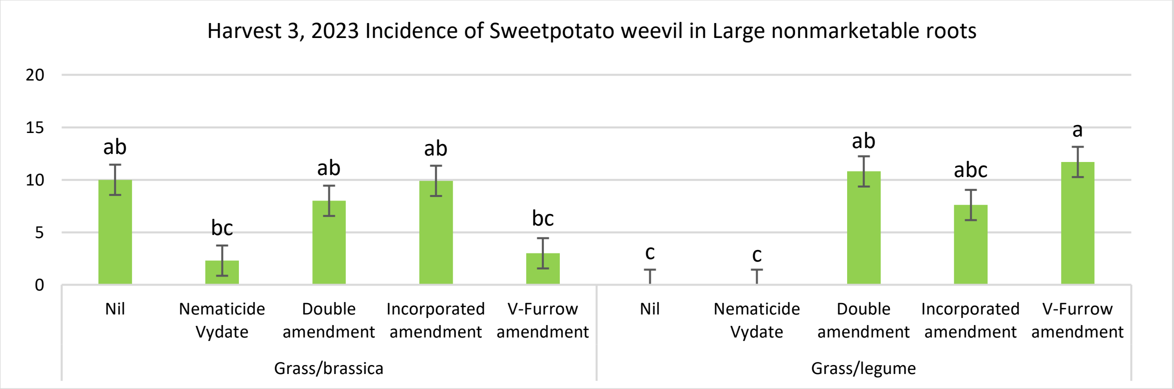


Figure 56 Sweetpotato weevil by treatment in Harvest 3.

Symphilids

Roots gown in the Nil treatment in Grass/legume plots had highest Symphilid damage rating. Symphilids damage was not recorded in any previous harvests.

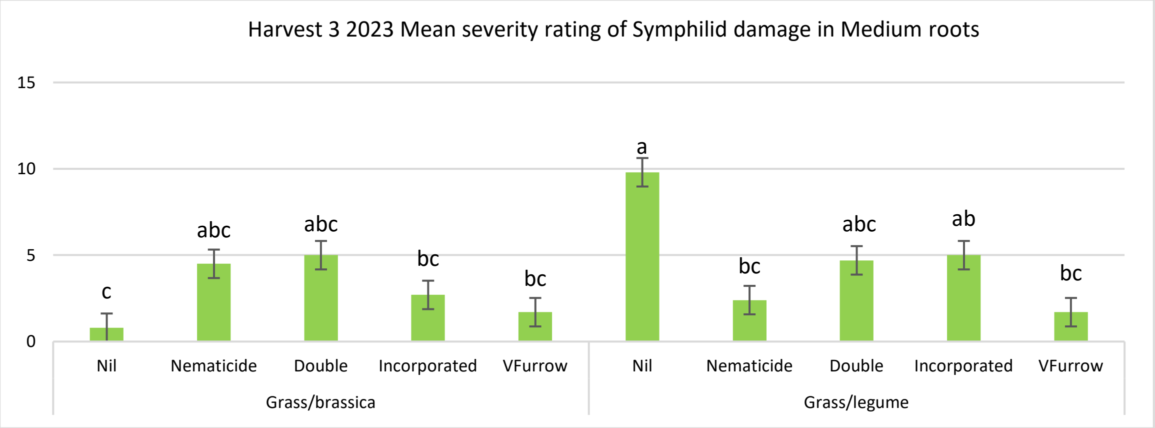


Figure 57. Incidence of Symphilids in Medium roots.

Bacterial and fungal lesions

Geotrichum sour rot

The Double, Incorporated and V furrow amendments in both the grass/brassica and grass/legume regimes produced roots with the highest severity rating of Geotrichum sour rot in 2023.

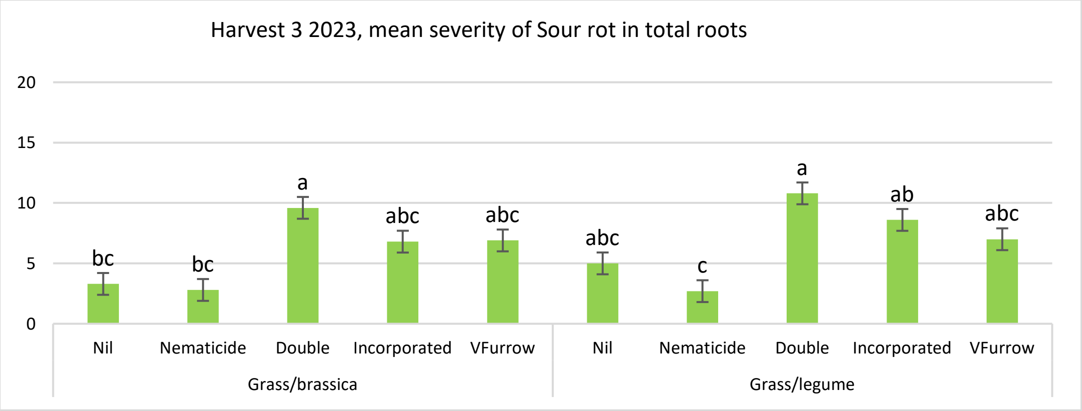


Figure 58 Incidence of Sour rot in Total roots.

Streptomyces Soil Rot (Pox), Streptomyces ipomoeae

Incidence of Soil pox is generally high for double, incorporated and V furrow for both treatment crops.

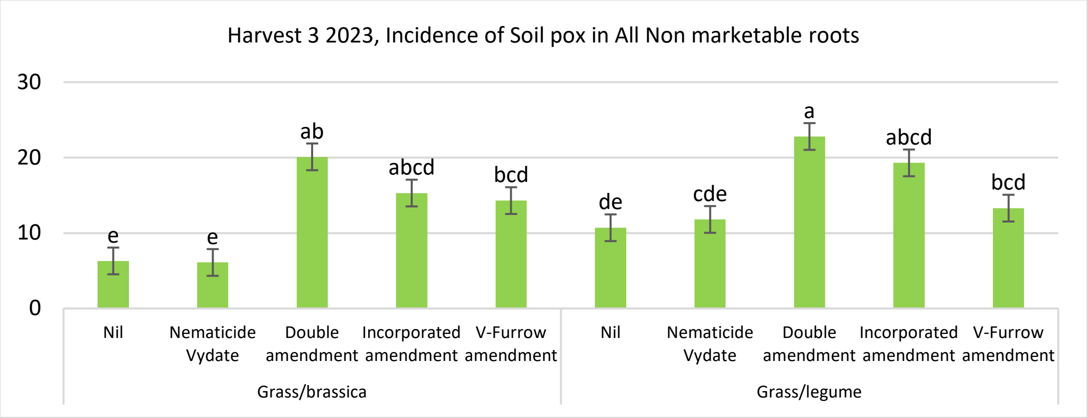


Figure 59 Incidence of Soil pox in 2023.

Severity presence of Soil pox in harvest 3 was generally highest in the Double, Incorporated and V furrow amendments for both crop treatments. Severity was the same in both total, and medium and large root sizes.

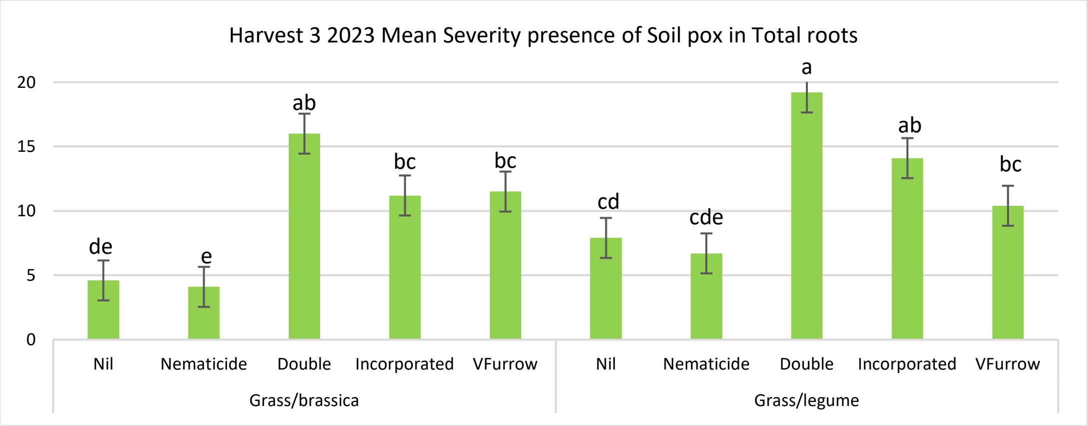


Figure 60 Severity of Soil pox in harvest 3, 2023.

Other defects

Darkened lateral root scars (DLSR)

There were no significant differences in the 2020 harvest. In 2022, the Nil and Nematicide treatments for both cover crops were had the highest incidence of DLSRs. There was no significant difference between the amendments within the grass/legume treatments.

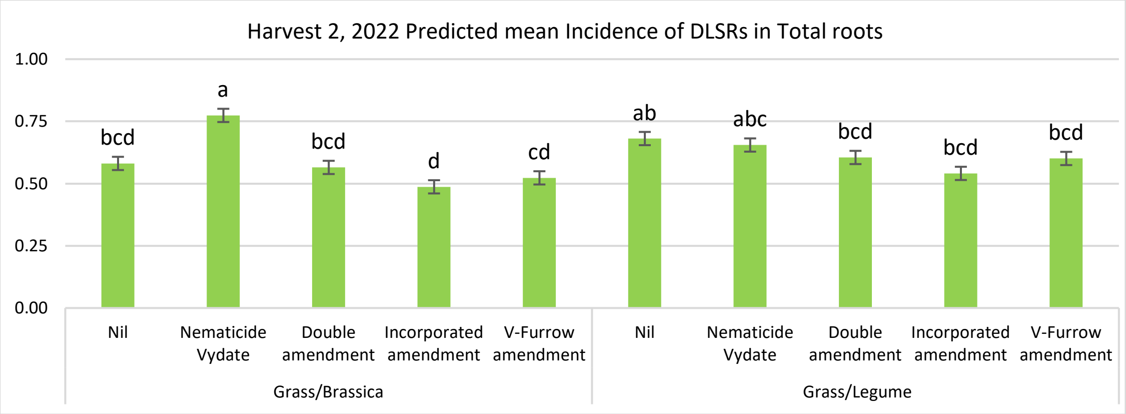


Figure 61. Incidence of DLSRs in 2022.

The 2023 harvest followed a similar trend to the previous harvest with significant differences in nonmarketable small roots. The lowest incidence of DLSRs occurred in the V furrow grass/brassica and Incorporated grass/legume plots.

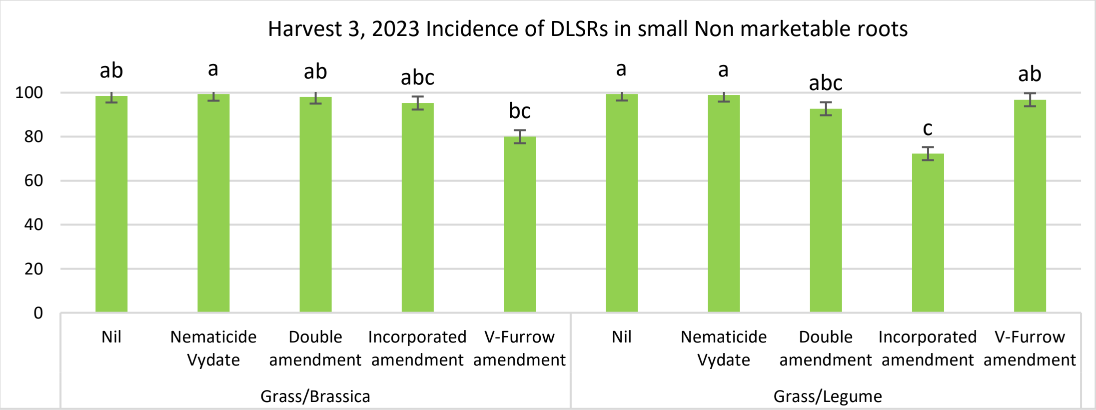


Figure 31. Incidence of DLSRs in 2023.

Miscellaneous defects

Generally, all treatments in the grass/brassica cover crop had a higher mean severity of Misshapen roots (Table 10), compared to grass/legume with the exception of the Double and V furrow amendments. The Nil and Nematicide treatments in the grass/legume cover crop and the Nematicide treatment in the grass/brassica cover crop had a significantly lower mean severity than all other treatments except the grass/legume, Incorporated treatment. This is in contrast to the grass/brassica, Incorporated treatment which had the highest severity rating. Further research needs to be conducted to determine if this severity is actually a treatment effect.

The mean severity of Elongated lenticels was not aligned to the cover crop type. The Double amendments in both cover crops were significantly higher than the Nil and Nematicide treatments in the grass/brassica, and the Nematicide and V furrow treatments in the grass/legume crop. This contrasts with the Nil grass/legume which had the highest severity of Elongated lenticels. Again, further research needs to be conducted to determine if this severity is actually a treatment effect or a spatial and assessment effect.

There were few significant differences in Sunken lenticel severity ratings between treatments, with the main difference being the grass/brassica, Nil treatment significantly better than grass/brassica, Incorporated and V furrow and grass/legume. The Grass/brassica, Nil treatment had the lowest severity rating, however this difference was not significant from some other treatments.

The grass/brassica, Double amendment had the highest incidence of Veining. This was significantly higher than all other treatments except for the grass/brassica, Nematicide and V furrow amendments in the grass/legume treatment. The grass/brassica, Nil treatment had the lowest incidence of Veining.

The highest mean severity of Veining was recorded for the grass/brassica, Double amendment. This was significantly higher than all other treatments except for the Double and Incorporated grass/legume treatments. The Grass/brassica, Nil treatment had the lowest severity rating, however not significantly different from some other treatments.

Table 55. Mean severity rating for total roots for misshapen, elongated & sunken lenticels & veining.

Defect		Misshapen	Elongated lenticels	Sunken lenticels	Veining
Size		Total roots	Total roots	Total roots	Total
Severity rating		High	High	High	Present
Crop	Amendment	Mean	Mean	Mean	Mean
Grass / brassica	Nil	26.8 bc	0.0 d	0.13 c	0.00 c
	Nematicide	20.5 e	0.39 cd	0.53 bc	0.63 b
	Double	25.8 bc	1.29 ab	0.59 bc	2.24 a
	Incorporated	32.0 a	0.94 abc	1.09 ab	0.39 bc
	VFurrow	28.6 abc	0.48 bcd	0.87 ab	0.55 bc

Grass / legume	Nil	17.9 e	1.56 a	0.52 bc	0.20 bc
	Nematicide	19.8 e	0.00 d	0.53 bc	0.21 bc
	Double	30.0 ab	1.53 ab	1.41 ab	0.96 ab
	Incorporated	20.5 de	1.00 abc	1.82 a	0.93 ab
	VFurrow	24.6 cd	0.29 cd	0.52 bc	0.82 b
F		11.66	5.54	2.63	4.23
p		<0.001	<0.001	0.005	0.002
Average 95% lsd		4.25	0.824	0.85	0.84

When the total roots (small, medium and large) were assessed for Longitudinal grooves (Table 11), the incidence in the Double amendment in both cover crop types was significantly less than that in the grass/brassica Nil and Nematicide and grass/legume Nematicide, which had the highest incidence of all treatments. When the medium roots were analysed separately, this pattern was more evident, with the Double amendment in both cover crops and the grass/brassica, Incorporated amendment being significantly better than in all Nil and Nematicide amendments.

Table 56. Mean incidence of longitudinal grooves in medium and total roots.

Defect		Longitudinal grooves	
Size		Medium	Total
Severity		Present	Present
Crop	Amendment	Mean	Mean
Grass /brassica	Nil	35.7 a	24.0 ab
	Nematicide	36.1 a	25.2 a
	Double	11.3 c	10.3 cd
	Incorporated	10.6 c	11.7 bcd
	VFurrow	28.8 ab	24.6 abc
Grass /legume	Nil	37.6 a	22.3 abc
	Nematicide	36.9 a	24.6 a
	Double	12.8 bc	6.8 d
	Incorporated	25.3 abc	22.3 abc
	VFurrow	22.6 abc	18.2 abc
F		3.43	2.33
p		0.006	0.047
Average 95% lsd		16.96	13.82

When severity of Longitudinal grooves (Table 12), was analysed, the results were similar to the incidence reporting, with the grass/legume Double amendment treatment being significantly better than all Nil and Nematicide treatments.These results could be useful in informing future projects which would investigate causes in the occurrence and severity of defects observed during this experiment.

Table 57. Mean severity of longitudinal grooves in medium, large and total roots for all treatments.

