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Improving farming systems for managing soil-borne pathogens of ginger in Fiji and Australia

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1 Acknowledgments

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2 Executive summary

The project has demonstrated that Pythium Soft Rot is responsible for serious damage to ginger crops both in Fiji and Australia, and disease epidemics are triggered by wet weather events when soils remain saturated for lengthy periods during summer and early autumn. Molecular and morphological studies have identified *Pythium myriotylum* as a causal species which is found on ginger in both countries; however *P. vexans* and *P. graminocola* have also been isolated from diseased rhizomes in Fiji and *P. zingiberis* has been tentatively identified in Australia.

Chemical control options have so far proven to be largely ineffective and likely to be too expensive or impractical for Fijian growers with small holdings. Other strategies such as controlling water-logging and limiting surface water movement by deepening the furrows between beds and increasing the number of cross-row drainage channels have demonstrated effectiveness in limiting spread of the disease. Likewise use of suitable rotation crops and lengthening the period between susceptible ginger crops may limit the build-up of pathogen loads in the soil. However development of more disease suppressive soils is also a viable strategy and the project has demonstrated that ginger-growing soils can be managed in such a way to create microbial communities capable of suppressing Pythium Soft Rot in ginger. Soils amended with poultry manure and sawdust, as well as cropped soils subjected to minimal disturbance were the most suppressive to the disease and the best for harvestable rhizome yield.

Root Knot Nematodes (*Meloidogyne* spp.) and Burrowing Nematode (*Radopholus similis*) were also found to be limiting yield and causing damage to ginger rhizomes, particularly in mature crops. The former is a problem in Australia, while the latter is responsible for serious damage and crop losses in Fiji. *Radopholus similis* was found to be present on planting material, on volunteer ginger in fields of taro and cassava which are common rotation crops and poor hosts of *R. similis*, and on weeds such as crowsfoot (*Eleusine indica*). As for *Pythium* control, clean planting material is essential, as is the need for adequate crop rotation and removal of volunteers and weeds that may be acting as hosts for pathogens. Our research has also shown that timely applications of poultry manure can be very effective in controlling soil infestations of burrowing nematode.

Farming systems experiments were conducted on the farms of more progressive growers, so that a participatory research approach was adopted. In addition, field days and workshops were held so that the research results could be communicated to a wider audience. Often the cooperative growers shared their understanding of the applications of these practices on their own farms at these occasions. It was also critical that an awareness of the importance of clean planting material was achieved and that industry has put in place more sustainable strategies and practices to ensure pathogens are not being introduced on ‘seed’ used for planting.

ACIAR, through the John Allwright Fellowship scheme and this project, provided support to enable two Fijian staff from the Ministry of Primary Industries to attain a Master in Plant Protection and a Master of Philosophy (Agricultural Economics) at the University of Queensland. Support was also provided to enable plant protection staff to undergo professional and technical training in Australia, to attend and present their research at international conferences and symposia, and to undertake a study tour of the Australian ginger industry. Furthermore the ability of staff to undertake plant pathology and nematology research at Koronivia Research Station was improved through upgrades to facilities and equipment necessary to undertake these studies.

3 Background

3.1 Fijian and Australian Ginger Industries

Edible ginger (*Zingiber officinale*) production in Fiji dates back to the 1950s when a small area was grown in the Suva peninsula with produce exported to New Zealand. In the 1960s the production dramatically increased as Fiji started exporting fresh ginger to North America and new production areas were identified. Production increased to 5,000 metric tonnes in the 1980s and stayed around that figure for some time until 1999 when the North American market collapsed due to competition from China. The industry has since recovered and restructured with an emphasis on exports of fresh immature ginger and the entry of ginger processors that preserve immature ginger in brine or syrup for export markets. In exports alone, the industry was valued at FJD$4.2 million in 2004 when this project first commenced activities.

Ginger is planted in Fiji between September and early November, and immature (green) ginger is harvested January-March (70% of the crop) and mature (brown) ginger in June-July. Ginger is also harvested for 'seed' which provides the vegetative planting material for next season's crop. Ginger is mainly grown in the wetter areas of Viti Levu (Suva/ Nausori/Navua) and predominantly by Fijian smallholders as an important cash crop. Exporters and processors contract growers to produce an agreed quantity of good quality ginger at a set price.

The past 15 years has seen a decline in ginger production and greater wastage due to soil-borne diseases mainly occurring during the wetter, warmer months. Several recent surveys, HortResearch/Fiji Government (1996-98) in Fiji and Biological Crop Protection/Horticulture Australia (1997-2001) in Australia, provide convincing evidence that soil-borne diseases are the major problem. A major constraint to production in Fiji is the soil-borne pathogen, *Pythium myriotylum* (*Pm*), which infects seed-pieces and causes rot and early death of plants. *Pm* was killing up to 30% of plants during surveys undertaken during 1997/98 but is capable of completely destroying the entire crop. In Australia the major soil-borne pathogen of edible ginger was widely regarded as *Fusarium oxysporum* f. sp. *zingiberi* (*Foz*), until the wet summer of 2007/08 when *Pythium myriotylum* was isolated on a few farms. Both are now responsible for extensive rhizome rots. The epidemiology of both *Pm* and *Foz* is also influenced by nematode damage to roots and rhizomes, which can exacerbate disease development. Annual farm-gate losses due to soil-borne pathogens were estimated in 2004 at FJD$530,000 for Fiji and AUD$990,000 for Australia, and the situation was deteriorating.

These pathogens limit production and affect rhizome quality, which in turn can decrease profits and destabilise the market. Furthermore pressure is placed on 'seed' beds as a source of material to satisfy contracts. If the best material is sold and pathogen infected material used for planting, then a downward spiral begins. If serious enough, pathogens can even lead to market failure. It was important that the disease/pest cycle be broken.

A review of the ginger industry was undertaken by the Fijian Ministry of Agriculture in conjunction with a major growers' meeting during 2004. The major issues and priorities, as listed at the meeting, included:

1) Increasing threat of disease – production losses/poor quality/lack of seed ginger
2) Increasing cost of production under current farming system
3) Scarcity of labour
4) Low labour productivity
5) Lack of credit facilities
6) Environment degradation
7) Urban drift – farming no longer an attractive option for the younger generation
8) Institutional problems

Despite these concerns the industry concluded, “Fiji ginger is known for its taste but can no longer be complacent in terms of quality and price. There is great potential for expanding the processing sector and fresh immature ginger may become a specialty product in the hands of a few exporters. Fiji is capable of producing quality ginger and at a competitive price providing the problems highlighted above are addressed effectively and in time.”

It is interesting to note that the priorities identified by the Fijian ginger industry are almost identical to the Australian ginger industry, and in the same order. ACIAR project PC/2004/049 attempted to address the priority issue of soil-borne diseases and the use of more sustainable production practices should also address the issue of environmental degradation. Creation of a more profitable ginger industry should have flow on benefits for regional communities as well as businesses in the larger towns.

3.2 Research Strategy

The research strategy for the project involved developing a farming systems approach to ginger production using pathogen-tested planting material, bedding/mounding, reduced tillage, crop rotation and the use of mulches/organic amendments to improve soil physical and chemical properties and suppressiveness to soil-borne pathogens. The key was to achieve an active soil biology that was antagonistic to fungal pathogens, enhance populations of free-living nematodes to levels that maintain predators of nematodes (particularly fungal predators), and limit nitrogen to levels that encourage predatory activity (Stirling 1989; 2004). Improvements in soil health status were confirmed with some simple measurements of microbial activity, free-living nematodes, as well as measures of nutrient status and soil organic matter. Combining this with yield data and disease incidence enabled us to determine whether we improved the soil’s suppressiveness to key soil-borne pathogens and restored its biology. This knowledge immediately translates into practical recommendations for the most appropriate farming systems to use for ginger production in Fiji and Australia.

This project drew on findings related to ginger marketing and economics of the ACIAR project ASEM 2003/069 *Policy options for improving the value of land use in smallholder Fijian Agriculture*. This project undertook a small study to look at the economics and marketing of ginger during the second year of its implementation through a Masters Research project by Waisiki Gonemaituba at the University of Queensland. This project also had links with other ACIAR projects in the Pacific dealing with IPM of vegetables e.g. CP 2004/063 *Integrated pest management in a sustainable production system for Brassica crops in Fiji and Samoa*.