Defect		Longitudinal grooves					
Size		Medium	Medium	Large	Large	Total	Total
Severity		Low	Medium	Medium	High	Low	Medium
Crop	Amendment	Mean	Mean	Mean	Mean	Mean	Mean
Grass /brassica	Nil	16.2 bcde	15.6 a	7.6 abc	4.4 abcd	11.6 abc	9.3 a
	Nematicide	29.2 a	6.9 abc	16.4 a	1.5 bcd	18.4 a	6.4 ab
	Double	8.8 de	2.0 bcd	2.6 bc	0.0 d	8.0 bc	2.1 bc
	Incorporated	8.3 e	1.8 cd	8.4 ab	0.5 cd	8.1 bc	2.9 bc
	VFurrow	20.2 abc	7.9 abc	6.4 abc	3.3 abc	17.7 a	5.8 ab
Grass /legume	Nil	29.9 a	6.4 bc	16.8 a	0.9 bcd	16.7 a	4.9 ab
	Nematicide	26.3 ab	8.6 ab	19.9 a	9.3 a	15.9 a	6.7 ab

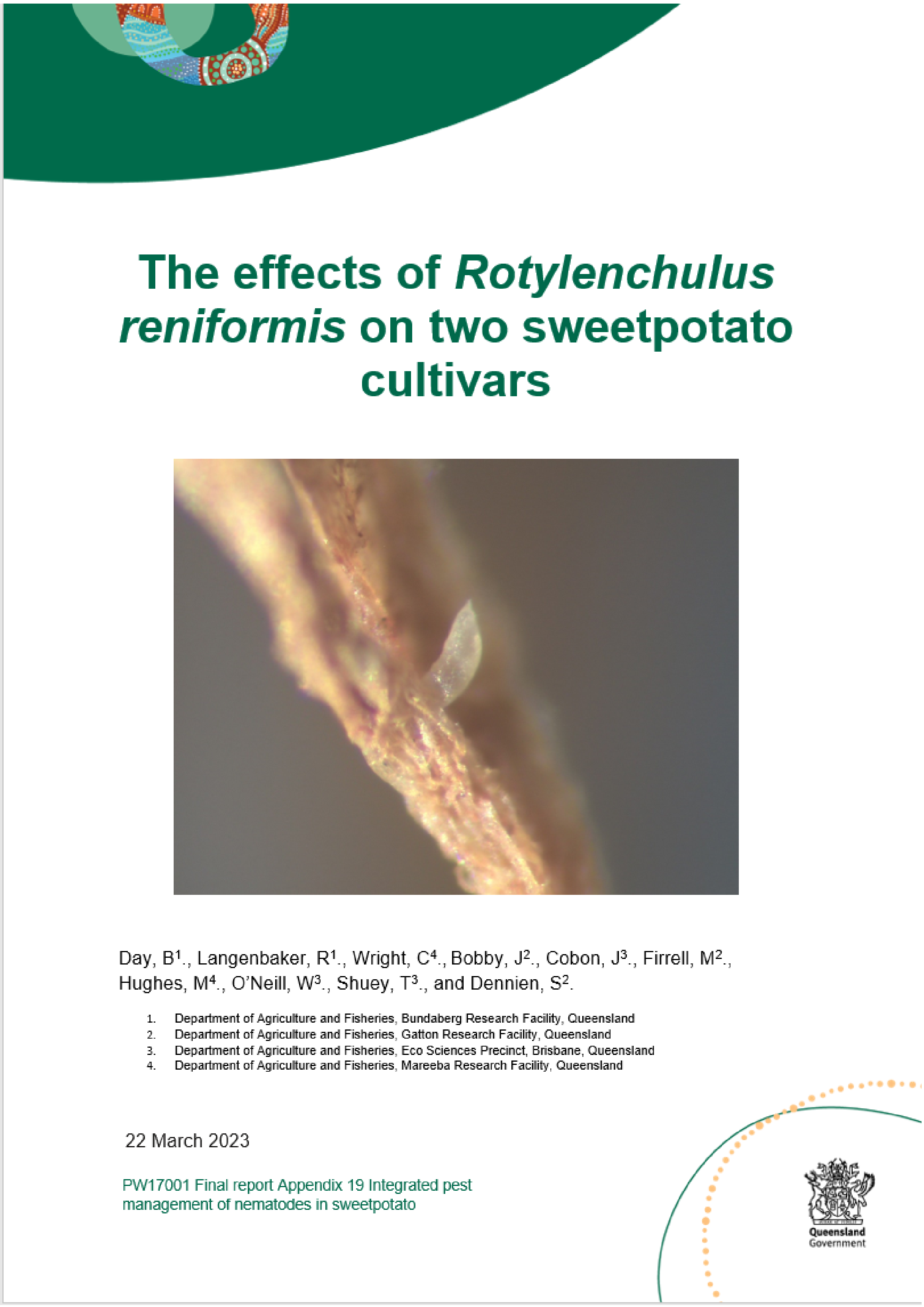
	Double	11.9 cde	0.6 d	0.8 c	0.4 cd	5.9 c	0.5 c
	Incorporated	19.1 abc	5.8 bcd	11.8 ab	5.1 ab	14.3 ab	6.4 ab
	VFurrow	17.6 bcd	4.4 bcd	8.3 ab	1.6 bcd	13.3 ab	3.8 abc
F		4.87	2.95	3.13	3.72	2.71	2.32
p		<0.001	0.014	0.010	0.004	0.025	0.048
Average 95% lsd		10.25	6.91	11.90	4.34	8.13	5.28

Acknowledgements

This trial was provided funding by Hort Innovation under the project, *PW17001 Integrated Pest Management of Nematodes* and the Department of Agriculture and Fisheries. The authors would like to thank DAF biometrician Dr. Carole Wright for conducting the data analysis. We also like to thank Russell McCrystal from McCrystal Ag, Daniel Prichard of C&KM Prichard and their support and assistance with this trial. Further, we would like to thank Justin Davies facility manager at Bundaberg Research Facility and the Bundaberg farm staff along with Andrew Kelly facility manager at Gatton Research Facility and the Gatton farm staff.

Appendix 19

The effects of *Rotylenchulus reniformis* on two sweetpotato cultivars



The effects of *Rotylenchulus reniformis* on two sweetpotato cultivars

Day, B[1]., Langenbaker, R[1]., Wright, C[4]., Bobby, J[2]., Cobon, J[3]., Firrell, M[2]., Hughes, M[4]., O'Neill, W[3]., Shuey, T[3]., and Dennien, S[2].

1. Department of Agriculture and Fisheries, Bundaberg Research Facility, Queensland
2. Department of Agriculture and Fisheries, Gatton Research Facility, Queensland
3. Department of Agriculture and Fisheries, Eco Sciences Precinct, Brisbane, Queensland
4. Department of Agriculture and Fisheries, Mareeba Research Facility, Queensland

22 March 2023

PW17001 Final report Appendix 19 Integrated pest management of nematodes in sweetpotato

Introduction

In 1960 R. reniformis was found pathogenic to sweetpotato (Martin 1960) and has since become an important pest in the United States (US) sweetpotato production (Smith et al 2017). The literature describing the damage on sweetpotato from R. reniformis is limited. Robinson (2002), Abel et al. (2007) and Smith et al. (2017) reported R. reniformis causes yield decreases, with minimal visual symptoms. On the other hand, Thomas (1982), Walters and Barker (1993) and Dutta et al. (2018) found R. reniformis reduced yields with visual symptoms of root cracking, root distortion, root necrosis and foliage stunting and yellowing. Stirling (2022) adds that problems caused by R. reniformis are difficult to diagnose as distinctive symptoms on roots are not produced.

R. reniformis can survive in air-dried soil stored at 20-25°C for seven months (Reddy 2021). Under drought conditions they can enter an anhydrobiotic state which can keep the nematode alive for up to two years outside of a host plant (Robinson et al 1997, Wang 2001). A trait which enhances survival and makes the pest more difficult to control.

In the state of Louisiana and Georgia in the US, the R. reniformis has proven to be a problematic nematode affecting sweetpotato production. Previously M. incognita was considered the most important parasite of sweetpotato, but the increase and spread of R. reniformis populations has seen the rise of prominence of this nematode (Smith et al 2017).

R. reniformis is present in Australia. It has long been established on horticultural crops in tropical parts of the country and was detected in soils of cotton farming systems of Emerald in 2003 (Roughly & Smith 2015). The nematode has also been found in Queensland's sweetpotato production areas (Stirling 2022, Dennien et al 2022a). An integrated pest management project aimed at nematodes found that R. reniformis populations may increase as root-knot nematode populations decrease (Dennien et al 2022b). Thomas, alone (1982), then later with Clark (1983), observed a competitive and inhibitive dynamic between the two nematode species that would often see one species dominate the other.

The aim of this pot trial was to assess the effects of R. reniformis on two popular Australian sweetpotato cultivars, Beauregard and Bellevue, to determine the damage the nematode causes to storage roots. The cultivars were chosen due to their nematode resistance. Bellevue, developed by Louisiana Agricultural Experiment Station, is considered highly resistant to southern root-knot nematode, Meloidogyne incognita (La Bonte et al 2015). Beauregard is a susceptible variety with Walters and Barker (1993) describing the cultivar as an excellent host for nematodes.

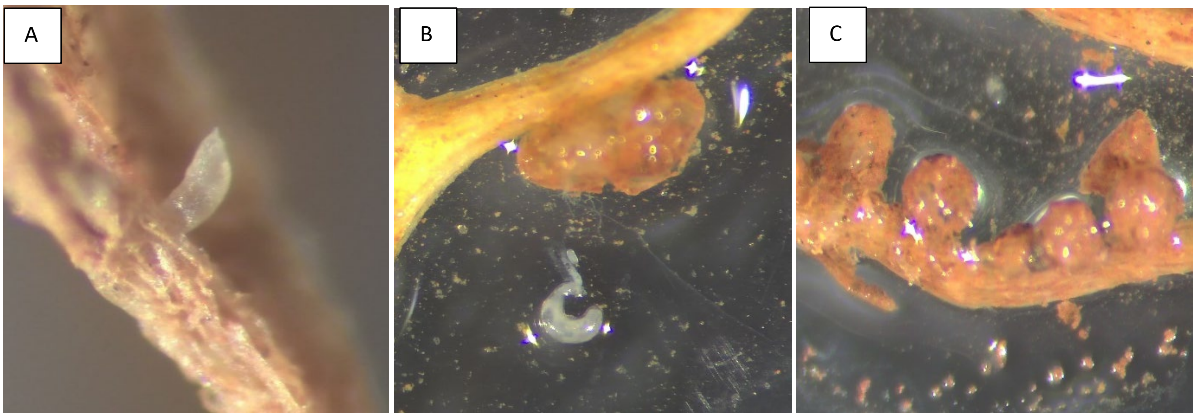


Image 1. a) *R reniformis* attached to a fibrous root; b) detached *R. reniformis* alongside an egg mass attached to the fibrous root; c) *R. reniformis* egg masses on fibrous roots.

Methodology

Experimental Set Up

This experiment was a randomised pot trial grown in pasteurised soil in an insect proof plant house. The trial consisted of two sweetpotato cultivars (Bellevue and Beauregard) each with two treatments, a nematode treatment (pots inoculated with a known number of juvenile *R. reniformis* nematodes) and a control treatment, (no inoculation) and six replicates of each cultivar/nematode treatment (Table 1). Twelve cuttings of each cultivar were grown in individual pots giving a total of 24 pots. This pot trial was grown according to best sweetpotato practice for 132 days, approximately the duration of a commercial crop.

Table 1. Pot trial design

Cultivar	Number of plants	Treatment	
Beauregard	12	6 x inoculated with R. reniformis	6 x control
Bellevue	12	6 x inoculated with R. reniformis	6 x control

The vines were planted on the 27th of September 2022 (Image 2a & 2b). The inoculation of R. reniformis occurred 16 days later, once the vines had established a thriving root system, ensuring an effective delivery of the nematodes onto plants.

Image 2. a) Beauregard (back) and Bellevue (front) vine; b) vine is laid in the furrow with all 4 nodes buried; c) inoculum mix evenly distributed into the furrows.

Inoculation was delivered by applying a bag of sand and root mixture infested with *R. reniformis* derived from a pure population into furrows dug 5cm deep either side of the vine (Image 2c). Each bag consisted of 100g of infested roots mixed with 200ml of nematology sand mix. The approximate reniform egg count being delivered to each pot was 156,800 eggs/pot (5807 eggs per litre of soil).

The trial was harvested on the 6 February 2023. The above ground biomass was removed, and roots obtained from each pot were washed free of soil. A representative soil sample was collected from each pot and sent to DAF nematology experts to determine the nematode populations per pot.

Assessment and Measurements

Roots harvested from each pot were individually inspected for damage according to sweetpotato nematode assessment protocols. Individual root weight, length, and diameter were recorded as was an overall weight of fibrous roots. While weights were taken, grading was done by damage level using industry standards to determine first grade, second grade or non-marketable sweetpotatoes.

Data was collected;

- Quantitative measurements using balance and calipers.
- Qualitative measurements;

Damage was rated using the proportion of skin surface area affected:

- Low: 0 – 33% of the sweetpotato surface area
- Medium: 34 – 66% of the sweetpotato surface area
- High: 67 – 100% of the sweetpotato surface area
- Presence / Absence of listed defects were also recorded.

Data analysis

The total root weight, mean root weight, mean root length, mean root diameter, and fibrous root weight were analysed using analysis of variance (ANOVA). The proportion of roots with the different types of damage were analysed using a generalised linear model (GLM). The number of roots in each pot were analysed using a Poisson GLM with a log link function. Analysis results were deemed significant at the 0.05 level. Where a significant effect was found, the 95% least significant difference (lsd) was used to make pairwise comparisons.

Results

Nematode Counts

All inoculated pots had high numbers of R. reniformis in the soil samples, indicating that the pest had established and reproduced. Counts ranged from 3455 to 22467 per 200g of soil (dry weight). The variety Beauregard had a mean count of 13 432/200g soil whereas Bellevue had a mean of 7021. This indicates that Bellevue's resistance to root-knot nematode may also confer some partial resistance to R. reniformis. Further data analysis is required to determine statistical significance of this finding.

Root Count

There was a noticeable difference of treatment effect on root count. Both Beauregard and Bellevue produced less roots in the nematode inoculated pots. However, the analysis showed this was not significant ($p = 0.260$). When comparing the treatment effect without cultivar influence, a marginally significant effect of treatment is found suggesting the nil treatments produced more roots per pot than the nematode treatment (Table 2).

Table 2. Root count by treatment

Root Count by Treatment		
Treatment	Pred Mean	se
Nematode	7.6	0.79
Nil	10.0	0.91

Root weight and size

Although there were no significant differences in total root weight by treatment ($p > 0.05$), the mean individual root weight was significantly higher in the nematode treated pots than compared with the nil treatments (Table 3). While not significant ($p > 0.05$), the roots from the nematode treatments had a higher mean root length and mean root diameter (Table 4).

Table 3. Mean individual root weight by treatment

Treatment	Pred Mean
Nematode	116.2 a
Nil	91.8 b
p-value	0.031
$F_{(1,15)}$	5.66
se	7.26
95% lsd	21.87

Table 4. Mean root length and mean root diameter per cultivar / treatment

Cultivar	Treatment	Mean Root Length	Mean Root Diameter
Beauregard	Nematode	134.8	38.8
	Nil	128.9	37.7
Bellevue	Nematode	149.4	36.5
	Nil	141.0	34.0

Darkened Lateral Root Scar

Darkened lateral feeder root scars (DLRS) were found on both cultivars. For both cultivars, the nematode treated pots had significantly higher mean proportion of DLRS than the nil treatments (Figure 1). The analysis suggests the incidence of darkened lateral feeder root scars is driven by treatment.

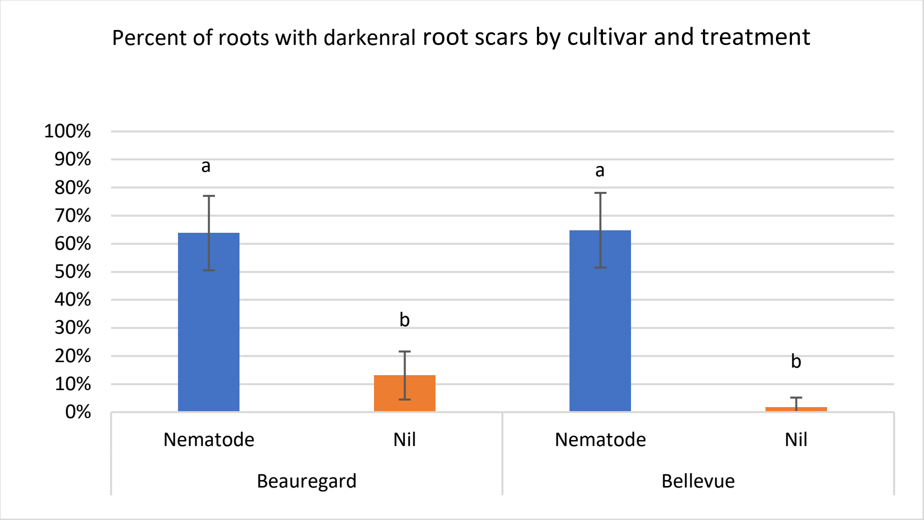


Figure 1. Percent of DLRS by cultivar and treatment

Black Pimple

Black pimples were another visual defect that was detected on both cultivars. Analysis on the occurrence of black pimples was marginally significant when comparing inoculated pots with nil treatment (Table 5).

Table 5. Mean incidences of black pimple by treatment

Treatment	Pred Mean	se
Nematode	0.2218	0.08028
Nil	0.0414	0.03345

Discussion

Nematode treated pots produced a lower quantity of roots. However, the roots produced had a higher mean root weight, length, and diameters (i.e. were larger roots). This trend was evident in both cultivars. R. reniformis may reduce the number of developing storage roots. Thomas (1982) observed a significant root growth stimulation in R. reniformis infested plants. Reducing the number of developing roots could direct more nutrients and energy to fewer roots, leading to an increase in size but a reduced yield overall. The nematode free pots have more roots competing for space and nutrients. Overly large sweetpotatoes in a commercial crop are not desirable and are downgraded as “Jumbos”. This experiment shows that the presence of R. reniformis lead to fewer, larger storage roots and so could cause economic losses that are not obvious to a grower.

Two visual defects that affect marketability were found to be related to the presence of R.reniformis in this experiment. DLRS occur when the lateral roots are damaged, and a wound response is initiated. The result is an indent on the root surface filled with a darkened scab-like layer on the periderm. Nematode treated pots had a significantly higher level of DLRS. As DLRS were still found on the nil treatments, this may a naturally occurring event that nematodes exacerbate. R. reniformis were not observed with microscopic examination of the DLRS.

While only marginally significant, higher levels of black pimples were found on nematode treated roots. Finding black pimples on nil treated roots also suggests this is a natural defect. Higher proportions on nematode treated roots may indicate that R. reniformis intensifies the occurrence.

There were no cracks or rots recorded in this trial. This does not rule out the possibility that R. reniformis may cause these defects in the field. Barnacle defects (extensive areas of raised lesions) were found exclusively on Beauregard roots and were not significant, suggesting this may not be caused by R. reniformis but instead may be a cultivar issue. Raised pimples, elongated lenticles and sunken lenticles while found on both cultivars and treatments showed no significant relationships.

Conclusion

While it is difficult to definitively distinguish the damage caused by R. reniformis, this experiment indicates that the nematode has an impact on the quantity and quality of sweetpotato crops. R. reniformis will reduce the number of roots a plant can produce though the remaining roots may be larger due to less roots competing for resources. The reduction in root numbers and the inclination for R. reniformis to feed on fibrous roots, suggest that the most damage comes while the roots are still forming and therefore prevent development. This observation supports the findings of Clark and Wright (1983) who suggested that R. reniformis won't develop on storage roots once they enlarge past approximately 5 – 10mm in diameter.

DLRS and black pimple will be found in higher proportions than is naturally occurring when R. reniformis is present, reducing the quality of sweetpotato. The presence of the nematode will reduce the quantity and quality of sweetpotato harvests. It is recommended that the current best practice for nematode management be followed to ensure the harvest of quality sweetpotatoes.