A farmer participatory research (FPR) approach was used at 3 farmer trial sites in Fiji (Waibau, Navua and Veikoba) and 2 trial sites in Australia (Kandanga and North Arm). This research was also linked with the Fijian Ministry’s extension service and a senior officer was devoted full-time to ginger and six other officers were located in the major ginger producing areas with 30% of their time responsible for providing support to ginger growers in the area. In addition the exporters/processors, who have a vested interest in the supply of quality material, have liaison officers who work with farmers as well as the Ministry’s Extension Division. These people knew the growers and had the necessary social-cultural skills to help drive the FPR model. FPR, both in Fiji and Australia, had the advantage that industry champions were identified so the project was tailored to more effectively deliver agreed outputs.

The Fijian government targeted support for export crops as very high priority and there was strong support and commitment for the ginger project at all levels. In this context the Ministry had a policy in place to set up model farms to not only provide demonstrations of best farming practice, but to provide industry support in the form of clean planting material.

4 Objectives

The overall aim of the project was to improve profitability (yield and quality) of ginger in Fiji and Australia through better management of soil-borne diseases. This was to be achieved through the following three objectives:

4.1. Develop practical systems for production of clean planting material

- Overcome the practical problems involved in maintaining blocks of clean planting material on ginger farms in Fiji and Australia, and demonstrate the value of clean planting material for managing soil-borne diseases.

4.2. Develop soil management systems to improve soil health and reduce losses from soil-borne diseases

- Improve the suppressiveness of ginger-growing soils to soil-borne pathogens (particularly *Pythium myriotylum, Fusarium oxysporum* f.sp. *zingiber*, *Meloidogyne* spp. and *Radopholus similis*) by incorporating rotation crops (e.g., taro, cassava, brassicas, legumes, grasses), minimum tillage, mulches and organic amendments (e.g., rice husks, sugar cane trash, mill mud) and plant defence activators (e.g., silicon) into the ginger farming system.

4.3. Implement improved ginger production systems

- To communicate results at grower and community forums and coordinate activities with local industry groups.
- To develop a plan for engagement and adoption of the recommendations made by the project team through a consultative process. The network of contracted growers is the focus of activities.

The outcome of these studies will be to increase the production of high-quality ginger in Fiji and Australia. They will lead to the development of farming systems for ginger that improve soil health, sustain productivity and increase profitability.

5 Methodology

5.1 Develop practical systems for production of clean planting material

The methods for tissue culture propagation of ginger are well established (Smith and Hamill, 1996) and in routine use at Maroochy Research Station and Koronivia Research Station. Small trial plots of tissue cultured material were established in Fiji and Australia and seed-pieces harvested from these plots were used to establish nursery beds for the continued production and supply of superior quality 'seed' material.

Nursery sites were identified that have not grown ginger or used water from dams for past ginger production. The nursery sites were also managed as if they were quarantined from the rest of the ginger industry. Sustainability of such schemes will depend on clear demonstration of benefits and results from our studies have highlighted the value of clean 'seed' as compared to the 'seed' currently in use. This is particularly important in Fiji to stop the practice of buying second-grade seed or in using market reject material as planting material.

Seed treatments consisted of allowing the seed to suberise for 4-5 days under ambient temperatures *vs* seed that had been cut and immediately planted, as well as hot-water treatments where seed was dipped in water maintained at either 48°C for 20 minutes or 54°C for 15 minutes.

5.2 Develop soil management systems to improve soil health and reduce losses from soil-borne diseases

5.2.1 Observations on crop losses and disease etiology: Pythium Soft Rot

5.2.1a Pythium Soft Rot in Fiji

Fijian fields were checked for signs of Pythium Soft Rot and plants with yellow or dead shoots were inspected. If symptoms were typical of soft rot, rhizomes were collected and the diagnosis confirmed by isolating the pathogen in the laboratory. Ginger brought to the processing factory in February 2007 was also checked for soft rot and other pests and diseases. Twenty consignments of ginger from various parts of Fiji were carefully inspected, the amount rejected for various reasons was recorded and pathogens associated with disease symptoms were confirmed in the laboratory. Since most Fijian crops are harvested in February as immature ginger, observations on the development of rhizome rot later in the season were limited to crops retained for planting material.

The spatial distribution of the disease was monitored in eight fields (four near Veikoba and four in the Waibau region) that ranged in area from 48 to 240 m^2. All crops were disease-free in February 2008 and were therefore retained to provide seed later in the season. Fields were inspected in March, April and May 2008 and the location of all plants showing disease symptoms was marked on a map. Final observations were made when crops were harvested for seed during late July and early August 2008 and seed losses were estimated in consultation with the grower.

5.2.1b Pythium Soft Rot in Australia

Pythium Soft Rot had never been observed on ginger in Australia until late December 2007, when a severe outbreak occurred on two farms in Queensland that were 28 km apart but owned by the same family. Initial observations were made soon after the disease was reported by the grower and disease spread was then monitored in four fields that had distinct patches of diseased ginger surrounded by green, healthy plants. Three of the fields were at Eumundi and one at Kandanga, and they varied in size from 1.4 to 3.6 ha. Datum plots (10 m long with three rows of ginger contiguous along beds 1.9 m wide) were marked out in each field and disease severity was rated every few days as follows: 0 = no yellow and necrotic shoots in the datum plot; 1 = <2%; 2 = 3–5%; 3 = 6–10%; 4 = 11–33%; 5 = 34–67%; 6 = 68–100% diseased shoots in the datum plot. The rate of

disease spread was measured by first marking the edge separating diseased and yellowing shoots from green and healthy shoots. The daily rate of spread was calculated by measuring the distance the diseased edge had moved between recording dates. Fields were monitored every few days from mid-January to early February 2008, and final observations were made just before harvest of immature ginger in late February 2008.

5.2.1c Rainfall and temperature data

Since outbreaks of soft rot are known to be associated with hot and consistently wet conditions, temperature and rainfall data were collated for two sites: Koronivia Research Station, Nausori, Fiji and Maroochy Research Station, Nambour, Queensland, Australia. Both stations are located within 20 km of the major ginger-growing areas in each country and have a climate that is broadly similar to those areas. The records date back to 1973 for Nausori and 1952 for Nambour. Long-term averages for December–May and data from the 2006–07 and 2007–08 ginger-growing seasons were retrieved for rainfall, the number of rain days and minimum and maximum temperature.

5.2.1d Isolation and identification of Pythium

Ginger rhizomes showing disease symptoms were washed thoroughly in water, dipped in ethanol and flamed briefly before tissue from the leading edge of lesions was transferred to media that were selective for *Pythium*. In Fiji, isolations were done on cornmeal agar with carbendazim (2 mg/mL), ampicillin (250 mg/mL), rifampicin (10 mg/mL), pimaricin (5 mg/mL), and pentachloronitrobenzene (100 mg/mL), while a medium containing penicillin, polymixin and pimaricin was used in Australia (3P medium of Eckert and Tsao 1962). To check for fungal pathogens other than *Pythium*, tissue was also plated onto potato dextrose agar containing streptomycin (120 mg/mL).

Pythium isolates were identified using methods outlined by Van der Plaats-Niterink (1981). Growth rates at various temperatures were determined on potato carrot agar while sporangia, antheridia, oogonia and oospores were produced by transferring the fungus to autoclaved grass leaves floating in sterile water. The identity of isolates used in pathogenicity tests was confirmed by sequence analysis of rDNA internal transcribed spacer (ITS) regions containing ITS1 and ITS2 and intervening 5.8rDNA using the primer pair ITS1/ITS4 (White et al. 1990).

5.2.1e Pythium Soft Rot pathogenicity experiments

Experiments were set up in Fiji and Australia using isolates of *P. myriotylum* from each country. Inoculum was prepared by placing 50 g sorghum seed in 250-mL Ehrlenmeyer flasks, soaking the seed overnight in water, pouring off the excess water, autoclaving twice on successive days and then inoculating the seed from cultures on agar. The inoculum was used after the oomycete had fully colonised the substrate (usually 7–10 days at 25°C). Plants were grown in pots containing steam-sterilised potting mix (3 sand : 1 peat) and were inoculated 2–5 months after a seed piece had been planted in each pot. After 4 g of inoculum was added, the soil was kept moist for 4 days and then a wet/moist cycle (4 days wet and 3 days moist) was imposed by placing a saucer under the pot for 4 days and removing it for 3 days. At the end of each experiment, small pieces of tissue from rotting rhizomes were transferred onto a selective medium (see above) to check for the presence of *Pythium*.

In both experiments, the level of disease in each pot was assessed periodically by rating aboveground symptoms using the following scale: 0 = healthy plant; 1 = some leaves starting to turn yellow; 2 = plant alive, but shoots either totally yellow or dead; and 3 = all shoots dead.

5.2.2 Observations on crop losses and disease etiology: plant parasitic nematodes

Surveys of plant parasitic nematodes that could also be responsible for yield losses were conducted in farmers' fields from all the major ginger growing areas in Fiji. Soil was collected from around the roots and rhizomes, mixed gently and a 200 ml sample was

placed on a standard extraction pan for 2 days. Nematodes recovered by sieving twice on a 53 µm sieve were counted.

A total of 20 consignments of ginger were checked at the Frespak factory at Lami by inspecting ginger on the conveyor belt after washing and in the reject bins. About 100 rhizome pieces in each consignment were carefully inspected and lesions possibly caused by nematodes were teased out under water to check for the presence of root-knot nematode (*Meloidogyne* spp.) and burrowing nematode (*Radopholus similis*). The washed weight of each consignment and the weight of ginger rejected were obtained from factory records.

Radopholus. Relatively small (5-15 mm diameter), light brown or water-soaked lesions generally extending only 1-2 mm below the surface.

Meloidogyne. Slight eruptions of tissue usually near the base of developing buds.

5.2.2a Burrowing nematode pathogenicity experiment

On 12 September 2008, a potting medium consisting of 2 parts washed river sand and 1 part commercial potting mix was heated to 70ºC for 30 minutes. Twenty 4L pots were then filled with this medium and a metalaxyl-treated seed piece of ginger (*Z. officinale*) was planted in each pot. Pots were transferred to a glasshouse and after 6 weeks, when plants had shoots up to 10 cm long, half the pots were inoculated with 1,500 *Radopholus similis*. The nematode was originally obtained from a ginger farm at Veikoba, Fiji and had been multiplied in the laboratory on sterile carrot tissue.

On 9 February and 20 March 2009 (15 and 20 weeks after pots were inoculated), the total number of shoots and the number of yellowing or dead shoots in each pot was recorded. At each harvest date, the above-ground biomass in five inoculated and five control pots was measured and seed pieces and newly-developing rhizomes were then removed from the pots for assessment. Roots were chopped into segments <1 cm long and mixed with the soil, and a 200 ml sample (about 220 g) of soil and roots was spread on a Baermann tray. After 2 days, nematodes were recovered on a 38 µm sieve.

Portions of seed pieces and rhizomes that showed symptoms possibly caused by *R. similis* were assessed by removing small pieces of tissue (about 1 mm^3) from affected areas, macerating them in water and checking for nematodes after 24 hours. Discoloured tissue was also checked for fungal pathogens by placing small pieces of the tissue onto potato dextrose agar (PDA) or corn meal agar with carbendazim, ampicillin, rifampicin, pentachloronitrobenzene and pimaricin (CARPP) and observing plates after 24 and 48 hours.

The nematodes present in larger pieces of discoloured or rotting tissue (i.e. 0.5 – 4 g) were recovered by macerating the tissue in 200 ml of water in a blender and then placing it on a Baermann tray for 24 hours. This maceration technique was also used to recover nematodes from the remaining part of each seed piece or rhizome. In cases where nematodes were extracted from several pieces of tissue from the same seed piece or rhizome, the counts were added to obtain the total number of nematodes.

5.2.3 Developing farming systems to control soil-borne pathogens and improve yield

In Fiji a field trial at Waibau was established in September 2006 to examine the effect of nitrogen (N) on Pythium Soft Rot. The experiment consisted of four rates of poultry manure (0, 5, 12.5 and 17.5 t/ha) applied before planting to four replicate plots (each 20 m^2) set out in a randomised block design. In Australia the trials were larger, with more treatments and larger blocks to accommodate mechanised operations. An experiment was established to examine the influence of cover cropping, pasture leys, organic amendments and minimum tillage in a ginger farming system over 2 crop cycles.

Soil textural and chemical analyses were made from soil sampled to a depth of 10 cm and major and minor elements were measured using a commercial nutrient analysis service in Australia (Incitec Pivot, Werribee) or the Soil Testing Laboratory at Koronivia Research Station.

The presence of soil-borne pathogens was confirmed by collecting soil samples from a depth of 0-10 cm on 6 April 2006. The soil was mixed gently, spread on a standard nematode extraction tray and after 2 days, nematodes were recovered by sieving twice over a 38 µm sieve. Bioassays in which tissue-cultured ginger plants were planted into 1 L of field soil diluted either 1/10 or 1/100 with autoclaved soil and grown in a glasshouse for up to 8 months to detect presence of fungal pathogens.

The basic experiment consisted of 5 cropping/tillage treatments × ± poultry manure amendment × 4 replicates. The cropping tillage treatments were set out in a randomised block design, with the amendment as a split plot. The main treatments were: (A) conventional tillage with continuous cropping and a conventional tillage ginger crop, (B) minimum tillage with continuous cropping and a conventional tillage ginger crop, (C) conventional tillage with a summer crop only and a conventional tillage ginger crop, (D) minimum tillage with a summer crop only and a minimum tillage ginger crop, and a four-year pasture ley further split into (ECT) conventional tillage ginger crop and (EMT) minimum tillage ginger crop. A fumigated control (F) was included where conventional tillage summer crops were followed with a conventional tillage ginger crop, however the beds were treated with 500 kg/ha 1,3-dichloropropene (Telone®) 3-4 weeks prior to planting ginger.

Field experiments were grown as per commercial practice.

5.2.3a Growth and yield measurements of ginger crop

Shoot emergence and number of shoots were counted from a 3 m length of bed on the 26 October 2009, 11 November 2009 and 3 December 2009. Rhizomes were harvested from a 1 m section of bed and an estimate of yield extrapolated from the weight of uninfected rhizomes (t/ha). Rhizome that had been rejected due to rot was weighed and expressed as a percentage of the total rhizome harvested from the plot.

The first-late harvest occurred on 4 May 2010 and again rhizomes were harvested from a 1 m section of bed and both rejected (due to rot) and sound rhizomes were weighed and yields calculated. Root knot nematode damage was slight (none would have been rejected) and was expressed as the percentage of 10 randomly selected rhizomes that showed any signs of damage.

5.2.3b Soil-borne pathogen assessments

For the first ginger crop at early harvest on the 12 March 2008, the ginger in a datum plot 1.15 m long was harvested and the number of rhizomes showing rot symptoms caused by soilborne fungi was recorded. Laboratory isolations indicated that these symptoms were primarily caused by *Pythium myriotylum*. However by mid-April yellowing of plants was associated with *Foz* infection of the rhizomes and it was estimated that another 10% of the trial was affected. On 14 April 2008 (2 days prior to first-late harvest), three independent observers estimated the percentage dead and severely yellowing shoots in an 18 m datum plot in the centre of each plot. Estimates were then converted to a disease rating of 1 to 6, where a rating of 1 indicating that <5% of shoots showed symptoms and a rating of 6 indicating 45-55% of shoots were affected.

For the second ginger crop and prior to early harvest (31 March 2010), the percentage of yellowing and necrotic shoots in the entire length of the bed was estimated for each treatment, and plots were rated for disease severity (0 = all shoots green and healthy to 5 = total collapse and death of shoots).

Root knot nematode populations were monitored during the growing season by collecting soil samples prior to planting, at early harvest and 2 days prior to first-late harvest by the

method described previously. At each sampling time, 10 cores were collected from each plot to a depth of 0-20 cm using a 2.5 cm diameter sampling tube.

Since root knot nematode was not detected in soil samples collected prior to planting of the first ginger crop, the nematode was inoculated at one point in each plot in an attempt to determine whether some treatments were more suppressive to nematode multiplication than others. Inoculum of *M. javanica* was obtained by retrieving eggs from glasshouse-grown tomato plants using NaOCl and 50,000 nematode eggs were then inoculated at a depth of 15 cm, at a point 4.5 m from the end of each plot. Eggs were added on 15 October 2007, three weeks after ginger was planted but before any emergence had occurred.

On 3 March 2008 (early harvest), all plants within 20cm of the inoculation point were dug up and all rhizomes (generally 3-5 pieces) were rated for root knot nematode damage on the following scale: 0 = no damage; 1 = a low level of damage (1-2 areas erupted due to the nematode per rhizome); 2 = moderate damage (3-5 erupted areas); 3 = high (6-10 erupted areas) and 4 = very high (rhizomes unmarketable due to root knot nematode damage). After rhizomes had been removed, the soil in this area was sampled and nematodes were extracted and counted as described previously.