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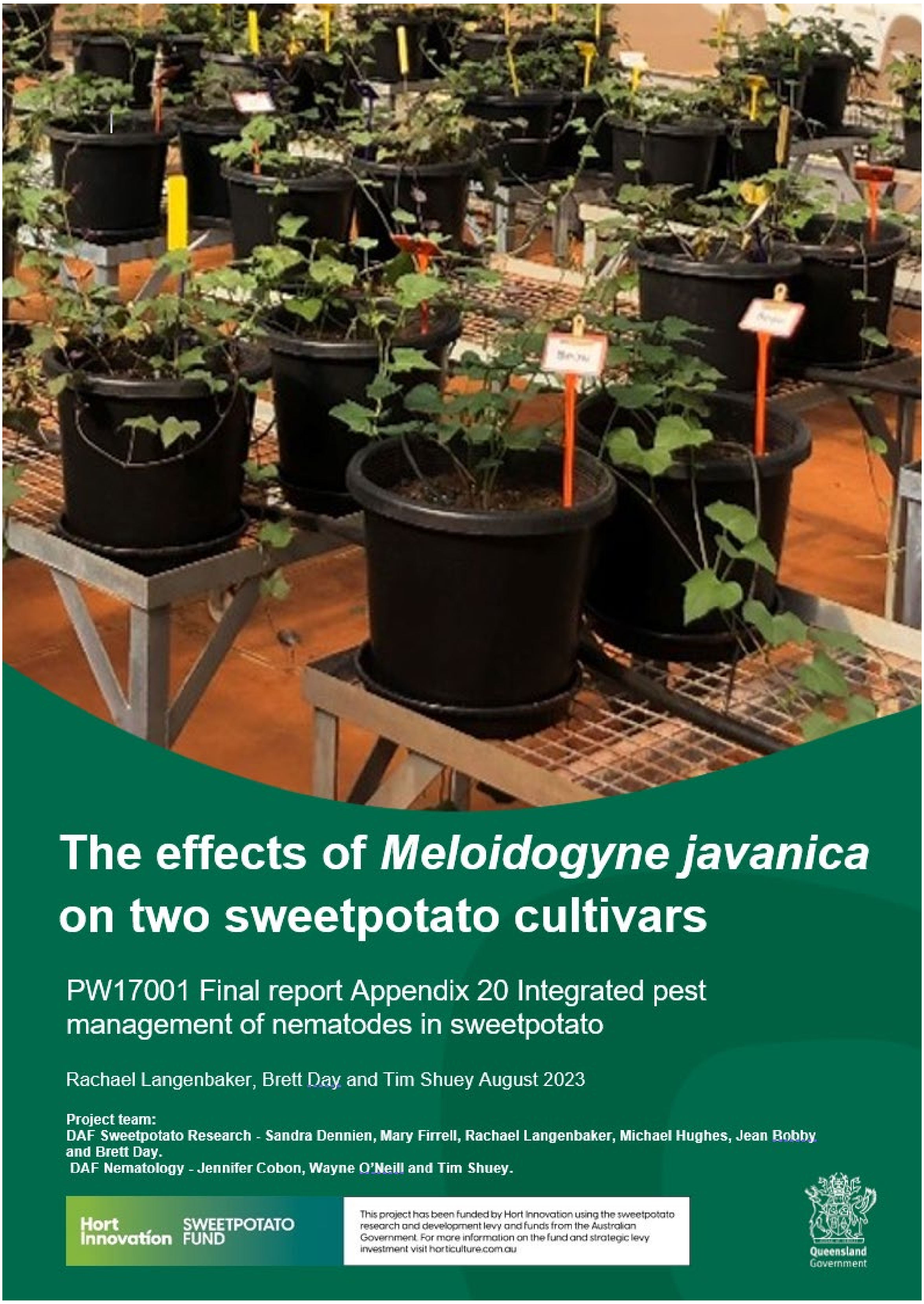
Appendix 20

The effects of *Meloidogyne javanica* on two sweetpotato cultivars



The effects of *Meloidogyne javanica* on two sweetpotato cultivars

PW17001 Final report Appendix 20 Integrated pest management of nematodes in sweetpotato

Rachael Langenbaker, Brett Day and Tim Shuey August 2023

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

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Summary

To determine the effects of RKN species M. javanica infection on storage roots, a long term pot trial was conducted in 2022 at the Bundaberg Research facility plant house. A report on the trial can be found in Appendix 17. The trial was designed to investigate the damage to skin quality caused by Root-knot nematode (Meloidogyne javanica) on the storage roots of two sweetpotato cultivars Beauregard and Bellevue.

Outputs

Results indicated that the higher the *M.javannica* population in the soil, the lower the number of premium roots and the higher the percentage of non-marketable roots. Data indicates that the Beauregard cultivar is more susceptible to *M. javanica* infection than Bellevue, with mean *M. javanica* counts more than 3 times that of the Bellevue plants. There also appears to be some evidence that Bellevue is more resistant to barnacles than Beauregard. The data from this trial supports previous studies suggesting that Beauregard is highly susceptible to *M. javanica* and Bellevue moderately susceptible (Cobon et al., 2021).

Infection with *M. javanica* reduced both the number of roots produced and the overall weight of roots and was associated with reduced marketability, ultimately negatively impacting crop value.

Outcomes /Take home message/key findings.

The mean M. Javanica count in pots from Beauregard plants was more than 3 times that of the pots containing Bellevue plants, indicating that the Beauregard variety is more susceptible to RKN infection.

The higher the *M.javannica* population in the soil, the lower the number of premium roots and the higher the percentage of non-marketable roots.

Infection with *M. javanica* reduced both the number of roots produced and the overall weight of roots and was associated with reduced marketability, ultimately negatively impacting crop value.

The effects of *Meloidogyne javanica* on two sweetpotato cultivars

Introduction

Root-knot nematode (RKN), *Meloidogyne* spp. are a species of great importance to the sweetpotato industry in Australia. Root-knot nematode is estimated to cost the industry $20 million per year (Cobon et al., 2021). Stirling (2021) states that nematode damage often results in 5–20% of marketable sweetpotato being discarded, occasionally reaching as high as 75% in some cases. *M. javanica* is one of the four *Meloidogyne* species associated with sweetpotato in Australia. It can be found throughout southern Queensland and northern coastal New South Wales and is the most widespread RKN species in areas where sweetpotatoes are grown (Stirling et al., 2020).

The above-ground symptoms of *Meloidogyne* spp. can sometimes be seen, but not always, in the form of stunting, wilting, and yellowing (Stirling, 2016; Quesada-Ocampo, 2018; Grabau & Noling, 2021). Below-ground, infested feeder roots display a distinctive galling which can range from 1-2mm to the size of marbles (Stirling 2016). Quesada-Ocampo (2018) reported that cracking of the storage roots maybe another below-ground symptom. Grabau & Noling (2021) state that storage root cracking is infrequent in modern cultivars. Smith et al (2017) describes roots damaged by root-knot nematode as being rough textured, malformed, and cracked. On the Beauregard variety, the nematode can cause pimples or raised areas in which root-knot nematode can sometimes be found (Smith et al., 2017). Thomas (1982) found malformed, deeply indented roots with rough scabs that are linked with newly developed sprouts that have been attacked and destroyed. Hajihassani (2022) describes symptoms as veiny appearance, surface cracking, and bumpy yellow to brown-coloured specks.

This pot trial was developed to assess the effects of *M. javanica* on two Australian grown sweetpotato cultivars, Beauregard and Bellevue. Both cultivars are known hosts, with Beauregard found to be highly susceptible to *M. javanica* and Bellevue moderately susceptible (Cobon et al 2021). Anecdotal evidence from sweetpotato growers suggests that Bellevue planted into blocks with populations of M. javanica rarely display symptoms of RKN infection Dennien pers. Comm., 2021.

Methodology

Experimental Set Up

The pot trial experiment was a randomised design conducted in an insect proof plant house. Pots were filled with pasteurised field soil. Two sweetpotato cultivars (Bellevue and Beauregard) were each subjected to two treatments, a nematode treatment (pots inoculated with a known number of M. javanica eggs), and a control treatment (no inoculation). Both treatments consisted of six replicates (Table 1). Twelve cuttings of each cultivar were grown in individual 27L pots giving a total of 24 pots. Plants were grown using best practice agronomy for 132 days, the approximate duration of a commercial crop.

Table 58 Pot trial design

Cultivar	Number of plants	Treatment
Beauregard	12	6 plants inoculated with *M. javanica*
Beauregard	12	6 plants inoculated with *M. javanica*
Bellevue	12	6 control plants not inoculated
Bellevue	12	6 control plants not inoculated

Sweetpotato vines were planted on the 27th of September 2022 (Image 3a & 3b). The inoculation of *M. javanica* occurred 16 days later, once the vines had established a thriving root system ensuring delivery of the nematodes onto plants.

Image 38 a) Beauregard (back) and Bellevue (front) vine; b) vine is laid in the furrow with all 4 nodes buried; c) inoculum mix evenly distributed into the furrows.

Inoculation was delivered by applying a bag of nematode infested sand and root mixture into furrows dug 5cm deep either side of the vine (Fig. 3c). Each bag consisted of 100g of infested roots mixed with 200mL of Queensland DAF nematology sand mix. The approximate root-knot egg count being delivered to each pot was 295,200 eggs/pot (10,933 eggs per litre of soil).

The trial was harvested on the 6th February 2023 at 132 days after planting. The canopy biomass was removed before carefully excavating the roots of each pot. The roots were then carefully hand washed to remove dirt prior to assessment. A representative soil sample of approximately 500g from each pot was collected and sent for extraction and quantification of nematodes.

Assessment and Measurements

Roots harvested from each pot were individually inspected for damage according to sweetpotato nematode assessment protocols. Individual root weight, length, and diameter were recorded, as was an overall weight of fibrous roots. Each storage root was assessed for damage severity and size graded using industry standards to determine first grade, second grade or non-marketable.

Data collection:

1. Quantitative measurements using balance and calipers.
2. Qualitative measurements:
    - Damage was rated using the proportion of skin surface area affected:
    - Low: 0 – 33% of the sweetpotato surface area
    - Medium: 34 – 66% of the sweetpotato surface area
    - High: 67 – 100% of the sweetpotato surface area
3. Presence / Absence of listed defects was also recorded.

Data analysis

Total and mean root weight, length and diameter, and total fibrous root weight were analysed using analysis of variance (ANOVA). The proportion of roots with the different types of damage was analysed using a generalised linear model (GLM). The number of roots in each pot was analysed using a Poisson GLM with a log link function. Analysis results were deemed significant at the 0.05 level. Where a significant effect was found, the 95% least significant difference (lsd) was used to make pairwise comparisons.

Results

Raised Pimples

Raised pimples were observed on storage roots in both treatments and both cultivars during assessment. Analysis of sweetpotato roots with raised pimples found that the nematode inoculated pots had a significantly higher prevalence of raised pimples compared to the control pots (Fig. 1). There was a high incidence of raised pimples in pots 12 and 15, which were treated pots. Five plants with a medium damage rating had been inoculated. Raised pimples were found only in low numbers in some control pots. RKN were found to have contaminated one of these control pots. Since the raised pimples were assessed in control plants where RKN were absent, the raised pimples on control plants may have been shoots in the early stage of formation. Another explanation could be that shoots will form a raised pimple and RKN may take advantage of the fresh vulnerable shoot. This could explain why RKN are found in some raised pimples and not all.

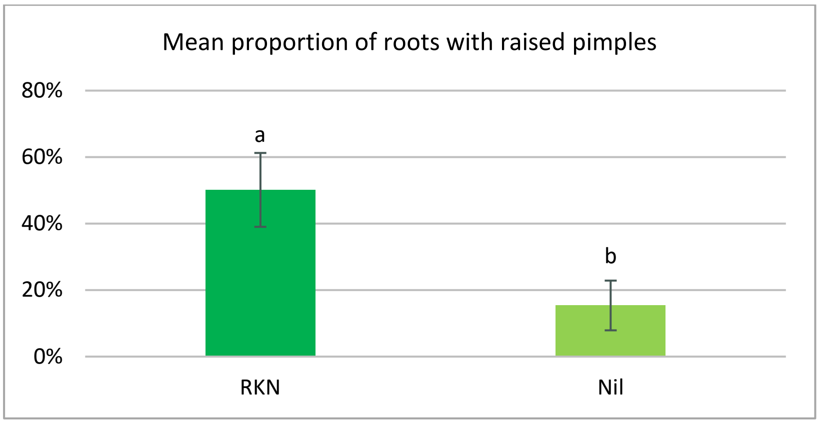

Figure 62 Mean proportion of roots with raised pimples.

Black Pimples

There was a significantly higher proportion of Black pimples on roots form the inoculated pots than the uninoculated pots of both Beauregard and Bellevue varieties (Table 2). Of all pots where RKN were detected, only three were found to have an absence of black pimples during the assessment. These three pots had the lowest RKN counts at 5, 48 and 108 RKN / 200g soil. The lowest RKN count with an incidence of black pimples was 135 RKN/ 200g soil. Black pimples were found in high incidences in 4 pots; of those, the lowest count was 321 RKN / 200g soil.

Table 59 Mean proportion of Beauregard and Bellevue roots with black pimples.

Black Pimple Mean Proportion		
Treatment	Mean	se
RKN	0.4615 a	0.06791
Nil	0.0000 b	0.00019
	95% lsd = 0.1457	

Barnacles

Roots with barnacle defects were found in significantly higher proportions in the Beauregard variety inoculated with RKN (Fig. 2). All Beauregard roots inoculated with nematodes, except one, displayed barnacles.. High incidences of the defect (four roots all with a high incidence of barnacles) were found in the nematode inoculated Bellevue pot 8, which had a RKN count of 7,984 / 200g soil. No barnacles were found on uninoculated Bellevue roots.

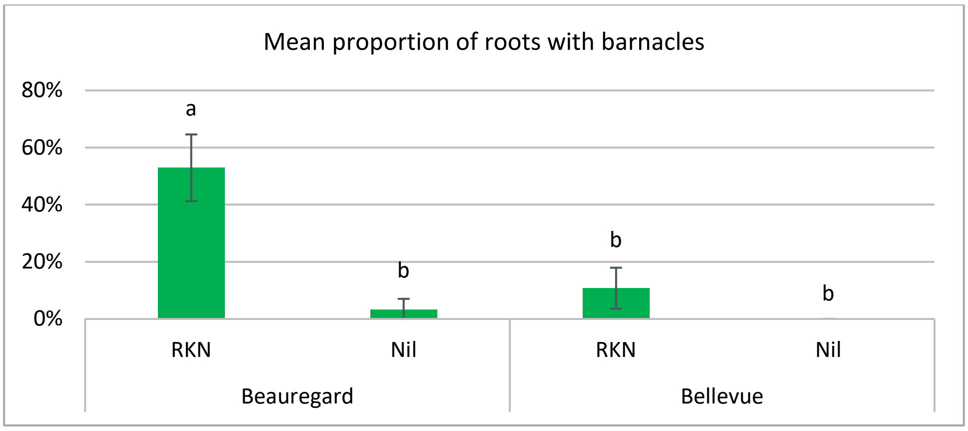

Figure 63 Mean proportion of roots with barnacles.

Darkened Lateral Root Scars

Darkened lateral root scars (DLRS) were found to be significantly higher on roots of Beauregard plants inoculated with nematodes (Fig. 3). Roots produced by uninoculated Beauregard plants were similar in DLRS incidence as the inoculated Bellevue roots. DLRS were found in all pots with the exception of five uninoculated pots.

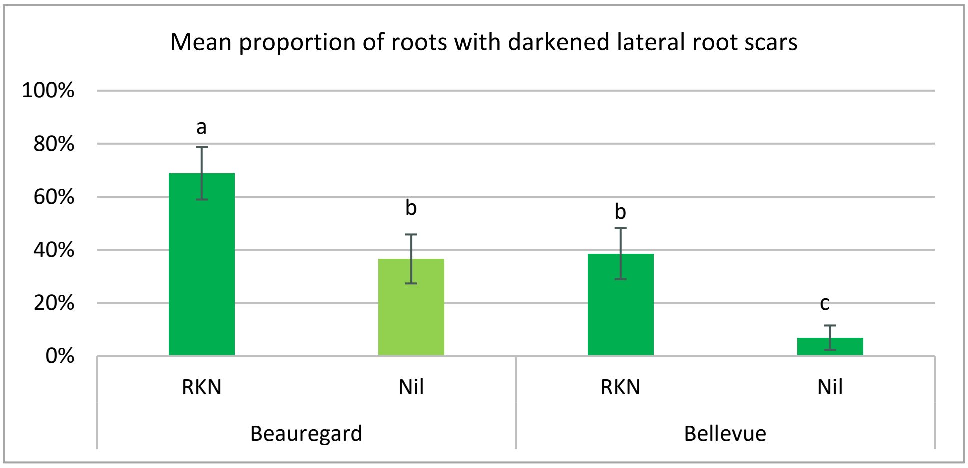

Figure 64 Mean proportion of roots with DLRS.

Elongated Lenticels

Significant differences were only found in roots that had a medium incidence of elongated lenticels (Fig. 4). Roots form inoculated Beauregard plants had a significantly higher medium rated incidence of elongated lenticels than both of the uninoculated varieties. Elongated lenticels were only found in low quantities on uninoculated Bellevue roots. Roots from twelve of the 20 plants exhibiting elongated lenticels were recorded at low severity.