5.2.3c Pythium suppression bioassays

In September 2009 (just before ginger was planted and four years after the experiment commenced), soil was collected from each plot and half was irradiated at 25 kGy. Both irradiated (IR) and non-irradiated soils were placed in 2 L plastic planter bags and planted with a 60 g piece of ginger rhizome. *Pythium myriotylum* was cultured on autoclaved sorghum seed and on 10 December 2009, when plants had 1 or 2 shoots up to 50 cm long, each pot was inoculated with two *Pythium*-colonised seeds. The assay was repeated on 19 January 2010, except each pot received only one colonised seed. The mean maximum temperature during December and January was over 30°C and overhead sprinklers in the screen house provided a watering regime conducive for *Pythium* infection. After approximately 3 months for each assay, plants were assessed for disease severity on a 0-3 scale where 0 = no disease; 1 = some leaf yellowing; 2 = most shoots yellow or dead; 3 = rhizomes rotted and plants dead. Assessments were based on 17-21 plants for each treatment in the first assay and 11-16 plants per treatment in the second assay. *Pythium* was confirmed in a random selection of affected rhizomes at the end of the assays.

5.2.3d Statistical analysis

Data were subjected to analysis of variance followed by least significant difference test at P=0.01 or 0.05 (ANOVA; GenStat – Sixth Edition © 2002, Lawes Agricultural Trust). Percentage data were transformed via arcsine before analysis.

5.3 On-farm implementation of improved ginger production systems

Farms for farming systems test sites were selected in consultation with researchers, extension staff, as well as leading exporters/processors. Three sites were chosen to conduct trial work in Fiji, while there were two in Australia.

Key staff met with selected growers before crop planting to discuss pathogen and crop problems and their experience with different practices, to prioritise problems and possible alternatives for testing, and to identify indicators for evaluating progress. At key periods in the crop cycle, they met again to compare plant growth and disease levels. They also discuss the progress of their experiments. At each meeting they also conducted field visits and discovery exercises to strengthen their ecological knowledge of the crop, pathogens and soil factors. At the end of the cycle, they identified major lessons to be learned in the next crop cycle and problems for further experimentation or study.

6 Achievements against activities and outputs/milestones

Objective 1: To develop practical systems for production of clean planting material

no.	activity	outputs/ milestones	completion date	Comments
1.1	Provision of tissue cultured plants	Plants available for nursery production	On-going; PC, A	In Australia it has become an integral component for the production of clean planting material. TC plants are also the safest way to distribute plants across quarantine boundaries.
1.2	Provision of clean seed	Seed available for production	On-going; PC,A	In Fiji the Government, with support from private businesses, is assisting industry with clean planting material by producing ginger rhizomes on government-owned research stations.
1.3	Seed treatments	Improved treatments for provision of good quality seed	Year 4; PC	Hot-water treatment, as well as chemical control options based on metalaxyl and phosphonic acid, have proven effective in controlling soil-borne pathogens of ginger.

PC = partner country, A = Australia

Provision of tissue cultured plants and clean seed

A clean-seed scheme operated in Fiji in the past and there is interest from a number of exporters to reintroduce the scheme. Koronivia Research Station also has a tissue culture laboratory that is currently producing tissue cultured ginger for agronomic evaluation. An inspection of the facility and discussions with staff revealed that capacity exists within the Ministry to multiply and harden-off tissue cultured ginger plants.

In Fiji, two sites have been established by the Ministry of Primary Industries for the production of clean seed for use by industry: one is in the Western Division of Viti Levu near Nadi and the other in the Northern Division of Vanua Levu at Seaqaqa Research Station. These areas are declared free of *Radopholus similis* and helped alleviate short-falls experienced in supply of planting material during the 2008/09, 2009/10 and 2010/11 seasons.

Tissue cultured plants of the improved ginger variety, 'Buderim Gold', were imported to Fiji under permit and established at Koronivia Research Station (KRS). 'Buderim Gold' is a tetraploid white ginger cultivar developed by the former Queensland Department of Primary Industry and Fisheries (QDPI&F) and has significantly larger rhizomes compared to the mother plant, 'Queensland'. After discussions with Fijian fresh ginger exporters on previous visits, they felt a market may exist for this product in Japan and the USA. After discussions with Buderim Ginger Limited, who helped fund the developmental work on 'Buderim Gold', it was decided to release it in Fiji and determine if international markets may exist for a large, white fresh ginger product.

Most of the 'Buderim Gold' plants were established in pots in a glasshouse under shade, but six plantlets were retained for tissue culture multiplication at KRS, while another six plantlets were to be placed in the *in vitro* germplasm collection at the Secretariat of the Pacific Community (SPC).

Two Australian 'seed' producers were each supplied with consignments of 1500 tissue cultured plants over the course of the project. This was part of an on-going process to ensure that disease-free and pest-free material is introduced into the nursery production system. In addition, the project team continued to test for soil-borne pathogens on these farms to ensure the spread of diseases and pests on planting material is minimised. Demand for clean seed by the ginger industry continues to exceed supply.

Seed treatments

In Fiji, seed is typically allowed to air-dry under shade for 8-10 days before planting, whereas the economic imperative in Australia is to plant seed as soon as possible following cutting and fungicide treatment. This means that cut surfaces may not be sufficiently suberised before planting and the physical barrier to prevent pathogen invasion may not be fully formed. Pot experiments were conducted in the glasshouse to test the effect of seed drying treatments on germination and susceptibility to pathogens.

When planted into sterilised soil, seed germination was faster when not allowed to dry for 10 days, even though 17% developed *Erwinia* soft rots in soils that were occasionally watered and this increased to 35% when soils where maintained at field-capacity. Seed that had been allowed to dry for 10 days and had a suberised barrier at the cut end did not develop any rots. These experiments suggest that seed requires a period for suberisation to occur on the cut ends prior to planting to minimize rots and improve establishment of the ginger crop.

In Australia, seed is hot-water treated at 48^{o}C for 20 min and then dipped in fungicide to control *Meloidogyne*. This is often restricted to 'seed' being used to establish nursery blocks as the hot-water treatment can reduce yields by up to 20%. This is deemed acceptable because the rhizomes used for next season's planting material must remain undisturbed in beds for up to 12 months.

In Fiji, A small (1.2 m^3) gas-fired vat was loaned by the Ministry of Agriculture for the purposes of hot-water treating ginger seed. A farmer at the Veikoba trial site used his 'standard' method of treating seed which consisted of half-filling the vat with approximately 600 L of water, waiting until the temperature of the water approached 50^{o}C (varied from 48^{o}C to 50^{o}C) and placing a maximum of eight 20 kg bags of seed in the vat and leaving for 15 min. The temperature of the water was 40^{o}C at the end of this 'standard' treatment. Our project team was allowed to treat one bag of the grower's own seed using the Ministry's recommended treatment of 54^{o}C for 10 min (this time the temperature was held constant over the treatment period).

A sample of seed was collected and tested. Whereas live nematodes were recovered from seed using the farmer's 'standard' treatment, no live nematodes were detected using MAF's recommended procedure. A significant finding was that *Radopholus* was detected in grower's seed from 4 of the 8 plots sampled. This is strong evidence that burrowing nematodes are being introduced into prepared plots on seed that has been insufficiently hot-water treated.

In another study, Waiski Gonemaituba's survey for his Masters research at the University of Queensland revealed that only 9% of Fijian farmers treated their seed with hot water during the 2006-07 season. Therefore the implication is that nematodes are not being controlled before seed is planted, and if it is being hot-water treated then it is being done incorrectly.

Objective 2: To develop simple soil management systems to reduce disease

no.	activity	outputs/ milestones	completion date	comments
2.1	Establish base line data	Chemical and biological parameters established	Year 1; PC, A	Pest and diseases surveys were completed and chemical and biological parameters of soils measured.
2.2	Investigate treatments to study and monitor pathogens	Test and revise control measures for soil-borne pathogens	Year 4; PC, A	Organic amendments and tillage practices have been identified that lead to soils more suppressive to soil-borne pathogens.
2.3	Establish rotational cropping systems to study and monitor pathogens	Test and revise control measures for soil-borne pathogens	Year 4; PC, A	Rotation crops have been identified that are poor hosts to the soil-borne pathogens that infect ginger.

PC = partner country, A = Australia

Pest and disease surveys

The evidence collected from Fiji and Australia strongly supports the association of Pythium Soft Rot with long periods of wet, overcast weather and in situations where the soils remain saturated.

All *Pythium* isolates obtained from ginger in Fiji and Australia grow well at high temperatures. They continue to grow slowly at 41^{o}C and have radial growth rates on agar of about 30 mm/day at 37^{o}C. The Australian isolates from ginger have been identified as *P. myriotylum* and possibly *P. zingiberis*, whereas the Fijian isolates have been identified as *P. myriotylum, P. graminicola* and *P. vexans*. Pathogenicity tests performed in Fiji and Australia confirmed we are dealing with highly pathogenic isolates that are more virulent when soils are saturated and infection does not required damage to the host roots or rhizomes as caused by the nematodes *Radopholus* or *Meloidogyne*.

It was established that *Radopholus* is a primary pest causing damage to the roots and rhizome, but economic losses are negligible for the immature harvest. However by the harvest of mature ginger, particularly for rhizome that is used as ‘seed’, damage can be severe and the wound sites lead to development of rots that can result in extensive losses in the field.

Control measures for soil-borne pathogens

Pythium Soft Rot was widespread and occurred in all of the major ginger growing areas in Fiji. It has resting oospores that can still be infectious even after long fallows. It is also transferred on infected planting material as our studies confirmed. *R. similis*, on the other hand, occurred on a few farms, and only in the Veikoba region. The nematode was sometimes not detected in soil at the time ginger was planted, but was invariably introduced in planting material. It then multiplied rapidly and was readily detected later in the season. The highest population densities recorded from ginger fields were 170 nematodes/200 ml soil at immature harvest and 410 nematodes/200 ml soil at mature harvest. *R. similis* was never found in taro or cassava roots, but was occasionally found at low population densities in soil associated with roots of those crops. However, moderate to high populations were invariably found on volunteer ginger, which was always present as a weed in the following taro and cassava crops.

Soils amended with poultry manure and sawdust (PS) and cropped soils that were subject to minimal disturbance (MT) were most suppressive to Pythium Soft Rot and plant parasitic nematodes. Conversely, treatments where the soil microbial community was disturbed or diminished (i.e. fumigated and bare fallow soils) had significantly lower levels of suppressiveness compared to the Crop/MT/PS treatment. These results demonstrate that the way soil is managed influences its suppressiveness to soil-borne pathogens. It should therefore be possible to reduce the impact of these pathogens by modifying the current ginger farming system. Furthermore, in the Fijian ginger farming system, ginger is generally grown every 3 years, with crops of cassava and taro planted in the years between ginger crops. Our results indicate that this is an excellent rotation for managing both Pythium Soft Rot and plant parasitic nematodes. Taro and cassava are poor hosts for both of these pathogens. Even in the Australian context, a 3-year break from ginger is still likely to be useful in managing soil-borne pathogens, as inoculum densities will decline during the break if non-host plants are used, and thus reduce disease severity when ginger is planted.

Objective 3: To implement improved ginger production systems

no.	activity	outputs/ milestones	completion date	Comments
3.1	Establish FPR for project	Framework developed for project activities	Year 1; PC, A	Updated annually
3.2	Conduct field experiments to assess treatments	Successful options tested and communicated to industry	Year 4; PC, A	Field trials have been conducted at research stations and growers' farms both in Fiji and Australia. A successful R&D program has informed industry of the best and most current methods to control soil-borne pathogens of ginger.
3.3	Extension activities	Field days and walks held with supporting literature	On-going PC, A	Annual Ginger Growers' Field Days are held each year in Australia. Two R,D&E meetings have been held in Fiji for ginger growers and a final project workshop was held for all industry participants in July 2010

PC = partner country, A = Australia

A framework was developed for the project activities through regular meetings with research and extension staff, as well as external consultants, and was updated annually. This process provided direction to the project and improved our understanding of the soil-borne pathogens affecting ginger production and provided growers with better options for control in two markedly different environments and cropping systems. In addition a survey of the technical efficiency and output losses (pathogens and soil erosion) of Fijian ginger growers was completed by Mr Waisiki Gonemaituba as part of his Masters studies at the University of Queensland. His study has important policy implications that the Fijian government can use to create a more profitable and sustainable ginger industry.

In terms of industry extension, project staff presented the results of the first, 2-year phase of research completed in Fiji and Australia at a seminar held at Koronivia Research Station on 13 February 2009. Research staff from the Ministry was present, as were interested SPC plant protection staff and ginger growers. Towards the completion of the project a major workshop was held on 30 July 2010 at a local processor/exporters premises in Navua and was very well attended, drawing the support of the Minister of Agriculture and the Permanent Secretary of Agriculture, together with the Heads of Departments and influential local growers. The workshop proved to be a catalyst for gaining the support of private business partners in establishing a clean seed scheme in areas declared free from *R. similis*. It also provided impetus for the printing of information

leaflets in the local language and in launching field days and walks for growers in the major production areas.

In Australia, Field Days organised by the Australian Ginger Growers' Association (AGGA) were held in January for each year of the project and results of project activities were presented through field walks, oral presentations and hand-outs. Project updates have also been provided to growers at quarterly AGGA meetings.

Also in Australia, with support from Queensland Primary Industry and Fisheries (QPIF) trade and investment officers, a consultative process was commenced to identify pathways by which all stakeholders within the ginger industry supply chain may increase their profitability. The activities undertaken during the reporting period included a preliminary investigation of the ginger industry to better understand issues within the industry, which was followed up with a detailed investigation of the industry to identify market trends and opportunities for the industry. A report was made available to the Australian Ginger Growers' Association on 11 May 2009. Forward momentum was maintained by the convening of a Ginger Industry Development Workshop on 27 May 2009 at Maroochy Research Station to develop an action plan that will guide future investment in the industry and foster its development. An industry R&D levy has since received the support of growers and processors and will be administered by the Rural Research & Development Corporation.

7 Key results and discussion

7.1 Pythium Soft Rot of ginger

7.1.1 Observations on crop losses and disease etiology

Our observations, together with the unpublished results of Fullerton and Harris (1998), show that losses due to Pythium Soft Rot occur regularly in Fiji. In 1997–98, rhizome rot destroyed ~30, 75, 30 and 100% of mature ginger crops at four field sites in Fiji (Fullerton and Harris 1998), and we observed similar losses to seed ginger in 2007–08. We suggest that given the typically wet Fijian climate, rhizome rot is likely to occur on seed crops in most years and will often limit the amount of material available to plant the next ginger crop.

Since most Fijian ginger is now harvested in February for the immature market, total losses from the disease are probably not as great as they were 10 years ago. Nevertheless, immature ginger can suffer heavy losses when conditions are unusually wet for a month or two before harvest. Such a situation occurred in the 2008–09 season, as losses of 25–50% were observed in immature crops in the Navua district following 789 mm of rain on 29 days during January 2009.

The fact that rhizome rot occurred in Australia during the time we were studying the disease in Fiji was fortuitous in some ways, as the summer of 2007–08 was the wettest in the Australian ginger industry for more than 30 years. During the 2 months from mid-December 2007 to mid-February 2008, temperatures were high and rain fell almost every day; conditions that occur regularly in Fiji. Although severe losses from rhizome rot have never previously been observed in Australia, it is possible that the disease occurred at low levels before 2007–08 and had never been reported. Australian ginger growers normally assume that patches of yellowing plants with rotting rhizomes are affected by Fusarium yellow (caused by *Fusarium oxysporum* f. sp. *zingiberi*), as this disease occurs on almost every farm in the industry (Pegg and Stirling 1994; Stirling 2004).

Dohroo (2005) noted that wet conditions, high soil water and relatively low soil temperatures were the most important factors influencing the development of rhizome rot in India and our observations suggest that the first two are also important in Fiji and Australia. Continuity of wetness may be as important for disease development as total rainfall, as the disease is clearly associated with free water and saturated soils. Under such conditions, zoospores disperse in soil water and spread the disease to adjacent clumps (Dohroo 2005), although our observations of greater downhill than uphill movement suggest that mass flow of water is also involved. However, we question the contention of Dohroo (2005) that *Pythium* infection is favoured by low soil temperatures. Although this may be true for some *Pythium* species, *P. myriotylum* is most active at mid-summer temperatures. Both Fijian and Australian isolates have high optimum temperatures (radial growth rates of 28–34 mm/day on agar at 37°C) and high temperatures enhance the pathogenicity of *P. myriotylum* on other crops in Queensland (Stirling et al. 2004).

Although our pathogenicity experiments were performed with *P. myriotylum*, we also found other species of *Pythium* which were associated with the disease (see next section).