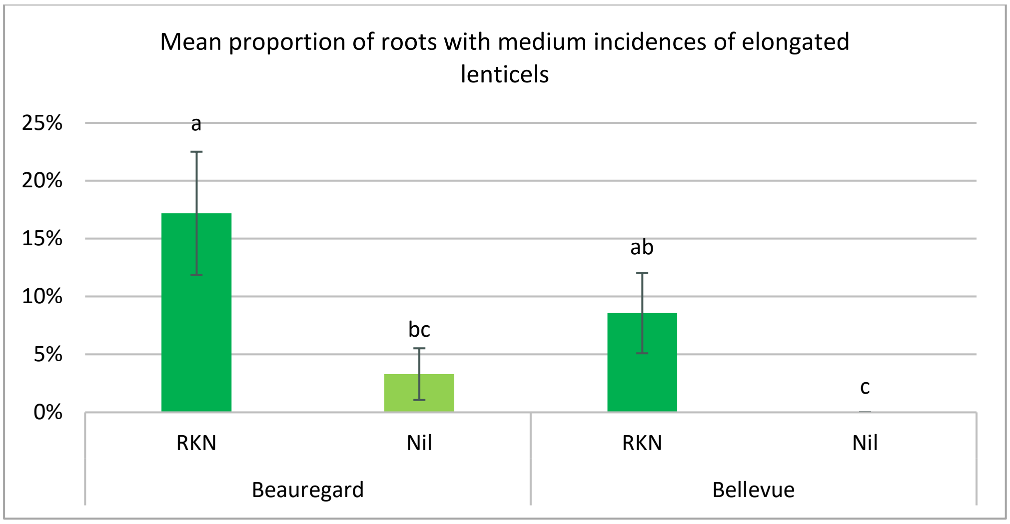

Figure 65 Mean proportion of roots with medium incidences of elongated lenticels.

Marketability

The Bellevue uninoculated plantswere found to produce the highest proportion of premium marketable first grade roots (Fig. 5). The inoculated Bellevue plants produced a significantly higher proportion of marketable first roots than both the inoculated and uninoculated treatments of Beauregard. The innoculated Beauregard did not produce any premium roots in this trial. This is a cultivar effect with Bellevue being a superior, higher yielding cultivar.

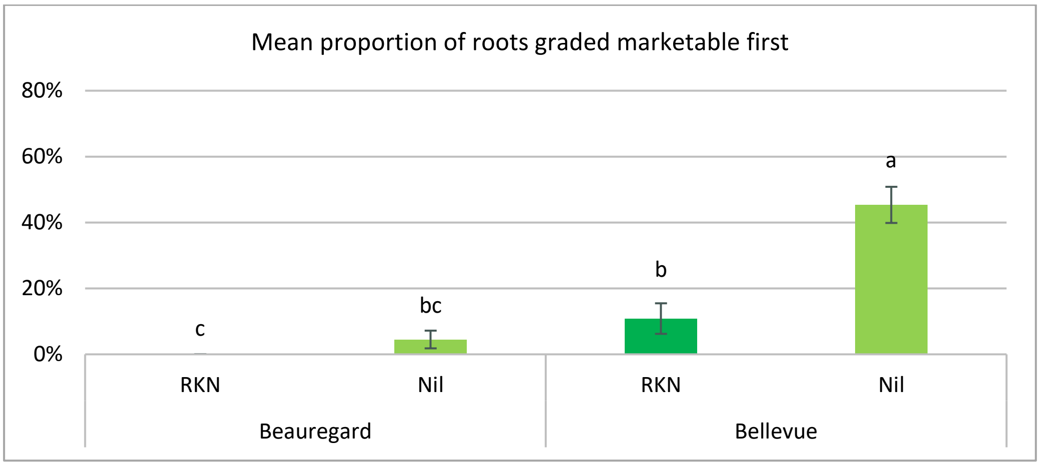

Figure 66 Mean proportion of roots graded marketable first.

The highest proportion of non-marketable roots were recorded in the inoculated Beauregard treatment, which was significantly higher than both Bellevue treatments (Fig. 6). Inoculated Bellevue roots were found to be non-marketable in higher proportions than the uninoculated Bellevue.

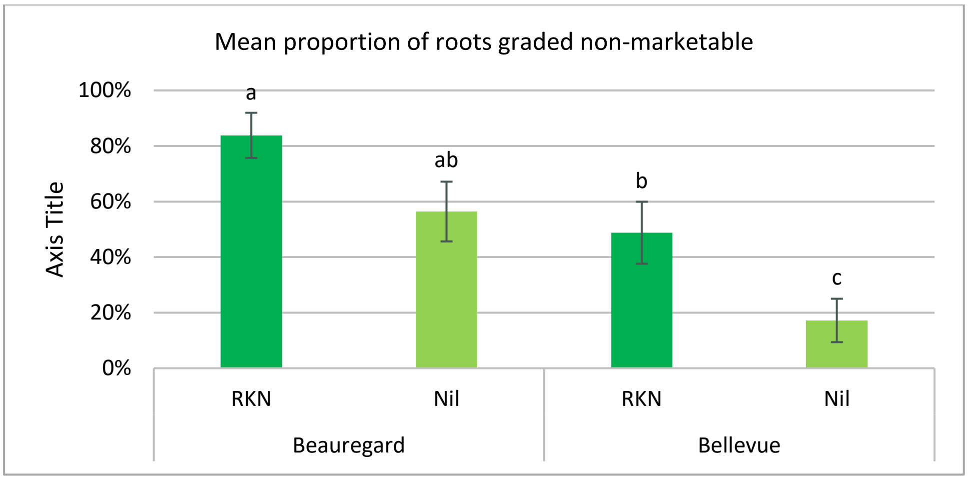

Figure 67 Mean proportion of roots graded non-marketable.

Discussion

The mean M. Javanica count in pots from Beauregard plants was more than 3 times that of the pots containing Bellevue plants. The uninoculated or Nil treatment Bellevue plants produced a significantly higher mean proportion of marketable first grade roots than the M. javanica inoculated plants. This was significantly higher than both the uninoculated Beauregard (did not produce any premium roots) and inoculated Beauregard plants. Inoculated Beauregard plants produced a significantly higher mean proportion of non- marketable roots and this was significantly higher than uninoculated Bellevue plants. Both Beauregard and Bellevue inoculated plants had a lower mean fibrous root weight than the uninoculated Beauregard and Bellevue plants. Across both cultivars overall, plants in the nil treatment (uninoculated plants) had a significantly higher mean root count than the nematode treatment (M. javanica inoculated plants).

A number of defects were found to occur on both inoculated and uninoculated roots suggesting that factors other than nematode infection were involved in the development of some skin defects whereas some skin defects were increased significantly in the inoculated pots indicating that the presence of M. javanica could intensify these defects. Plants of Beauregard and Bellevue inoculated with M. javanica produced a higher mean proportion of roots with black pimples than the uninoculated plants which did not display any black pimples.

Occurrences of DLSRs were assessed on a high, medium and low scale. The mean proportion of roots with medium rated DLSRs was significantly higher in roots produced by inoculated Beauregard plants compared to all other treatment combinations.

An analysis of relationships between pot soil counts of M. javanica, root characteristics and presence or absence of skin defects using Spearman’s rank correlation coefficient identified the following significant correlations:

- As the M. javanica count increased, the number of roots produced decreased.
- As the M. javanica count increased, the mean root weight decreased.
- As the M. javanica count increased, the percentage of roots with a low rating of black pimple appears to have increased. No roots had a black pimple rating of low when the RKN count was 108 or less. Black pimple at a low rating was observed when the RKN count reached 135.
- As the M. javanica count increased, the the percentage of first grade roots produced by plants decreased.
- As the M. javanica count increased, the percentage of reject grade roots appears to have increased.

Results indicated that the higher the *M.javannica* population in the soil, the lower the number of premium roots and the higher the percentage of non-marketable roots. Data indicates that the Beauregard cultivar is more susceptible to *M. javanica* infection than Bellevue, with mean *M. javanica* counts more than 3 times that of the Bellevue plants. There also appears to be some evidence that Bellevue is more resistant to barnacles than Beauregard. The data from this trial supports previous studies suggesting that Beauregard is highly susceptible to *M. javanica* and Bellevue moderately susceptible (Cobon et al., 2021).

Infection with *M. javanica* reduced both the number of roots produced and the overall weight of roots and was associated with reduced marketability, ultimately negatively impacting crop value.

Conclusion

The root-knot nematode *M. javanica* negatively impacts the commercial sweetpotato varieties Beauregard and Bellevue. RKN infection reduced both the number of roots produced and the overall weight of roots. *M. javanica* infection was also associated with reduced marketability, ultimately negatively impacting crop value. *M. javanica* enhanced the skin defects as well as causing defects such as black pimple or barnacles. The negative impact of this pest on a sweetpotato crop is severe enough to warrant the use of best practices in the management of this nematode.

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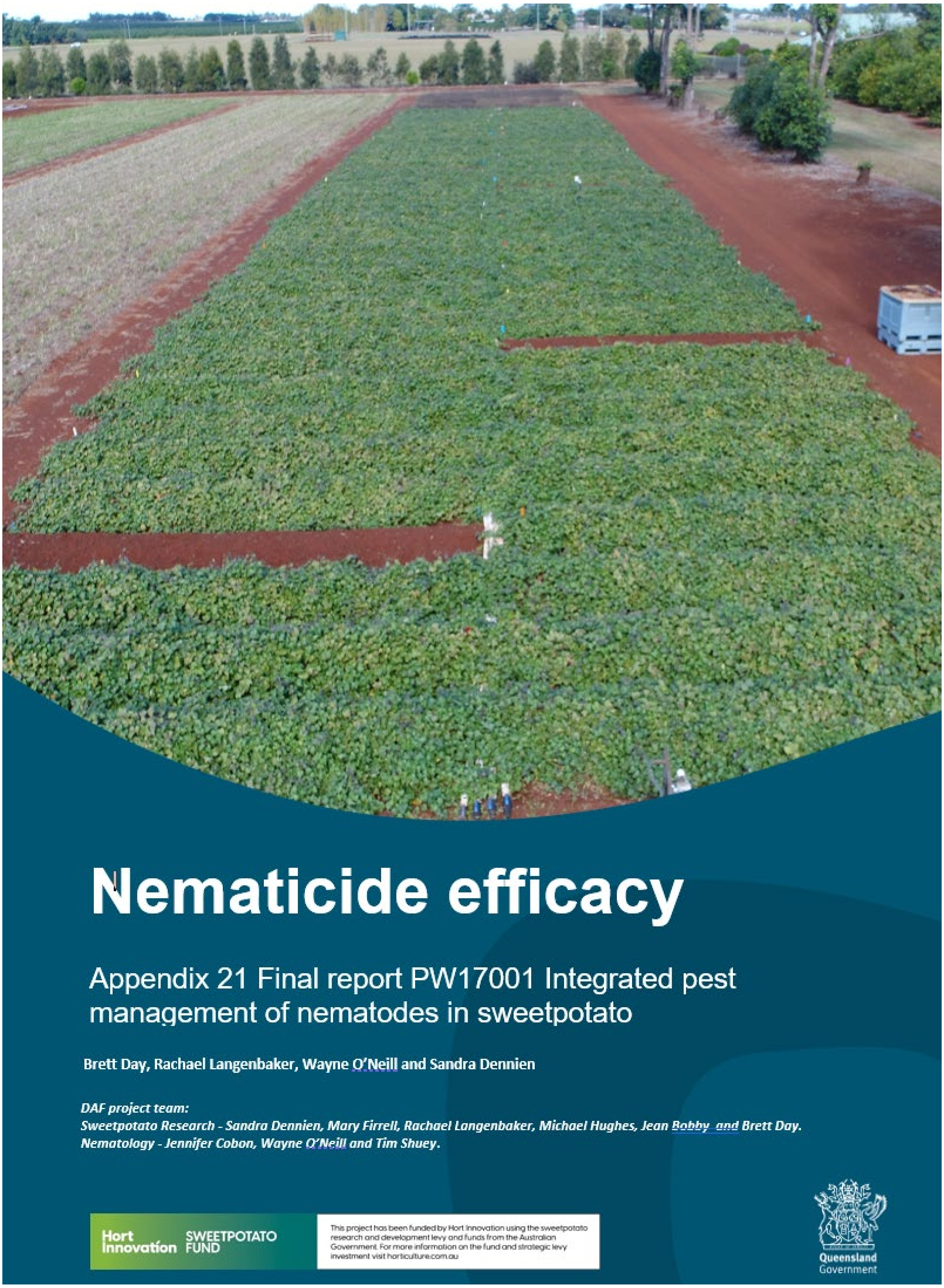
Appendix 21

Efficacy of current nematicides



Nematicide efficacy

Appendix 21 Final report PW17001 Integrated pest management of nematodes in sweetpotato

Brett Day, Rachael Langenbaker, Wayne O'Neill and Sandra Dennien

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

Hort Innovation SWEETPOTATO FUND

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Queensland Government

Summary

The sweetpotato industry has limited nematicides and fumigants available for nematode control. In response to industry priorities, two trials were designed to evaluate the efficacy of currently registered nematicides for RKN control over the long winter growing period.

Trial one was conducted a sandy loam due to low nematode numbers at this site, a susceptible mung bean crop was grown prior to the trial to build numbers. Efficacy was assessed by monitoring nematode populations and crop yield and quality assessments at commercial harvest. The trial was planted to sweetpotato cultivar Orleans on 24th May 2021 in collaboration with Mitchel Feint of AgPD. The crop was grown to commercial crop standards with trial site maintenance conducted throughout the growth of the crop. The trial design was a randomised block with six replicates with five treatments: Nimitz (incorporated spray), Vydate, Metham Sodium, a Nimitz alternative application method and a nil control treatment. All nematicides were applied at recommended label rates and timing. The trial was harvested in January 2022, 231 days after planting.

All nematicide treatments had significantly higher marketable yield than the nil treatment. Metham Sodium and Vydate also had significantly higher total yield than other treatments. There were also significant differences for certain defects that can be associated with nematode damage. For example, all nematicide treatments also had significantly less barnacle lesions than the nil control. In the medium size category, all nematicide treatments also had significantly less blind pimple lesions compared with the nil treatment.

The nematicide trial was sampled to assess plant-parasitic nematode numbers in May, June, August, October, and at harvest in January. Findings are based on mean nematode counts for each treatment.

Root-knot nematode counts at the start of the trial averaged around 30 per 200g dry soil across all plots when treatments were applied in May 2021. The Metham treatment had a rapid effect on plant-parasitic nematodes. No root-knot nematodes and very low numbers of other plant-parasitic species were recovered from Metham treated plots when the trial was sampled approximately two weeks after application.

When the trial was again sampled in June and August, root-knot nematode numbers had declined to undetectable levels in almost all plots (including untreated controls), likely due to limited root mass in the young crop and slow reproduction in the cooler months. However, by the October sampling, root-knot nematode numbers had increased dramatically in most treatments, with a mean of over 2000 RKN/200g dry soil in the untreated controls. Nimitz (normal application) had the lowest mean root-knot nematode count at this point in the trial, but despite the large differences in mean counts, the results for root-knot nematode were not significantly different as there was high variation between replicates. Vydate had the lowest numbers of total plant parasitic nematodes (spiral and reniform nematodes were the other abundant plant-parasitic nematodes).

Mean count of microarthropods increased significantly over time, with the last two assessments having significantly higher mean counts. Decline of microarthropods on 29-Jun-21 may be attributed to nematicide application. Nematicides, pesticides and fertilizers, have proven to reduce microarthropods population and or the soil microbiological community (Winter et al 1990, Seymour 2006, Stirling 2016).

The site where this trial was located has a sandy loam soil which can be more conducive to rapid build-up of RKN populations than some other soil types. Despite this limitation, some of the nematicides seem to have given sufficient protection in the crucial early stages of the crop to allow increased yield and reduced defects, despite RKN rapidly increasing to high levels by the end of the trial.

Trial 2 was conducted at the Bundaberg Research facility on red soil. This trial included a bare fallow and alternative application methods of Nimitz and Salibro. The ran from autumn 2022 to spring 2023.To increase the RKN population, susceptible cover crop species and inoculated tomato plants cv. Tiny Tim were planted across the trial block in autumn and spring of 2022,followed by a crop of RKN susceptible Mung beans and Lab Lab in December 2022. The trial was planted in March 2023 to cultivar Beauregard and designed as a randomised complete block with eight treatments and six replicates. Soil samples were collected to assess plant-parasitic and free-living nematode numbers in March, May, August, and at harvest in October 2023.Roots were dug on the 30th of October at 238 DAP.

Outcomes

Trial 1

- Metham treatment had a rapid effect on plat-parasitic nematodes.
- Microarthropod count increased overtime.
- All nematicide treatments had significantly higher marketable yield than nil.
- Metham sodium and Vydate had significantly higher total yield.

Trial 2

- The Nimitz alternative application provided the most consistent RKN control for the duration of the trial.
- The Nimitz alternative application provided consistent control of reniform nematode. Vydate and the alternative Salibro application also provided control for much of the trial period.
- Free-living nematode populations were impacted by some of the nematicides in the mid-trial period, but by the final sampling there were no significant differences between treatments for free-living nematodes.
- Without a susceptible host the root-knot nematode population dropped to low levels in the bare fallow treatment, as expected. Free-living nematode counts in the bare fallow treatment were not significantly different from those in the nil control sweetpotato crop.
- There was no treatment effect of nematicides on microarthropods.
- Vydate and Metham treated plots tended to produce a higher weight of total and medium sized roots and a higher number of roots. Roots grown in the Metham treated plots had a significantly higher occurrence of wireworm damage,

Nematicide Trial 1 - Sandy Soil

Introduction

Root-knot nematode (RKN) management is an integral step for sweetpotato growers as they pose a significant threat to the Australian sweetpotato industry. The damage that RKN are able to inflict on sweetpotato crops can result in high yield losses, with estimations that it costs the industry $20 m per year (ASPG per.com). Faced with the prospect of severe losses if left untreated, growers require effective and reliable products to treat RKN if pre-plant levels indicate losses are likely. The aim of this trial was to investigate the effects of currently registered commercial nematicides (Metham, Vydate and Nimitz) on RKN populations in a winter sweetpotato crop to gauge their efficacy.

Method

Due to long running drought conditions over most sweetpotato cropping areas during 2019 and 2020 this activity had to be deferred to 2021. This decision was not only based on the fact that there was a lack of available water but also an associated decline in nematode numbers throughout sweetpotato cropping areas. Despite sampling multiple on-farm blocks with previously high populations, no suitable sites could be found with high enough nematode numbers to run trials. Private research businesses contracted to chemical companies were in the same situation.

A suitable site with a mung bean crop in a sandy loam soil, conducive to rapid build-up of RKN populations was identified in January 2021, however sampling indicated very low nematode numbers. After a return of rainfall in April, the block was sampled again and numbers had increased, though were still not ideal. Despite this, a decision was made to proceed with the first trial and the Bundaberg site was planted with sweetpotato cultivar Orleans in May 2021.