The fact that severe rhizome rot was initially observed on only two Australian farms raises questions about factors that may have caused the disease to express itself on those farms. Rainfall and soil type did not appear to be involved, as farms near the affected Eumundi farm received similar rainfall; the affected farm at Kandanga was slightly drier than other farms in the industry and the disease was not observed on adjacent farms with similar soil types. The most likely explanation is that the soils on the affected farms had deteriorated due to long-term cultivation. The Eumundi and Kandanga farms were first

planted to ginger in 1960 and 1978, respectively, and are therefore amongst the oldest in the Australian ginger industry and probably the most intensively cultivated. Variously classified as ferralic nitisols, red ferrosols or krasnozems (McKenzie et al. 2004), these soils were originally relatively fertile and drained readily. However, after 30–50 years of cultivation, it is possible that drainage is now somewhat impeded due to compaction and declining levels of organic matter. Since *Pythium* is a relatively poor competitor in microbially active soils (Hoitink and Boehm 1999; Stone et al. 2004), a reduction in the soil's biological buffering capacity may also be a contributing factor.

7.1.2 Molecular identification of Pythium isolates

BLAST analysis revealed that three *Pythium* species, *P. myriotylum, P. vexans* and *P. graminicola*, were identified each from three different ginger growing localities (Veikoba, Navua and upper Naitasiri, respectively). The two Australian ginger isolates revealed sequence alignment with *P. myriotylum* and *P. zingiberis;* the capsicum isolate was confirmed as *P. myriotylum* (Table 1).

Table 1. Pythium isolates from Fiji (KRS suffix) and Queensland (BRIP suffix) showing location collected, species identification based on ITS sequence similarity and Genbank accession number where deposited. All isolates from ginger except* from capsicum.

Sample	location	*Pythium* sp.	GenBank
KRS11	Navua	*P.vexans*	
KRS13	Muainaweni	*P.graminicola*	
KRS14	Veikoba	*P.myriotylum*	*FJ797574*
KRS15	Waibau	*P.graminicola*	
KRS17	Veikoba	*P.myriotylum*	*FJ797575*
BRIP39907*	Bundaberg	*P.myriotylum*	*FJ797576*
BRIP52426	Eumundi	*P.myriotylum*	*FJ797577*
BRIP52427	Eumundi	*P.zingiberis.*	*FJ797578*

This is the first record of *P. vexans* and *P. graminicola* from ginger in Fiji and the first putative record of *P. zingiberis* in Australia. According to Dohroo (2005) *P.graminicola* is present in Sri Lanka while *P.vexans* in India. The two species have been found to cause problems during rainy weather. The surveys are still relatively limited and there may be more species present in the Fijian ginger growing areas, or indeed other species present in Fiji and Australia with the capacity to cause rhizome rot in ginger. Consequently, more survey work is warranted. *P. zingiberis* has been recorded in Japan and Korea (Ichitani and Shinsu, 1980). In Japan, it has been isolated from various parts of rotten ginger, especially from the basal part of terrestrial stem and rhizomes regardless of stages of disease development and locations. It has been isolated from soils where ginger is growing and from areas where ginger has been previously grown. Morphologically, *P.zingerberis* is very similar to *P.myriotylum* and at the molecular level only a single base pair difference in the ITS2 region of the rDNA separates the two species (Levesque and de Cock, 2004). *P.zingiberis* has never been recorded in Australia, and to validate this record further morphological analysis is required.

7.1.3 Impact of soil management practices on soil health and suppressiveness to Pythium

In September 2005, various cropping, tillage and amendment treatments were established in a sandy clay loam soil (Grey Dermosol) on a ginger farm near Yandina. This site was free of ginger pathogens because it had previously grown sugarcane. A similar set of treatments was included in an experiment established in April 2006 on a light clay soil (Red Ferrosol) on a farm near Kandanga. The continuous cropping treatment consisted of growing maize, soybean or forage sorghum during summer and oats or brassica during winter under two tillage regimes [conventional tillage (CT) or minimum tillage (MT)]. There was also a permanent pangola grass pasture, together with a bare fallow that was cultivated regularly to control weeds (at Yandina) or a CT treatment at Kandanga that was fumigated with 1,3 dichloropropene in 2007 and 2009. Prior to establishing the crop and pasture treatments, half the plots received a poultry manure/sawdust amendment (PS) of 100 t/ha at Yandina or 20 t/ha at Kandanga.

Soil was collected from each experiment in September 2009, a week before the site was planted to ginger. Half the soil was irradiated at 25 kGy and both irradiated (IR) and non-irradiated (NIR) soils were placed in 2 L planter bags and planted with a 60 g piece of ginger rhizome, as described previously for suppression studies.

Leaf yellowing began within 2 weeks of inoculation and symptoms then increased in severity for the duration of the experiment. Less than 5% of the 216 non-inoculated controls developed rhizome rot, indicating that background levels of *Pythium* were relatively low in the soils used for the experiment. Disease severity was much greater in irradiated than non-irradiated soil (Table 2), indicating that biological factors influenced disease expression. Interestingly, the soil from Yandina ($pH_{(water)}$ = 4.7) was more suppressive to *Pythium* than the soil from Kandanga ($pH_{(water)}$ = 6.2). However, direct pH effects could not account for the difference in suppressiveness, as disease severity was high in both soils after they were irradiated. It is therefore possible that the soil microorganisms which were inhibiting *Pythium* (through competition, antibiosis or parasitism) were more active in acidic soils.

Table 2. Impact of irradiation and soil type on the severity of Pythium rhizome rot in ginger

Site	Irradiated	Non-irradiated
Kandanga	2.71 c	2.28 b
Yandina	2.56 bc	1.38 a

Values (disease severity ratings after 3 months) followed by the same letter are not significantly different (P = 0.01)

Soils amended with PS and cropped soils that were subject to minimal disturbance (MT) were most suppressive to rhizome rot (Table 3). Conversely, treatments where the soil microbial community was disturbed or diminished (i.e. fumigated and bare fallow soils) had significantly lower levels of suppressiveness compared to the Crop/MT/PS treatment. These results demonstrate that the way soil is managed influences its suppressiveness to Pythium rhizome rot. It should therefore be possible to reduce the impact of this disease by modifying the current ginger farming system.

Table 3. Impact of rotation, tillage and amendment treatments on suppressiveness to Pythium rhizome rot

Rotation/tillage/ amendment	Disease severity[AB]	% plants remaining symptomless[B]	
Kandanga		IR	NIR
Fumigated/CT/Nil	2.65 b	0	5
Crop/CT/Nil	2.25 ab	6	16
Crop/CT/PS	2.05 ab	9	18
Crop/MT/Nil	2.35 b	17	5
Crop/MT/PS	1.68 a	5	24
Pasture/Nil	2.60 b	0	0
Pasture/PS	2.41 b	5	16
Yandina			
Fallow/CT/Nil	1.93 b	9	25
Crop/CT/Nil	1.607 ab	5	35
Crop/CT/PS	1.39 ab	22	33
Crop/MT/Nil	1.44 ab	11	42
Crop/MT/PS	0.81 a	0	65
Pasture/Nil	1.61 ab	17	40
Pasture/PS	0.89 ab	20	55

For each site, numbers in each column followed by the same letter are not significantly different (P = 0.05). [A]Disease severity was assessed in non-irradiated soils after 3 months.

[B]Assessments were based on 17-21 plants.

7.2 Plant parasitic nematodes on ginger

To develop a clearer understanding of the plant parasitic nematode populations in the ginger crop it was decided to initiate a more detailed study across farms, districts and crops used in rotation with ginger. Populations were determined at (or near) the time of planting (P_i) and at (or near) the time of crop harvest (P_f).

Initial and final nematode population densities (P_i and P_f, respectively) were determined in typical ginger-growing fields in the Navua, Veikoba and Waibau regions. Ginger and the crops that follow it in the rotation (cassava and taro) were sampled at the time each crop was planted and harvested. Nematodes were extracted by spreading 200 ml soil on an extraction tray. Multiplication rates for particular nematodes were determined as P_f / P_i.

Multiplication rates for *R. similis* on taro and cassava were determined in 1 L pots of pasteurised sand and peat. Pots were inoculated with 1,000 *R. similis* and 40 weeks later, nematodes were extracted from soil (see above) and from roots that were macerated in a blender and then spread on an extraction tray.

R. reniformis was the most common plant-parasitic nematode in ginger-growing soils. It multiplied readily on ginger, whereas there was little multiplication on taro or cassava (Table 4).

Table 4. Initial and final populations (Pi and Pf), and multiplication rates (Pf/Pi) of reniform nematode (Rotylenchulus reniformis) on ginger, taro and cassava in various fields in Fiji

Crop	Nematodes/200 mL soil		
	P_i	P_f	P_f/ P_i
Immature ginger	93	2410	25.9
	30	710	23.7
	540	7600	14.1
Mature ginger	805	3550	4.4
	370	4560	12.3
	40	830	20.8
Taro	1535	350	0.2
	90	104	1.2
	2440	1328	0.5
	1640	1532	0.9
	530	672	1.3
Cassava	390	280	0.7
	436	130	0.3
	490	380	0.4
	1120	1560	1.4
	1010	380	0.4

Root-knot nematode was not present in enough fields to allow definite conclusions to be drawn about its multiplication rates on each crop. Also, final population densities on ginger were rarely greater than 200 nematodes/200 ml soil, while populations on taro and cassava were even lower. Occurrence was dependent on soil texture, with the nematode most common in well-structured clay loam soils of Waibau and silt loam soils of Navua.

R. similis occurred on a few farms in the Veikoba region. The nematode was often not detectable in soil at the time ginger was planted, but was invariably introduced in planting material. It then multiplied rapidly and was readily detected later in the season. The highest population densities recorded from ginger fields were 170 nematodes/200 ml soil at immature harvest and 410 nematodes/200 ml soil at mature harvest. *R. similis* was never found in taro or cassava roots, but was occasionally found at low population densities in soil associated with roots of those crops. However, moderate to high populations were invariably found on volunteer ginger, which was always present as a weed in the following taro and cassava crops.

Results from the pot test (Table 5) indicated that taro was not a host of *R. similis*. The nematode was recovered from cassava roots, but the final nematode population density was lower than the number of nematodes inoculated.

Table 5. Final nematode population densities on five replicate plants of taro and cassava 40 weeks after they were inoculated with 1,000 *Radopholus similis*

Crop	No. *R. similis*		
	Roots	/200 mL soil	/pot
Taro	0	0	0
Cassava	34 ± 17	64 ± 28	379 ± 168

In the Fijian ginger farming system, ginger is generally grown every 3 years, with crops of cassava and taro planted in the years between ginger crops. Our results indicate that this is an excellent rotation for managing the three plant-parasitic nematodes likely to cause damage on ginger. Taro and cassava are poor hosts of both *R. reniformis* and *R. similis*, while *Meloidogyne* spp. rarely reached high population densities in ginger-growing soils, regardless of the crop that is grown.

Through the survey work, a farm was identified in the Veikoba district to conduct more detailed field studies with the burrowing nematode (*R. similis)*, the most destructive of the plant parasitic nematodes of ginger in Fiji.

Our pathogenicity experiments have shown that *R. similis* multiplies initially on ginger roots and seed pieces and then invades newly-developing rhizomes. The nematode seems to feed first on outer parts of the rhizome and the resulting damage leads to yellowing at the base of shoots and of the lower leaf sheath. As more tissues are destroyed, older leaves turn yellow, shoots eventually collapse and discoloration extends further into the rhizome. The end result is that plants eventually die and the rhizome is totally destroyed. Given the results of our experiments, we suggest that *R. similis* is a pathogen of ginger in its own right. The nematode is capable of killing plants and destroying rhizomes, with secondary organisms playing little role in symptom development.

Field results at Veikoba mirrored those obtained in pots. They indicated that *Radopholus* multiplies readily on ginger but when initial nematode population densities are low, nematodes generally do not multiply to levels capable of causing economic losses to immature ginger. Also nematode numbers can vary markedly from plant to plant and this is correlated with levels of infestation in seed used for planting. Other findings were that nematode populations can be maintained between ginger crops on volunteer ginger and on a number of common weeds. These infestations can act as ‘hot spots’ for further spread when ginger is replanted. However the finding that *Radopholus* was found on the farmer’s seed is of most concern as it demonstrates unequivocally that *Radopholus* and other parasitic nematodes are being introduced on planting material.

Continued observations at the Veikoba farm demonstrated that the rotation with taro and cassava, together with the preparation of the beds with poultry manure, had significantly reduced parasitic nematode populations to the point that the two most serious plant parasitic nematodes of ginger, burrowing nematode and root-knot nematode, were undetected in the beds to be planted to ginger. However they have been detected in seed already planted or about to be planted. Even though the grower was culling infested seed in his seed sorting area, it was estimated that approximately 30% of the seed was infested and, in some instances, the infestation was very severe.

The results (Table 6) showed that populations of free-living nematodes increased to very high levels when poultry manure was added to the soil, largely because of an exponential increase in numbers of bacterial-feeding rhabditids. In contrast, populations of predatory mononchids were markedly reduced by even the lowest rate of poultry manure. Populations of *R. reniformis* and *R. similis* were significantly reduced by poultry manure at 20 t/ha.

Table 6. Populations of plant-parasitic and free-living nematodes six weeks after applying various rates of poultry manure to a ginger-growing soil

Poultry manure (t/ha)	*Rotylenchulus reniformis*	*Radopholus similis*	Mononchidae	Total free-living nematodes
0	227 a	37 a	71 a	3,630 b
10	189 a	34 a	1 b	27,541 a
15	152 a	33 a	0 b	63,095 a
20	41 b	4 b	0 b	85,112 a

Numbers in the same column followed by the same letter are not significantly different (P = 0.05)

Since the moisture content of the poultry manure was about 5% and it contained 3.89% N, the equivalent of 0, 370, 555 and 740 kg N/ha was applied in the various treatments. Given that much of this N would have been converted to ammonia and it is known to be toxic to nematodes at the concentrations likely to have been achieved with the highest application rate (Stirling 1991), it is not surprising that populations of plant-parasitic nematodes were reduced by the amendment. Although this might be seen by ginger growers as one of the benefits of applying poultry manure, its negative impact on the predatory nematodes that regulate nematode populations must also be considered. Predatory nematodes are particularly susceptible to N inputs (Tenuta and Ferris, 2004) and their demise may explain why populations of plant-parasites resurge strongly when ginger is planted.

Previous work on hot water treatment for nematode control in ginger was done with rhizomes infested with root-knot nematode (Vilsoni et al. 1981). Another experiment was established during this project to check that the recommended treatment is effective against burrowing nematode (*R. similis*).

In October 2009, ginger rhizomes infested with *R. similis* were obtained from Lee Tong's farm at Veikoba and either immersed in hot water (51°C for 10 minutes) or left untreated. They were then planted individually in 2L pots filled with pasteurised soil. Observations in February 2010 suggested plants in the hot water treatment were growing better than untreated plants. By late April 2010 the untreated seed were showing symptoms of damage caused by *R. similis*, however no nematodes were detected in the soil or roots of hot-water treated seed.

5.2.3 Developing improved ginger farming systems

An experiment was conducted at Kandanga on what had been an intensively cultivated red ferrosol, demonstrated that minimum tillage of cover crops and use of pasture leys was advantageous in a ginger farming system. The treatments where summer and winter cover crops were sown into raised beds with a minimum-till planter, or where pasture was grown on "permanent" beds for four years, prior to beds being rotary-hoed and reformed before planting ginger (treatments B and ECT, respectively), consistently gave the highest

yield of rhizome (Table 7). Improvements to crop yield by limiting mechanical disturbance to soils have been well documented (Hoyt et al., 1994; Morris et al., 2010). Furthermore, Bell et al. (1997) and Connolly et al. (1998) have found that the beneficial effect of pasture leys and stubble mulching under no-till systems persisted into a subsequent conventional cropping phase, but was lost thereafter.

Table 7. Effect of tillage and rotation crops on early harvest and first-late harvest yield (t/ha) of ginger crops over two seasons.

Treatment	A	B	C	D	F	ECT	EMT
			First Ginger Crop (2007-08)				
Early harvest	39.7 ab	41.1 a	36.1 ab	26.3 b	43.7 a		
First-late	41.4 ab	56.6 a	42.4 ab	33.3 b	50.0 ab		
			Second Ginger Crop (2009-10)				
Early harvest	52.4 a	47.6 ab	37.0 bc	31.9 c	14.2 d	52.1 a	
First-late	58.6 b	62.0 ab	50.1 bc	33.4 de	20.2 e	74.2 a	30.9 de

Treatments: A – Conventional till rotation crops summer and winter, conventional till ginger; B – Minimum till rotation crops summer and winter, conventional till ginger; C – Conventional till rotation crop in summer, conventional till ginger; D – Minimum till rotation crop in summer, minimum till ginger; ECT – Three year Pangola pasture, conventional till ginger; EMT – Three year Pangola pasture, minimum till ginger; F – Conventional till rotation crop in summer but fumigated with Telone, conventional till ginger. Yields for all treatments (except F) are means of amended and non-amended plots. Numbers in a row followed by the same letter are not significantly different (P = 0.05).