Figure 1 The nematicide trial block in Bundaberg, December 2021

The trial was designed to investigate the efficacy of three currently registered nematicides, Metham sodium, Vydate and Nimitz to control RKN populations in sweetpotato. Routine soil samples were collected to extract RKN and other plant-parasitic species, free living nematodes, microarthropods and nematode trapping fungi (NTF). The trial design was a randomised block with six replicates of five treatments. The treatments were Nimitz (standard spray application), Vydate, Metham, a Nimitz alternative application method and a nil control treatment with no nematicide. All nematicides were applied at recommended label rates and recommended timing.

The trial site was a 19.5 m x 50 m block consisting of 6 datum rows, each bordered by a single buffer row for a total of 13 rows (Figure 1). The plots were 10 m long comprising 8 m of datum and 1m buffer at each end with five plots per lineal row. The total trial area was 0.0974 hectares. The total datum area was 360 m^2, or 0.036 hectares.

The trial was scheduled for harvest in December 2021, but had to be postponed to mid-January 2022 due to wet weather. Unfortunately, the rescheduled harvest date coincided with a spike in COVID-19 infections in QLD. COVID safe work protocols were developed and the required departmental approvals were obtained to conduct this group activity. With movement restrictions around locations with active cases in place, project staff from Mareeba and Ecosciences precinct were unable to attend and assist in the assessment.

The block was top chopped on the 6th of January 2022, and roots from the 1m buffer zones were removed. The sweetpotatoes were given 4 days to harden before harvest on the 10th of January 2022.

Image 39 Top chopping the nematicide trial in Bundaberg, January 2021.

Image 40 Removing the buffer plants by hand.

Harvested roots were washed in a chlorine solution using a standard butternut pumpkin washer and assessed from the 17th – 21st of January. Over 8000 roots were individually weighed and sorted into eight size categories: extra small, small, small medium, medium, medium large, large and jumbo. Roots were then placed into one of three marketability grades, first or premium grade, second grade and non-marketable. Defects were recorded using the categorisation system developed for the Intensive and Extensive trials designed to capture 18 common defects found in commercial sweetpotato production. Each root underwent close visual scrutiny and was evaluated using this system.

Image 41 Roots from the nematicide trial undergoing assessment, January 2022.

Image 42 Covid safe protocols were followed by the assessment team in 2022.

Results - Nematode population monitoring

The nematicide trial was sampled to assess plant-parasitic nematode numbers in May, June, August, October, and at harvest in January. Findings are based on mean nematode counts for each treatment.

Root-knot nematode counts at the start of the trial averaged around 30 per 200g dry soil across all plots when treatments were applied in May 2021. The Metham treatment had a rapid effect on plant-parasitic nematodes. No root-knot nematodes and very low numbers of other plant-parasitic species were recovered from Metham treated plots when the trial was sampled approximately two weeks after application.

When the trial was again sampled in June and August, root-knot nematode numbers had declined to undetectable levels in almost all plots (including untreated controls), likely due to limited root mass in the young crop and slow reproduction in the cooler months. However, by the October sampling, root-knot nematode numbers had increased dramatically in most treatments, with a mean of over 2000 RKN/200g dry soil in the untreated controls. Nimitz (normal application) had the lowest mean root-knot nematode count at this point in the trial, but despite the large differences in mean counts, the results for root-knot nematode were not significantly different as there was high variation between replicates. Vydate had the lowest numbers of total plant parasitic nematodes (spiral and reniform nematodes were the other abundant plant-parasitic nematodes).

Table 60. October 2021 and January 2022, Mean Nematode Counts/200g Dry Soil.

	RKN		Total Plant Parasitic nematodes	
Treatment	October 2021	January 2022	October 2021	January 2022
Nil	2287	1914	2943	3828
Metham	512	1910	902	2342
Vydate	118	3798	174	4358
Nimitz	25	1953	762	2884
Nimitz trickle	532	1746	903	3328

At the January 2022 harvest, mean root-knot nematode counts were high for all nematicide treatments as well as the nil control. Vydate treated plots had the highest RKN and total plant parasitic nematode counts, although the reasons for this are unclear. Reniform nematode numbers were high in some plots, but its distribution was patchy in the trial (mainly confined to the southeast corner), so it is hard to draw any conclusions about the effectiveness of particular nematicides to control this species.

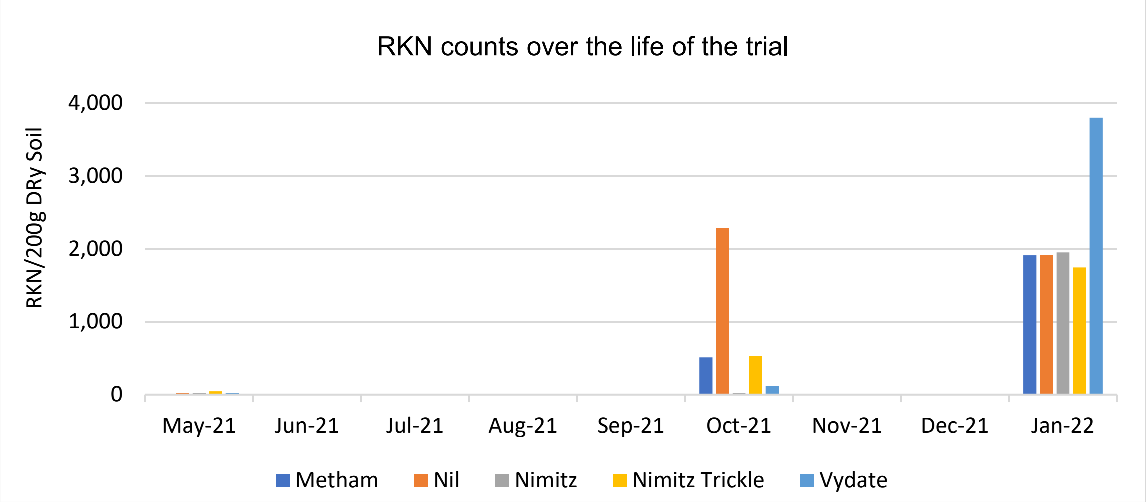

Figure 68 RKN counts over the life of the trial.

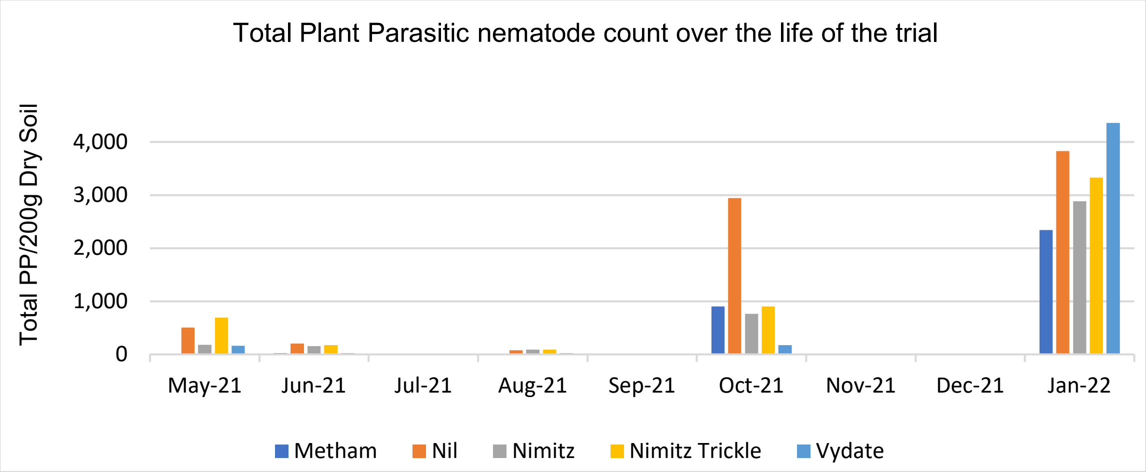

Figure 69 Total Plant Parasitic nematode counts over the life of the trial.

Results - Nematode trapping fungi and microarthropod monitoring

Data was collected on counts of microarthropods and nematode trapping fungi (NTF) and conidia. Data was collected on 5 occasions: 26/5/2021, 29/6/2021, 8/8/2021, 21/10/2021, 6/6/2022. A single count of microarthropods was recorded for each treatment plot, while the presence of NTF was recorded for 4 plates from each plot.

The counts of microarthropods were analysed using both a GLMM (generalised linear mixed model) and an ANOVA (analysis of variance). All significance testing was performed at the 0.05 level and where a significant effect was found, the 95% least significant difference (lsd) was used to make pairwise comparisons.

Microarthropods

Microarthropod data was analysed in several different ways to obtain a complete understanding of the results. Timepoint assessments were analysed together to investigate any temporal effects and then each assessment was analysed separately. A square root transformation was applied to the data prior to ANOVA in the combined assessment analysis to improve the normality assumption.

The results from the combined analysis suggest there is a significant main effect of collection date ($p < 0.001$), but the main effect of treatment was not significant ($p = 0.334$), nor was the interaction of collection date and treatment ($p = 0.893$). This indicates that there was no significant negative effect of any of the nematicide treatments on microarthropod populations in the sweetpotato crop, compared with the untreated control. Mean count of microarthropods increased significantly over time, with the last two assessments having significantly higher mean counts (Table 2).

Table 61 Mean microarthropod counts overtime.

Date collected	Means
26-May-21	0.767b
29-Jun-21	0.383b
08-Aug-21	0.717b
21-Oct-21	1.610a
06-Jan-22	1.703a

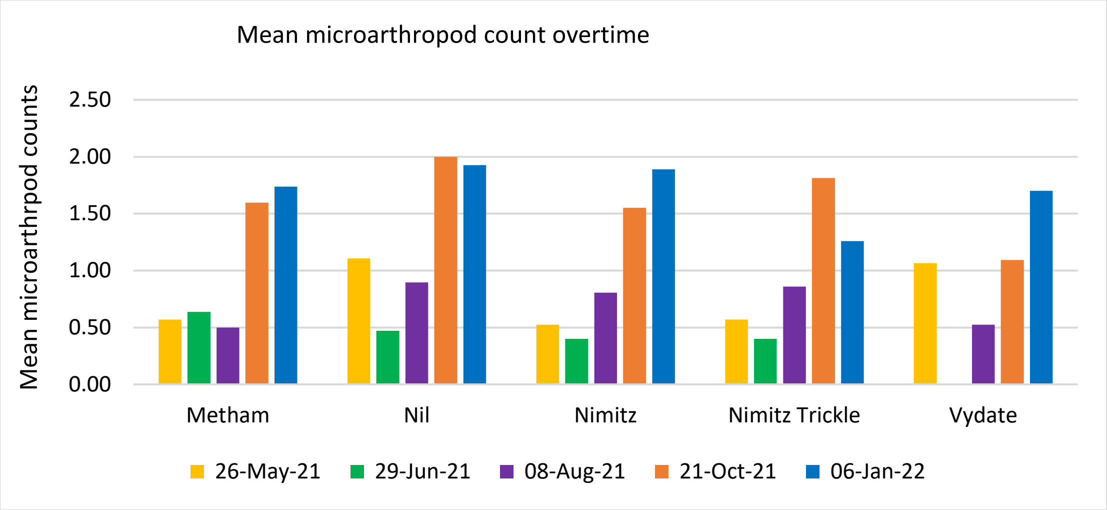

Figure 70. Interaction of collection date and treatment. Mean microarthropod counts increased overtime.

Nematode Trapping Fungi (NTF)

Nematode trapping Fungi (NTF) data was collected from 1gm of soil sample cultured on ¼ strength Corn Meal Agar. Count data was collected on five occasions. A total of 600 plates were assessed for the five occasions of sampling. Only 16 plates out of 600 had nematode trapping fungi present: 3 Vydate, 3 Metham, 4 Nimitz, 2 Nil and 4 Nimitz trickle. No conidia were recorded on any plate therefore this data has not been analysed.

Results – Sweetpotato yield and quality.

Data was analysed using Genstat statistical software package (19th edition). Linear mixed models (REML) were used to analyse continuous variables (root diameter, root length and total root weight), whilst generalised linear mixed models (GLMM) were used to analyse count variables (total number of nodes and total number of roots). Treatment means and differences between varieties were deemed significant at the 0.05 level. Pairwise comparisons were performed using the 95% least significant difference (LSD) on significant effects.

A $\log_{10}$ transformation was required to improve the homogeneity of variance assumption. The two-way interactions of Treatment and Size ($p = 0.024$) and Size and Marketability ($p < 0.001$) were significant.

Treatment had no effect on the mean root weight for the small and medium sized roots. For the large roots, the mean root weight was significantly higher for the Metham and Nimitz trickle treatments compared to the Vydate and Nil treatments.

There was no significant difference between the mean root weight for the marketable and non-marketable within the small and medium classes, but the non-marketable large roots were significantly heavier than the marketable large roots.

Table 62 Back transformed means for root weight for all treatments.

Treatment	BT Means
Metham	371.5
Nil	358.4
Nimitz	363.8
Nimitz Trickle	365.8
Vydate	363.7

Blind pimples are thought to be associated with nematode infection. The mean percentage of Blind pimples in each treatment is shown in figure 3, below. The Nil treatment had significantly higher mean percentage of blind pimples in large and medium sized roots than Metham, Nimitz trickle and Vydate but was not significantly different to Nimitz.

Although nematicidal effects had broken down by end of trial, nematicides appear to have given sufficient protection during the growth of the crop to allow increased marketable yield and reduction of some defects associated with nematode infection.

For example, all nematicide treatments also had significantly less barnacle lesions than the nil control. In the medium size category,

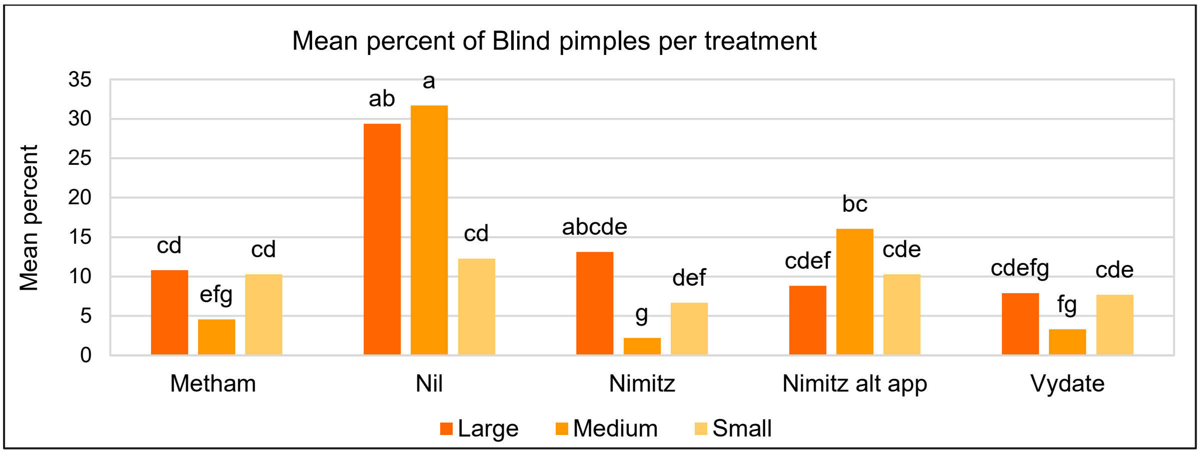

Figure 71 Mean percent of Blind pimples per treatment.

Nematicide Trial 2 – Red Soil

Introduction

Nematicide Trial 2 was conducted at Bundaberg Research facility on red soil. The aim was to investigate efficacy of currently available nematicides including alternative application methods of Nimitz and Salibro to control RKN in red soil. The trial ran from autumn 2022 to spring 2023.

Method

A Suitable site was selected at the Bundaberg Research facility. However, to increase the RKN population, the trial site was planted with a mixture of RKN susceptible cover crop species (Crimson Clover, Japanese Millet, Buckwheat Millet, Harpoon Barley, Chickpea and Jade Mung Bean) on May 10, 2022 before the trial. Species were chosen based on their suitability to the growing season, availability and susceptibility to RKN (Table 4).

Table 4. Cover Crop RKN Susceptibility.

Cover Crop	Root-k not Nematode Susceptibility	
	M. incognita	M. javanica
Buckwheat Millet	Moderately susceptible	Highly susceptible
Japanese Millet	Moderately susceptible	Moderately susceptible
Chickpea	Susceptible	Susceptible
Crimson Clover	Highly Susceptible	Highly Susceptible
Mung Bean	Susceptible	Susceptible
Harpoon Barley	Moderately susceptible	Moderately susceptible

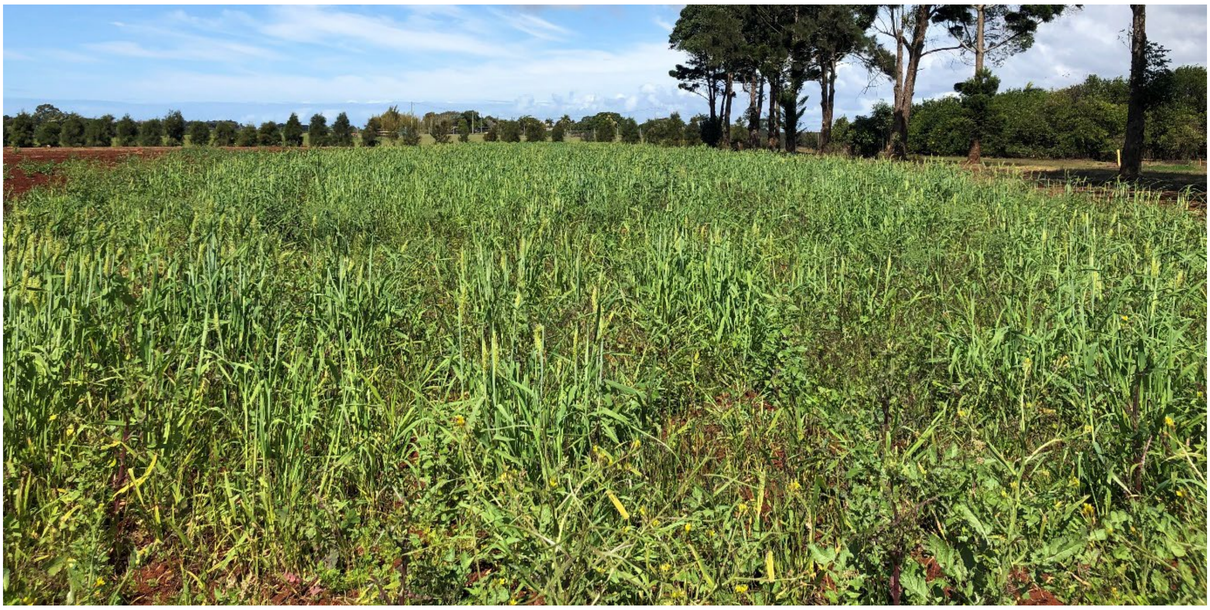

Image 43. The Nematicide trial block planted to mixed cover crops, August 2022.

Over 800 highly susceptible tomato plants cv. Tiny Tim, were germinated in the plant house at BRF and another 800 in the glasshouse at GRF in April 2022. After plant establishment, pots were inoculated with 2000 RKN (*M. javanica*) eggs in May 2022. On the 22nd August the cover crops were mulched to a height of approximately 200 mm to allow for the transplanting of 728 RKN infested tomato plants across the trial block. The remaining 728 tomato plants were transplanted on 14th of September 2022. At the start of December 2022, the cover crops and tomatoes were slashed, and the block was sown with RKN susceptible Mung beans and Lab Lab.

Image 44. Tiny Tim tomatoes inoculated with RKN, June 2022.

Image 45. C1 block Nematicide trial site - planting Tiny Tim tomatoes, September 2022.

Image 46 The Nematicide trial site planted to a Mung bean and Lab Lab cover crop, January 2023.

The block was sampled on January 23 to determine if the RKN population had increased sufficiently for the trial to commence. The block was divided into subsampling zones according to the location of the replicates for the experiment. Root-knot and reniform numbers were high across the block, although root-knot numbers were substantially lower in replicate 4 area. This was thought to be due to irrigation issues in that corner of the block.

Table5. Nematicide Trial 2 Pre-plant Nematode Counts / 200g Dry Soil.

Sample	RKN	Reniform	Free-living
C1 Rep 1	7226	2625	4033
C1 Rep 2	9370	2322	5165
C1 Rep 3	7070	543	2773
C1 Rep 4	450	249	2738
C1 Rep 5	4744	423	2652
C1 Rep 6	2305	243	3718
C1 Weedy	2339	535	4120

Image 47. The trial block with some of the bare fallow plots clearly visible.

The block was planted on the 6th of March 2023 to sweetpotato cultivar Beauregard and the soil was sampled the following day. There were eight treatments in the trial (table 5), each replicated six times and the trial was designed as a randomised complete block. The trial was sampled to assess plant-parasitic and free-living nematode numbers in March, May, August, and at harvest in October 2023.

Table 6 Nematicide treatments and application rates in trial 2.

Treatment	Application type	Application rate	Application date
Nil	Nil	N/a	N/a
Bare fallow	Nil	N/a	N/a
Metham	Fumigation	As per label rate - 750 L/Ha	Prior to bed formation on 9th January 2023,
Vydate	Via trickle tape	As per label rate - 18Lha, followed by 4 applications of 2L/ha every 2 weeks'	After planting, 18L/Ha on 15th March 2023 2L /ha on: 29th March 2023, 12th April 2023, 27th April 2023 and 9th May 2023
Nimitz	Standard	As per label rate - 8L/Ha	Prior to incorporation and bed forming on 23rd February 2023
Nimitz alternative	Via trickle tape	As per label rate - 8L/Ha	After planting on 15th March 2023, 17th April 2023
Salibro	Via trickle tape	As per label rate - 2L/Ha per application	After planting on 15th March 2023 and 29th March 2023
Salibro alternative	Via trickle tape	As per label rate - 2L/Ha per application	After planting on 15th March 2023, 29th March 2023, repeated on 17th April 2023, and 9th May 2023

Soil Monitoring

Soil samples were collected on the 6th March at planting, on the 22ndof May,23rd of August and the 30th of October 2023. Samples were sent to the project team nematologists for nematode extraction and to GRF for extraction of soil biologicals, microarthropods and Nematode trapping fungi (NTF). Results from these samples will allow investigation into correlation between soil characteristics, RKN populations and soil biology.

Trial maintenance

A maintenance schedule was developed for the trial block in conjunction with the PRG, following best practice. Regular soil and leaf tissue samples were collected for laboratory analysis to monitor critical nutrients such as nitrate analysis. Scheduled fertiliser applications were made based on the results of the analysis. Crop maintenance included irrigation scheduling, scuffling along with regular weeding until row closure and regular weeding of the bare fallow plots. DAF designed weevil traps (project VG98002) containing pheromone attractant for sweetpotato weevil (Cylas formicarius) were installed at each corner of the block. Regular insecticide applications were carried out during the growth period based on weekly pest and disease monitoring.

Harvest

To monitor growth, three plants were dug up from the buffer rows at around 90 and 120 days after planting, to monitor root development. Prior to the harvest, the 2m buffer zones on the end of each row were hand dug and roots were removed. Rows were top chopped (pulversied) to remove the foliage and roots were left to harden for 1 week to prevent skinning during harvest. Roots were dug on the 30th of October at 238 days after planting (DAP). A potato harvester was used to lift the sweetpotato roots to the surface where they were manually hand-picked into hessian bags and placed into plastic half ton bins (image 7). Roots were freighted overnight to Gatton Research Facility (GRF) for assessment.

Roots were washed in a chlorine solution using a standard butternut pumpkin washer. Over 4000 roots were individually weighed and sorted into six size categories: small, small medium, medium, medium large, large and jumbo. Roots were then placed into one of three marketability grades, first or premium grade, second grade and non-marketable. Defects were recorded using the categorisation system developed for the Intensive and Extensive trials designed to capture 18 common defects found in commercial sweetpotato production as described in

Appendix 18. Each root underwent close visual scrutiny and was evaluated using this system.

Results - Nematode population monitoring

1st Sampling

When the trial was sampled in March, sweetpotato vine had just been planted, Metham had been applied around 4 weeks prior and the standard Nimitz application around 2 weeks prior. At this point the Metham treatment had a significantly lower mean root-knot nematode count than all other treatments except the bare fallow.

2nd Sampling

At the second sampling in May, Metham, Nimitz alternative application, Vydate and the bare fallow all had significantly lower root-knot counts than the nil control.

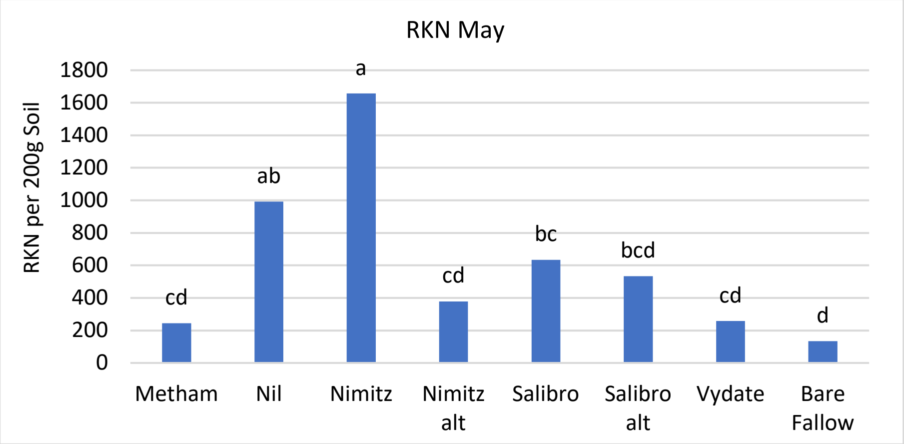

Figure 72 Mean root-knot nematode counts per 200g dry soil ($p < 0.001$)

All nematicides (except standard Nimitz) and the bare fallow had significantly lower reniform nematode counts than the nil control.

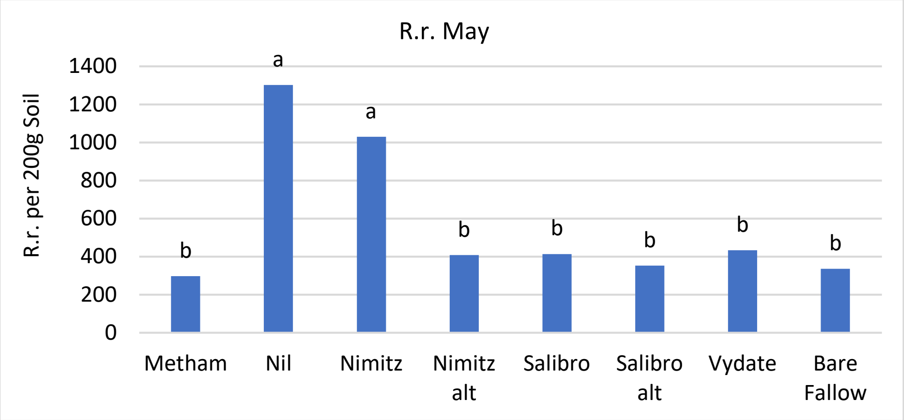

Figure 73 Mean reniform nematode counts per 200g dry soil ($p = 0.003$)

The Metham, Salibro alternative application and Vydate treatments had significantly fewer free-living nematodes in May, showing an impact by these nematicides on non-target organisms.

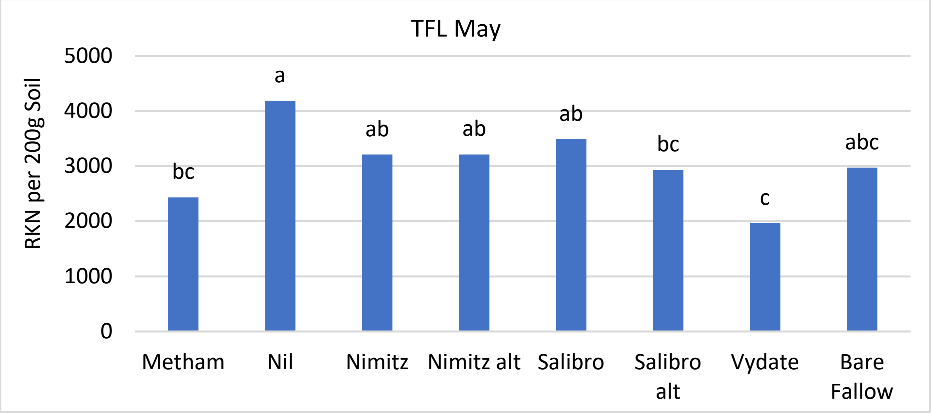

Figure 74 Mean free living nematode counts per 200g dry soil (p = 0.038)

3rd Sampling

In August, only the Nimitz alternative application and the bare fallow had significantly lower root-knot counts than the nil control.

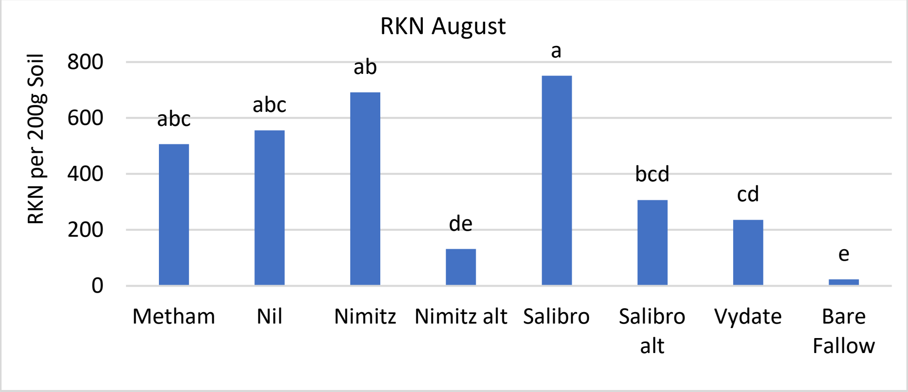

Figure 75 Mean root-knot nematode counts per 200g dry soil (p < 0.001)

The Nimitz alternative application, the alternative Salibro application, Vydate and the bare fallow had significantly less reniform nematode than control at this sampling.

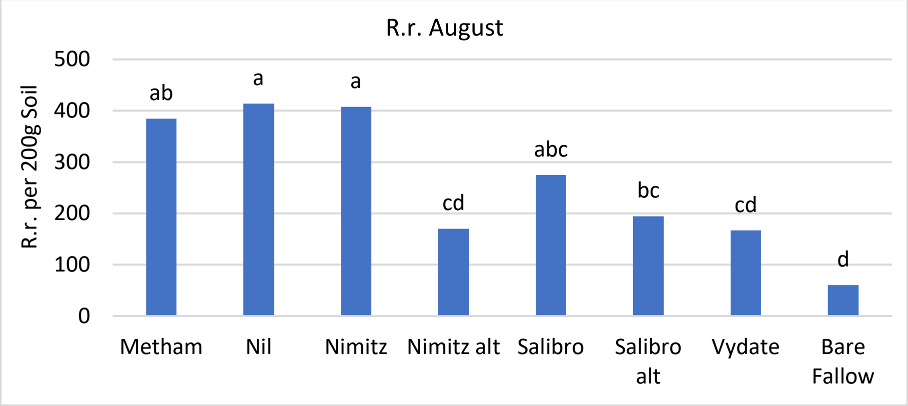

Figure 76 Mean reniform nematode counts per 200g dry soil (p < 0.001)

Vydate had significantly fewer free-living nematodes than all other treatments except Nimitz alternative application in August.

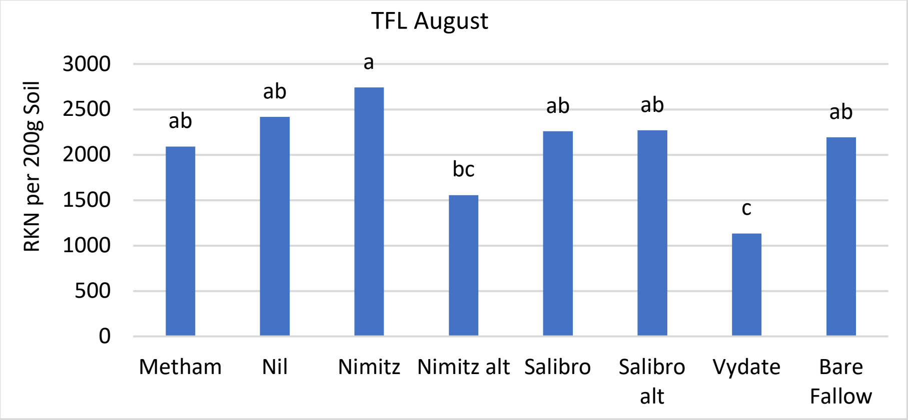

Figure 77 Mean free living nematode counts per 200g dry soil (p = 0.033)

4th Sampling

The final sampling was conducted in October, one week prior to harvest. The Nimitz alternative application, Vydate and the bare fallow had significantly lower mean root-knot nematode counts than Metham and Nimitz treatments and the nil control.

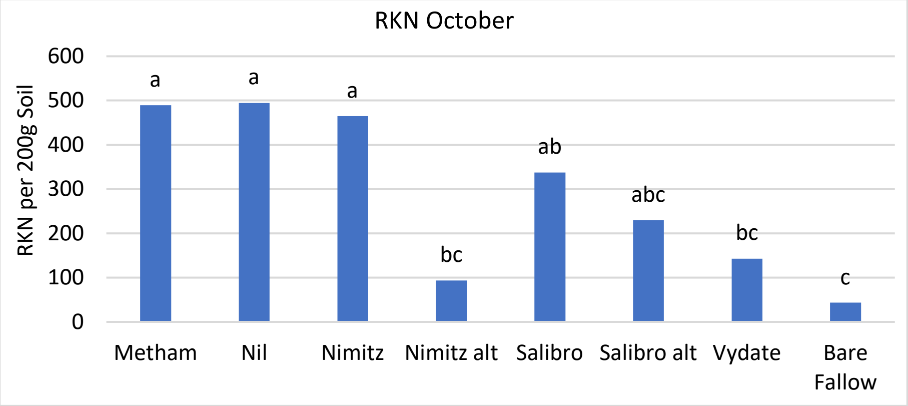

Figure 78 Mean root-knot nematode counts per 200g dry soil (p = 0.008)

The Nimitz alternative application, Salibro alternative application, Vydate and the bare fallow had significantly lower reniform nematode counts at the final sampling.

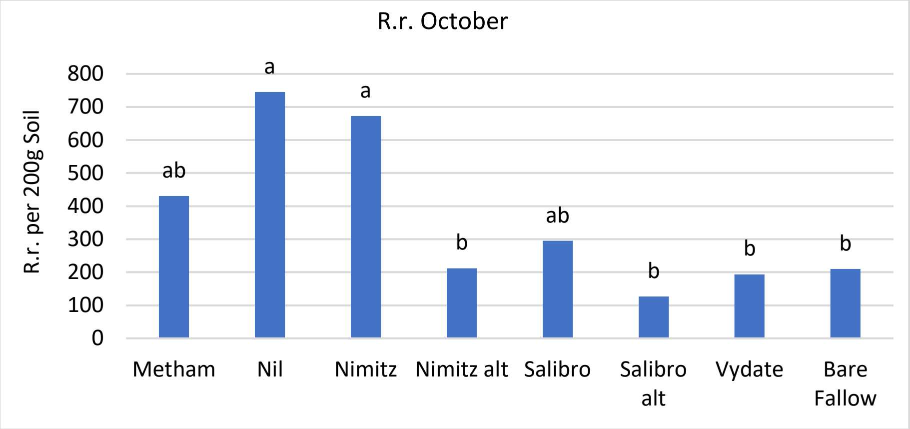

Figure 79 Mean reniform nematode counts per 200g dry soil (p = 0.032)

There were no significant differences in free-living nematode counts at the October sampling.

Having been applied almost a month prior to the first sampling, Metham Sodium had less root-knot nematode than all of the other nematicides and the nil control at the first sampling. By the second sampling, the Nimitz alternative application and Vydate also had lower levels of root-knot than the control. In August, the Nimitz alternative application was the only nematicide with lower mean root-knot counts than control, but at the final sampling both the Nimitz alternative application and Vydate were lower. So, for root-knot nematode, the Nimitz alternative application provided the most consistent control for the duration of the trial. Nimitz standard application, Salibro and the Salibro alternative application root-knot counts were not significantly different from the nil control at any of the 4 sampling points.

For reniform nematode, all nematicides except the standard Nimitz application had lower mean counts than control in May. At both the August and October samplings, Nimitz alternative application, the alternative Salibro application and Vydate had lower counts than control. So, as for root-knot, the alternative Nimitz application provided consistent control of reniform nematode. Vydate and the alternative Salibro application also provided control for much of the trial period.

Free-living nematode populations were impacted by some of the nematicides in the mid-trial period, with Vydate having the lowest counts in May and August. By the final sampling there were no significant differences between treatments for free-living nematodes. Most free-living nematodes have a very short life cycle, so can rapidly recover their populations when chemical effects have dissipated.

Without a susceptible host the root-knot nematode population dropped to low levels in the bare fallow treatment, as expected. Reniform nematode numbers also dropped but were still at relatively high levels (around 200 per 200g dry soil) at the final sampling, possibly reflecting the differing life cycles and survival strategies of the two species. Free-living nematode counts in the bare fallow treatment were not significantly different from those in the nil control sweetpotato crop.

Results – Biological monitoring

Microarthropod Counts

Data was collected on counts of microarthropods and nematode trapping fungi (NTF) from the Bundaberg nematicide trial. Data was collected at the replicate block level before planting (1/11/2022), at planting for the Nimitz plots before Nimitz application (7/3/2023) and for all plots after Nimitz application (7/3/2023, 28/8/203). Data was collected on the presence of NTF and conidia. Data was also collected from a single strip of weedy fallow at the southern end of the trial for comparison only.

The two assessments post Nimitz application (7/3/2023, 28/8/2023) were first analysed separately and then together to investigate any temporal effects. Analysis of the first assessment (7/3/2023) suggests there was evidence of over-dispersion. No significant treatment effect was detected at the first assessment on 7/3/2023 after Nimitz application ($F_{(7,35)} = 1.42$; $p = 0.227$), but there was a significant treatment effect at the second assessment on 28/8/2023 ($F_{(7,35)} = 3.00$; $p = 0.014$), (Table 7). Microarthropod population decreased.

However, pairwise comparison of the treatment means suggest no treatments are significantly different to the Nil treatment. Hence, low microarthropod scores could be attributed to the change of cropping system. Diverse mix cover cropping established prior to build up RKN populations also favoured buildup of microarthropods. However, microarthropods decreased could be attributed to monoculture of young sweetpotato crop as well as high rainfall recorded during the growth stage of the sweetpotato crop (Winter et al 2006). Chemical application as herbicide, foliar and fertilizer can reduce microarthropod population as well (Winter et al 1990, Seymour 2006, Stirling 2016).

Metham, Nimitz Trickle + 2nd application had the highest mean counts and were significantly higher than bare fallow, Nimitz and the two Salibro treatments.

Table 7 predicted means, standard error (se), BT Mean for two assessment dates.

Collection date	7/3/2023			28/8/2023		
Treatment	Pred Mean	se	BT Mean	Pred Mean	se	BT Mean
Bare fallow	3.44	0.470	31.0	-0.44 b	0.690	0.64
Nil	2.04	0.496	7.7	0.25 ab	0.553	1.28
Metham	2.47	0.484	11.8	1.04 a	0.461	2.83

Nimitz	2.18	0.492	8.8	-1.36 b	0.993	0.26
Nimitz Trickle alternate	2.50	0.484	12.2	1.04 a	0.461	2.83
Salibro	2.65	0.481	14.2	-0.44 b	0.690	0.64
Salibro alternate	2.20	0.491	9.0	-0.95 b	0.838	0.39
Vydate	2.64	0.481	14.1	0.35 ab	0.539	1.41
	average 95% lsd = 1.073			average 95% lsd = 1.573		
Weedy fallow			24.0			2.0

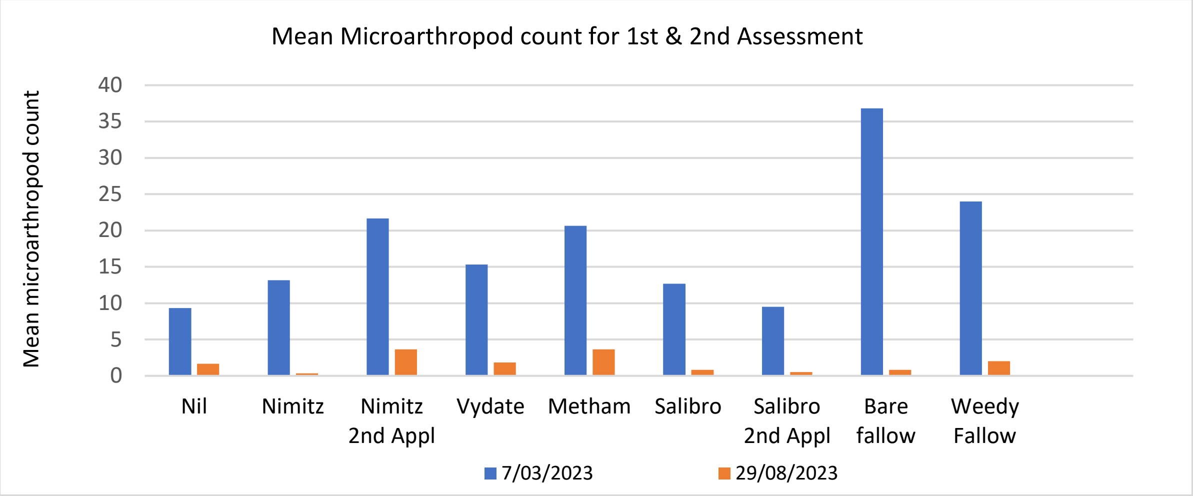

Figure 80 Significant treatment effect on second assessment.

Nematode Trapping Fungi

There were insufficient counts of NTF and conidia at the second assessment to enable a combined analysis. NTF were only detected on 4 plates at the 28/8/2023 sampling. These were 3 Vydate plates from the same plot and 1 Nil plate. This assessment date has not been analysed.

Results from the analysis of the first assessment on 7/03/2023 found no significant difference between the treatments ($F_{(7,35)} = 0.95$; $p = 0.483$), although only Metham and the standard Nimitz application had been applied prior to this sampling.

Conidia

Conidia were only observed on 4 plates from the 28/8/2023 sampling. These were 3 Vydate plates from the same plot and 1 Nil plate. This assessment date has not been analysed.

A third assessment on microarthropods and NTF was done on the 24/10/2023 (Table 8). The table is only based on average microarthropod count across all assessment dates. Microarthropod counts start increasing for Nil Treatments, Nimitz, Vydate and Salibro 2nd application as environment becomes conducive for population build up.

Table 8 Average microarthropod count for all treatments over time.

Assessment Dates	7/03/2023	29/08/2023	24/10/2023
Treatment no.			
Bare Fallow	36.83	0.83	0.66
Nil	9.33	1.66	2.16
Nimitz	13.16	0.33	2.83
Nimitz Trickle alternate	21.66	3.66	1.5

Vydate	15.33	1.83	2.16
Metham	20.66	3.66	0.83
Salibro	12.66	0.83	0.66
Salibro 2nd appl	9.5	0.5	1.16
Weedy Fallow	24	2	0

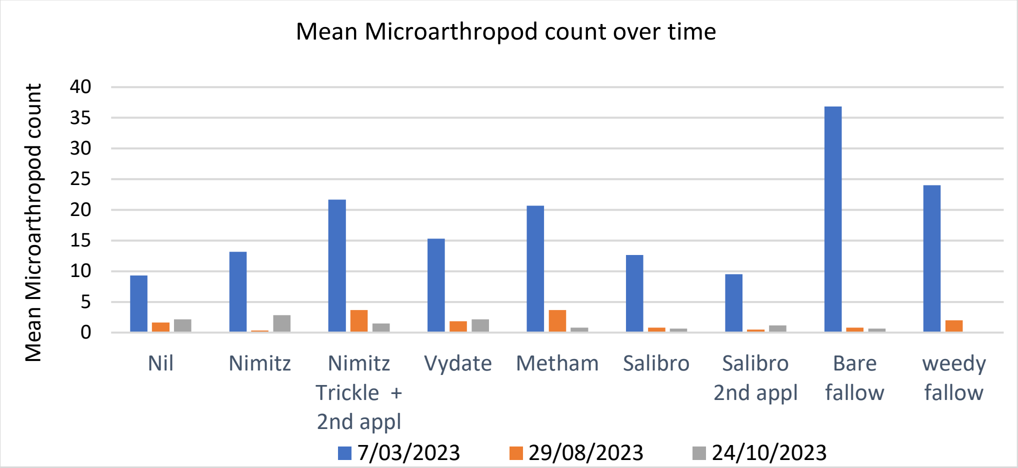

Figure 81. Mean microarthropod count over time.

Results - Sweetpotato yield and quality.

Root weight

Data was analysed by DAF biometrician Carole Wright. Root weight was analysed using analysis of variance (ANOVA), then a log10 transformation was applied to the total weight of marketable roots to improve the assumption of homogeneity of variance.

All roots with a weight of less than 150g were excluded from this analysis. In all instances below, the term “total roots” refers to small + medium + large roots.

Total roots (small + medium + large) and large roots grown in the Nil and Nimitz treated plots were significantly lower in weight overall than all other treatments except the Nimitz alternate treatment. The Vydate plots produced a significantly higher weight of roots per plot than the Nil, Nimitz and Nimitz alternate treatments, though this was not significantly different to plot weight in the Metham, Salibro and Salibro alternate treatments. Vydate plots produced roots with a significantly higher weight of medium roots than all other treatments except Metham.

Figure 82 the project team conducting the yield assessment on the final harvest.

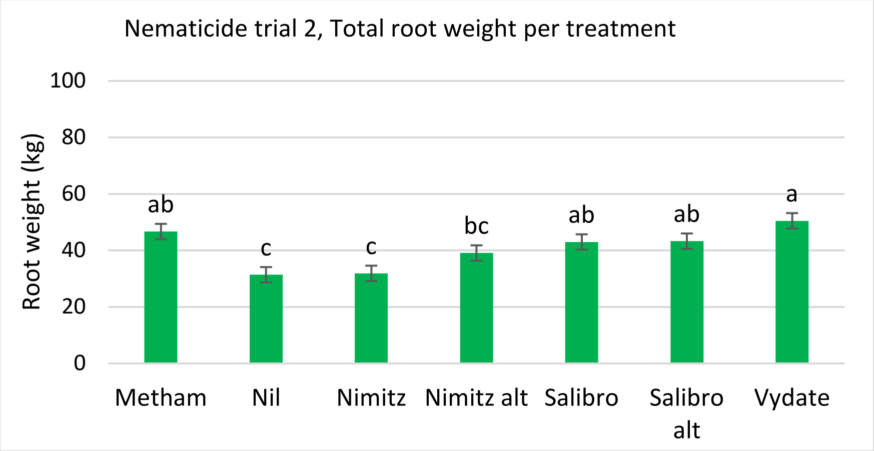

Figure 83. Total root weight per treatment.

Root number

Root numbers were analysed using a generalised linear model with a Poisson distribution and a log link, except for total counts in the marketable and non-marketable categories. There was more variation than expected by the Poisson distribution and so a Negative Binomial distribution was assumed.

The Metham and Vydate treated plots produced a significantly higher number of roots than Nil, Nimitz and Nimitz alternative treatments but was not significantly different to the Salibro and Salibro alternate treatments. The Nil and Nimitz plots produced a significantly lower number of large roots than all other treatments. Vydate plots produced a significantly higher number of medium roots, but this was not significantly different to the number of roots produced in the Metham, Nimitz alternate and Salibro alternate treatments.

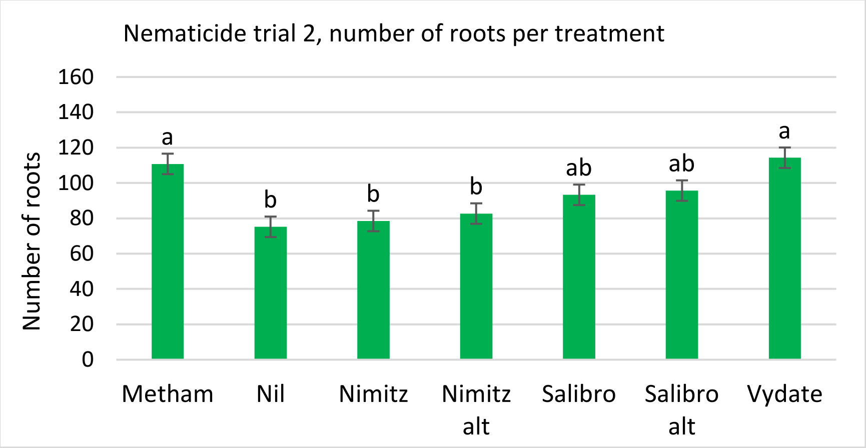

Figure 84. Number of roots produced in each treatment.

Defects

Incidence data was analysed using a generalised linear model with a Binomial distribution and complementary log-log link. The mean for incidence data is reported as a percentage.

Raised pimples

The incidence of raised pimples was too low to conduct an analysis across the treatments.

Black pimples

Total roots (small + medium + large) from the Vydate treatment had a significantly lower incidence of Black pimples than all other treatments. This was also a significantly lower incidence of Black pimples when each of the size categories (small, medium and large) were analysed individually.

Image 48 Black pimples (circled) within a nematode crack indicating a later RKN infection.

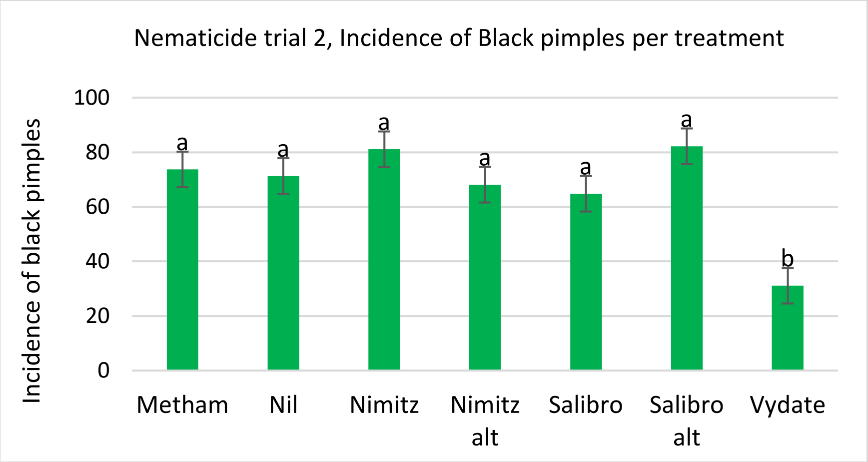

Figure 85. Incidence of Black pimples.

Nematode cracks

Image 49 Nematode cracks - a result of early RKN infection.

All roots (small + medium + large) grown in the Vydate treated plots had a significant lower incidence of nematode cracks than all other treatments. The Nil and Nimitz treatments produced roots with a significantly higher incidence of nematode cracks than all other treatments.

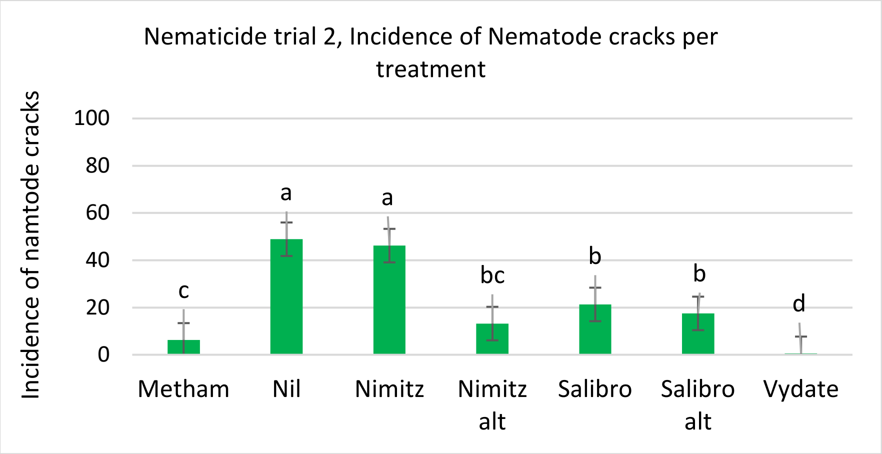

Figure 86. Incidence of nematode cracks.

Wireworm

All roots (small + medium + large) grown in the Metham treated plots had a significantly higher occurrence of wireworm damage than all other plots except Nimitz. A lower incidence of wireworm damage was observed on roots grown in the Nil, Nimitz alternate, Salibro, Salibro alternate and Vydate treatments though this was not significantly different to the Nimmitz treatment.

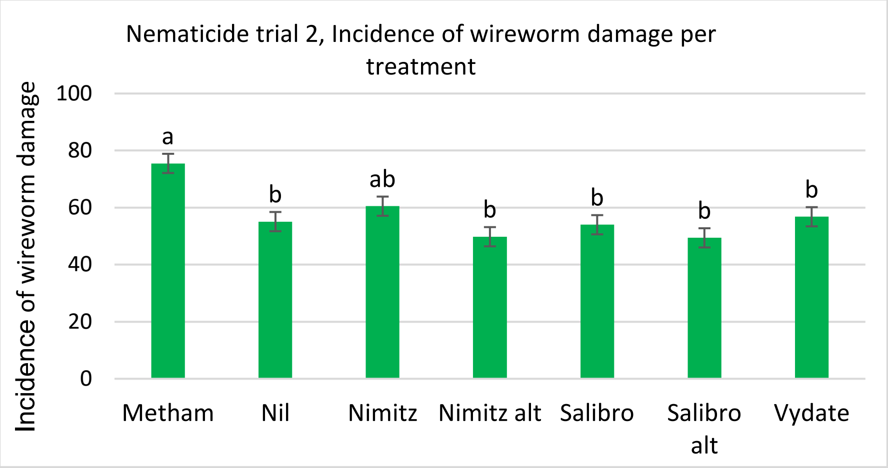

Figure 87. Wireworm damage on roots in each treatment.

Longitudinal grooves

Medium, large and the overall total roots (small + medium + large) grown in the Metham treated plots each had a significantly higher incidence of longitudinal grooves (LG) than all other treatments. However, this was not significantly different to the Salibro treated roots. The incidence of LG observed in large sized roots was not significantly different to that in the Nil or untreated plots.

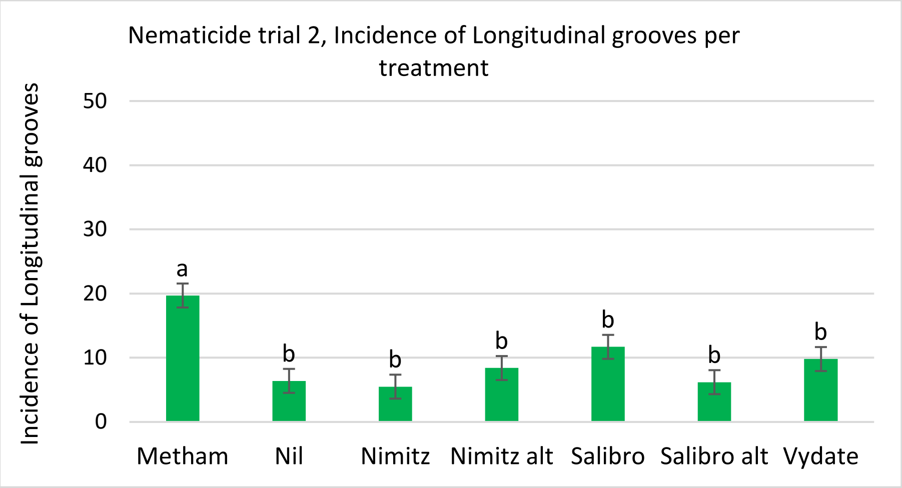

Figure 88. Incidence of longitudinal grooves per treatment.

Veining

When analysed as a group, total roots (small + medium + large) from the Metham treated plots displayed a significantly lower incidence of veining than roots grown in all other treatments. Roots in the Nimitz alternate treatment had a significantly higher incidence of veining that Vydate and Metham treated plots, but this was not significantly different to the Nil, Nimitz, Salibro and Salibro alternate treatments. When analysed separately by size category, the same significant differences were recorded across the small, medium and large size categories.

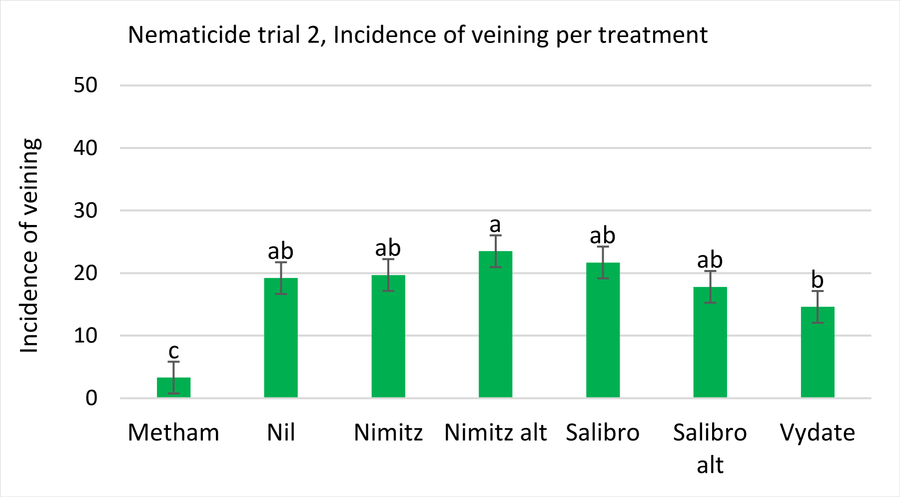

Figure 89. Incidence of Veining in each treatment.

Sunburn

Total roots (small + medium + large) from the Metham plots had a significantly higher incidence of Sunburn, however, this was not significantly different to Sunburn in roots from the Salibro and Vydate treatments. Roots in the Nimitz and Nimitz alternate treatments had a significantly lower incidence of sunburn, but this was not significantly different from roots in the Salibro alternate and Nil treatments.

Medium roots in the Metham, Salibro and Vydate treatments had a significantly higher incidence of Sunburn and this was not significantly higher than the Nil treatment. Small roots in the Vydate plots had a significantly higher incidence of Sunburn than all other treatments except Metham.

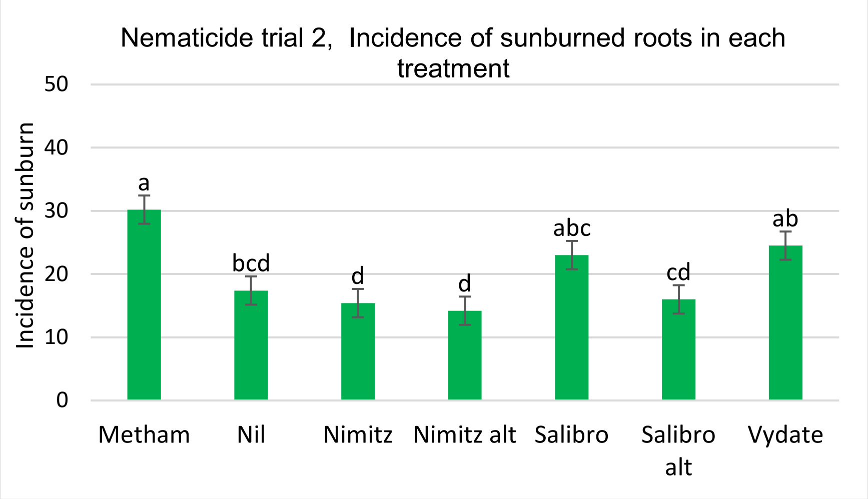

Figure 90. Incidence of Sunburned roots in each treatment.

Animal damage

Large roots in the Nil and Salibro plots had lowest incidence of animal damage though this was not significantly lower than the Nimitz, Nimitz alternate treatment, and Vydate. Roots in the Salibro alternate treatment had highest incidence of animal damage but this was not significantly different to those in the Nimitz and Metham treatments. There were no other significant differences.

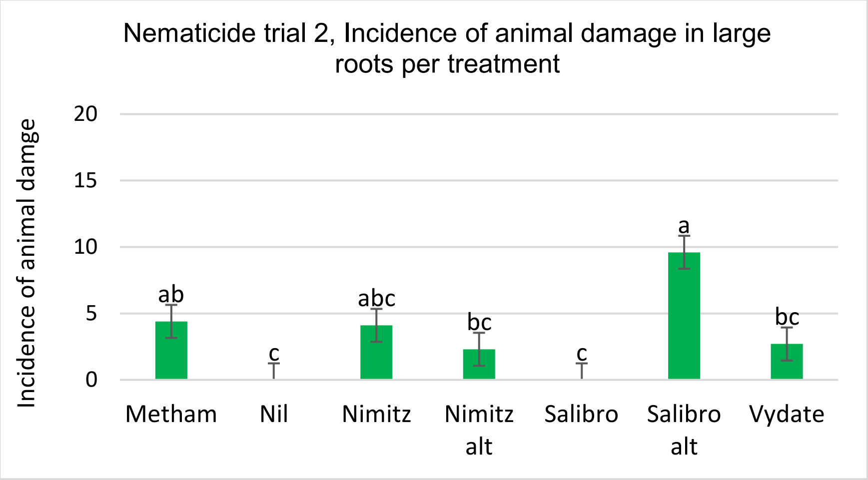

Figure 91. Incidence of Animal damage in large roots.

Other defects

There were no significant differences in any other defects.

Discussion

The Vydate and Metham treated plots tended to produce a higher weight of total and medium sized roots and a higher number of roots. Roots from the Vydate treated plots had a significantly lower incidence of nematode cracks and Black pimples. Roots grown in the Nil and Nimitz treated plots were lower in weight and number than all other treatments except the Nimitz alternate treatment.

Roots grown in the Metham treated plots had a significantly higher occurrence of wireworm damage, sunburn and longitudinal grooves, but a significantly lower incidence of veining. Sunburn occurs as roots push up above the soil surface and are therefore exposed. Any differences between treatments are unlikely to relate to efficacy of a chemical efficacy.

Large roots in the Nil and Salibro plots had lowest incidence of animal damage but roots in the Salibro alternate treatment had highest incidence of animal damage This may indicate that there was higher nematode pressure in the Nil and Nimitz plots affecting the development of large roots. Any differences between treatments are unlikely to relate to efficacy of a chemical in deterring animals.

Acknowledgements

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Appendix 22.

Conference abstracts

Presented at the 21st Australasian Plant Pathology Society conference, Tasmania (online conference), November 2021.

RESISTANT ROTATION CROPS TO REDUCE ROOT-KNOT NEMATODES IN SWEET POTATO PRODUCTION

JA Cobon[1], WT O'Neill[1], T Shuey[1] and S Dennien[2]
[1] Department of Agriculture and Fisheries, Ecosciences Precinct, 41 Boggo Rd, Dutton Park QLD 4102
[2] Department of Agriculture and Fisheries, Gatton Research Facility

The Australian sweetpotato industry is largely focused in south-east Queensland and northern New South Wales on well-structured ferrosol soils. Australian sweetpotato growers now produce the world's highest yields per hectare with a current farm gate value of $90M per annum. Plant-parasitic nematodes are a major constraint to sweetpotato production, accounting for considerable losses in yield and quality, with current estimates suggesting they cost the industry $20M per year.

Root-knot nematodes (*Meloidogyne* spp.) are the major plant-parasitic pest of sweetpotato, causing general unthriftiness and yield loss as well as blistering, bumpiness and cracking of the storage roots. Through molecular identification, *M. incognita* and *M. javanica* were identified as the two most common root-knot nematode species in sweetpotato production areas. Traditionally, chemical nematicides were used to control nematodes. However, these are costly, toxic and are increasingly being withdrawn from the market use globally.

Nematodes can be managed by removing host plants, in this case sweetpotatoes, growing resistant rotation crops and replanting with clean planting material. Resistant rotation crops do not support nematode feeding and/or breeding. This reduces plant-parasitic nematode abundance and increases productivity in the following sweetpotato crop while reducing the negative impact of nematode damage on the quality of storage roots.

Glasshouse screening trials were undertaken with the two most common species of root-knot nematodes on a range of possible crops that would be useful rotations for sweetpotato growers. Potential new rotation crop varieties, resistant to either or both these root-knot species, have been identified for use. There are now many options for short/long fallows, winter/summer fallows and for growers to design their own blends of compatible nematode resistant rotations for multispecies mixes.

A well-managed crop rotation phase in the cropping cycle can mean that sustainable sweetpotato production is not constrained by plant-parasitic nematodes.

Presented at the *11th Australasian Soilborne Disease Symposium, Cairns, August 2022.*

INTEGRATED MANAGEMENT OF ROOT-KNOT NEMATODE IN SWEETPOTATO

WT O'Neill[1], JA Cobon[1], T Shuey[1], R Langenbaker[2] and S Dennien[3]
[1] Department of Agriculture and Fisheries, Ecosciences Precinct, 41 Boggo Rd, Dutton Park QLD 4102
[2] Department of Agriculture and Fisheries, Bundaberg Research Facility
[3] Department of Agriculture and Fisheries, Gatton Research Facility

Plant-parasitic nematodes are important pests of sweetpotato, costing the industry an estimated $20 M per year in Australia. Root-knot nematodes are responsible for the majority of losses and are widely distributed throughout the growing regions. Two long-term field trials have been established in Bundaberg to assess the ability of rotation crops, organic amendments and novel management practices to control nematodes and improve soil health.

One field trial is close to current grower best practice and includes a nematode resistant rotation and different amendment treatments, as well as nematicide and nil controls. The other trial is more experimental and is being used to assess a variety of rotation crops and organic amendments. It also has a longer rotation phase and early bed formation, where beds are reformed just after harvest and are not intensively cultivated prior to planting.

Although results vary from one crop cycle to the next, organic amendment treatments are showing a trend for suppression of root-knot nematode and an increase in free-living nematode populations in both trials. For example, one treatment in the best practice trial (an incorporated band of chicken manure + sawdust) had significantly less root-knot nematodes than all other treatments at the second crop harvest (mean of 226 root-knot per 200g dry soil compared with 739 for nematicide), and significantly more free-living nematodes (mean of 8718 per 200g of dry soil compared with 2124 for the nil control).

In the experimental trial, treatments which received a double amendment (incorporated band of organic matter after harvest and a second application in a furrow prior to planting) consistently had the lowest root-knot numbers at harvest, although these results have not been significant to date. The legume sunn hemp proved to be a very effective rotation crop for reducing root-knot populations.

The trials are ongoing, and treatments will be monitored through further crop cycles for efficacy as well as effects on yield and quality.

Presented at the 11th Australasian Soilborne Disease Symposium, Cairns, August 2022.

PLANT-PARASITIC NEMATODES IN SWEETPOTATO PRODUCTION AREAS IN AUSTRALIA

JA Cobon[1], WT O'Neill[1], T Shuey[1], R Langenbaker[2] and S Dennien[3]
[1] Department of Agriculture and Fisheries, Ecosciences Precinct, 41 Boggo Rd, Dutton Park QLD 4102
[2] Department of Agriculture and Fisheries, Bundaberg Research Facility
[3] Department of Agriculture and Fisheries, Gatton Research Facility

Australian sweetpotato growers produce the world's highest yields per hectare with a current farm gate value of $90M per annum. Plant-parasitic nematodes are a major constraint to sweetpotato production. Worldwide, *Meloidogyne* spp. (root-knot nematodes), cause general un-thriftiness and yield loss, as well as blistering, bumpiness and cracking of the storage roots. Yield and quality reductions due to plant-parasitic nematodes in Australia are currently estimated to cost the industry $20M per year.

Surveys were undertaken in the main sweetpotato production regions in 2017/2018 to determine the presence and abundance of plant-parasitic nematodes. Soil was sampled from 45 sites in the Bundaberg region, 12 from the central Queensland region, 6 from Southeast Queensland, 3 from the Atherton Tablelands in North Queensland and 17 from Cudgen in northern NSW.

Root-knot nematode was morphologically identified at 50 of the 83 sites (60% of sites), ranging in abundance from 1 to 3,413 per 200 g dry soil. Through molecular identification, *M. javanica* and *M. incognita* were identified as the two most common root-knot nematode species present at 28% and 13% of positive sites, respectively. *Meloidogyne hapla* and *M. arenaria* were also identified at 9% and 2% of positive sites, respectively.

Rotylenchulus reniformis (reniform nematode) was present at 10% of sites, mainly in the warmer regions of central Queensland and Bundaberg. However, one site in SE Queensland and one site in Cudgen were also infested with *R. reniformis* (53 and 365 per 200 g dry soil respectively). *Pratylenchus zeae* (lesion nematode) was found at 49% of sites across all regions and was the most common lesion nematode present.

Other common plant-parasitic nematodes identified in low numbers included spiral, stubby, stunt, ring, dagger and *Rotylenchulus parvus* (another reniform nematode), suggesting sweetpotato was not a good host to these plant parasites.

Presented at the 11th Australasian Soilborne Disease Symposium, Cairns, August 2022.

GLASSHOUSE SCREENING TO IDENTIFY ROTATION CROPS RESISTANT TO RENIFORM NEMATODE (*ROTYLENCHULUS RENIFORMIS*) FOR THE SWEETPOTATO INDUSTRY

JA Cobon[1], WT O'Neill[1], and T Shuey[1]
[1] Department of Agriculture and Fisheries, Ecosciences Precinct, 41 Boggo Rd, Dutton Park QLD 4102
[2] Department of Agriculture and Fisheries, Gatton Research Facility

Plant-parasitic nematodes are a major constraint to sweetpotato production, causing considerable losses in yield and quality, with current estimates suggesting they cost the Australian industry $20M per year.

Reniform nematode (*Rotylenchulus reniformis)* is recognised worldwide as a major plant-parasitic pest of sweetpotato and was present at 10% of surveyed sites across the Australian sweetpotato production area. They mainly occurred on crops in the warmer regions of central Queensland and Bundaberg. However, one site in SE Queensland and one site in Cudgen NSW were also infested with *R. reniformis* (53 and 365 per 200 g dry soil respectively).

Nematodes can be managed by removing host plants, in this case sweetpotatoes and susceptible weeds, growing resistant rotation crops and replanting with clean planting material. Resistant rotation crops do not support nematode feeding and/or reproduction. This reduces plant-parasitic nematode abundance and increases productivity in the following sweetpotato crop, while reducing the negative impact of nematode damage on the quality of storage roots.

Reniform nematode was cultured in the glasshouse on tomato plants from a single egg mass obtained from a field-infested sweetpotato. Glasshouse experiments were undertaken to establish a suitable potting media for resistance screening. A range of potential crops that may be useful rotations for sweetpotato growers were then assessed in glasshouse trials for resistance to reniform nematode.

A well-managed crop rotation phase in the cropping cycle can mean that sustainable sweetpotato production is not constrained by *R. reniformis* and other plant-parasitic nematodes.

Presented at the24th Australasian Plant Pathology Society conference, Adelaide, November 2023.

Suppression of Root-knot Nematode in Modified Commercial Sweetpotato Production Systems

TA Shuey[1], WT O'Neill[1], JA Cobon[1], R Langenbaker[2], B Day[2], J Bobby[3], M Firrell[3], M Hughes[4] RD Corner[1], AB Pattison[5] and S Dennien[3]
[1] Department of Agriculture and Fisheries, Ecosciences Precinct, 41 Boggo Rd, Dutton Park QLD 4102
[2] Department of Agriculture and Fisheries, Bundaberg Research Facility
[3] Department of Agriculture and Fisheries, Gatton Research Facility
[4] Department of Agriculture and Fisheries, Mareeba Research Facility
[5] Department of Agriculture and Fisheries, Centre for Wet Tropics Agriculture

Meloidogyne spp. (Root-knot nematodes, RKN) are a major threat to the quality and quantity of marketable sweetpotato in Australia and world-wide. In relatively low numbers, RKN can affect the size, shape, appearance, and marketability of sweetpotato storage roots, and decrease both plant vigour and pest resistance.

Under commercial best practice, a field experiment comparing three different organic amendment treatments with a nematicide application for the control of RKN, was conducted over four growing seasons. Resistant rotation crops were sown outside the growing season and incorporated into each plot. Plant-parasitic and free-living nematodes were quantified before planting and at harvest each season. Storage root quantity and quality were analysed at harvest, recording visual defects to assess any detrimental effects attributed to nematode damage or from the application of organic amendments.

Results to date indicate suppression of root-knot nematodes and promotion of free-living nematodes via the addition of either; banded organic matter, banded compost, or a V-furrow amendment of compost, to current best practice production. Initially, there were detrimental effects from the amendments on yield and quality of the harvested product. By the second harvest, there were no significant differences in total yield between treatments, however the organic matter treatment had less marketable yield than the nematicide treatment. By the third harvest, the organic matter treatment had significantly higher total and marketable yield when compared to other treatments.