In our ginger farming system these “reduced tillage” treatments, particularly when amended with poultry manure, were suppressive to rhizome rots and root-knot nematodes (Table 8). The poultry manure amendment, particularly with the first ginger crop, significantly improved growth and yield. This effect diminished with the second ginger crop, probably because the poultry manure amendment was only added once at the commencement of the experiment. The suppressive nature of these minimally disturbed and amended soils to rhizome rot was further validated in pot experiments where disease severity caused by *Pythium myriotylum* was significantly diminished in comparison to other treatments (Table 3). The suppressiveness appeared to have a biological basis, as disease severity was higher when microorganisms that may have been inhibiting *Pythium* (through competition, antibiosis or parasitism) were destroyed by fumigation or irradiation. However, the results of a recent study of *P. myriotylum* on cocoyam (*Xanthosoma sagittifolium*) by Adiobo et al. (2007) suggest that non-biological factors may also be involved. Ferrosols were less suppressive than andosols, while high organic matter was probably mediating suppression by improving soil structure, increasing soil nutrient content and microbial biomass, and sustaining microbial activity.

Perhaps the most important result from this experiment was the yield and disease suppression advantage of the reduced tillage cropping system over the conventional ginger farming system, and the fact that it was obtained in successive ginger crops that were grown under moderate to high disease pressure. Average yields for ginger crops in southeast Queensland are 30 t/ha for immature rhizome and 45 t/ha for mature rhizome (Smith, 2004), whereas treatment B produced average yields of immature rhizome of 41.1 and 47.6 t/ha and yields of mature rhizome of 56.6 and 62.0 t/ha (Table 7). In the pasture treatment the four year break between ginger crops reduced disease pressure from *P.*

myriotylum and *F.oxysporum* f.sp. *zingiberi* even further, and this resulted in an even higher yield (74.2 t/ha in treatment ECT). Such observations demonstrate that the way a soil is managed influences both the amount of inoculum in the soil and its suppressiveness to disease. Consequently, it should be possible to reduce the impact of these diseases on yield by modifying the current ginger farming system.

When ginger was planted with minimum-tillage using a double disc opener, it consistently gave poor yields relative to conventional-tilled ginger, even though rhizome rots did not have a significant impact. This was particularly apparent when comparing the minimum-tilled and conventional-tilled pasture treatment (treatments EMT and ECT, respectively). One noticeable difference between the soils in minimum-tilled beds and cultivated beds was their water infiltration rates. The minimum-tilled beds had significantly reduced infiltration rates whereas rotary-hoeing temporarily restored the tilth and infiltration capacity of the soil, especially when stubble from cover crops was incorporated. Bridge and Bell (1994) have previously noted surface crusting and compaction to at least 60 cm depth in intensively cropped ferrosols, and this is the likely reason for the restricted root growth and poorer yields in minimum-tilled beds. Certainly, in this experiment, the non-tilled ferrosols were not as conducive to rhizome growth and yield compared to cultivated beds, while in the mini-plots; many rhizomes were tightly packed and had relatively small rhizome sections.

Table 8. Effect of tillage and rotation crops on incidence of rhizome rots from the second ginger crop (2009-10).

	A	B	C	D	ECT	EMT	F
Percentage of plot with yellowing shoots: Early harvest	40.0 b	18.2 ab	43.8 b	17.5 ab	6.1 a		71.2 c
Percentage of rhizomes with rots: Early harvest	12.0 a	15.7 a	19.1 a	12.4 a	16.5 a		54.3 b
Percentage of rhizomes with rots: First Late harvest	10.6 ab	5.0 ab	10.2 ab	11.6 b	7.0 ab	2.8 a	35.9 c

Treatments: A – Conventional till rotation crops summer and winter, conventional till ginger; B – Minimum till rotation crops summer and winter, conventional till ginger; C – Conventional till rotation crop in summer, conventional till ginger; D – Minimum till rotation crop in summer, minimum till ginger; ECT –Three year Pangola pasture, conventional till ginger; EMT - Three year Pangola pasture, minimum till ginger; F – Conventional till rotation crop in summer but fumigated with Telone, conventional till ginger. Numbers in a row followed by the same letter are not significantly different (P = 0.05).

Results of this study add to a body of evidence (Bridge and Bell, 1994; Moody, 1994) to indicate that some rehabilitation is possible in ferrosols that have lost their physical and chemical fertility due to continuous cropping (Bell et al., 1997). However, Bell (pers. comm.) states that these soils do not self repair easily, especially when organic matter is imported as occasional inputs, rather than grown *in situ*. Furthermore, even when soil structure is restored with 3-4 years of pasture growth, these soils can still set hard and inhibit root growth. A combination of extended organic matter addition and prolific root growth, accompanied by an occasional tillage-induced loosening upon which roots can capitalize and consolidate, seems to be required. However, frequent and continued tillage can undo these benefits within 2-3 years.

Our experiments have shown that minimum tillage and inputs of organic matter, when incorporated into the ginger farming system, can improve yield and reduce losses due to soilborne pathogens. The sustainable use of ferrosols for ginger production will therefore

depend on enhancing organic matter levels with rotation crops and regular application of amendments, replacing nutrients removed in harvested products and using minimum tillage and residue retention to reduce soil losses due to erosion. Such practices will also enhance biological activity and should result in soils with greater suppressiveness to soil-borne diseases and plant-parasitic nematodes (see reviews by Stirling (1991) and Stone et al. (2004)).The challenge facing ginger growers is to integrate these practices into a farming system that is both practical and profitable.

8 Impacts

8.1 Scientific impacts – now and in 5 years

Much of the research being conducted by the project is of significance and should form the basis for a number of publications that will impact on future studies. Serious scientific investigations into the effect of *Pythium* and *Radopholus* on ginger production are either lacking or reported in technical reports and newsletters. Few have received scientific scrutiny in peer-reviewed publications. Likewise the concept of minimum-tillage in ginger production and its relationship to suppression of soil-borne pathogens is novel. The findings to be published from these studies will not only be of significance to ginger but to other root and tuber crops.

Research areas that have been investigated during this project and that will have an influence on future work include:

- Etiology and pathogenicity of Pythium Soft Rot on ginger
- Molecular identification of Pythium isolates
- Etiology and pathogenicity of Burrowing Nematode on ginger
- Impact of crop rotation, tillage practice and organic amendments on developing soils suppressive to soil-borne pathogens
- Improved ginger farming systems

8.2 Capacity impacts – now and in 5 years

Two Fijian scientific staff have had opportunities to strengthen their knowledge and skills in plant pathology and plant nematology, respectively. Ms Mereia Fong was awarded a John Allwright Fellowship to undertake studies for a Masters of Plant Protection at the University of Queensland which was completed at the end of 2008. The degree was a combination of course work and two research projects. The projects investigated the behaviour of the Australian and Fijian *Pythium* isolates on ginger in *in vitro* studies (under quarantine) and molecular characterisation of these isolates under the supervision of Dr Liz Aitken. These results were presented as a poster at the 17th Biennial Plant Pathology Society Conference to be held in Newcastle from 29 September to 1 October 2009.

In addition, Ms Fong attended the 16th Biennial Plant Pathology Society Conference, as well as a plant bacteriology workshop, in Adelaide from 24-27 September 2007. This was her first plant pathology conference and reinforced for her the importance of establishing and maintaining contact with a network of other professionals. She also recognised the importance of structuring her research so that it can be published for the benefit of other professionals and senior decision-makers. These are important lessons that were reinforced during the project.

Ms Una Turaganivalu attended a training program in practical nematology under the direction of Dr Graham Stirling, Biological Crop Protection, during June 2007. She learned the basics about nematode biology and learned how to identify the important plant parasitic nematodes she is likely to encounter. She also learned the correct procedures for collecting soil samples, extraction and counting of nematodes, preservation of nematodes and maintenance of inoculum. Ms Turaganivalu has made great strides in becoming a competent nematologist and we have been very impressed with her work ethic and ability to carry out a research program in Fiji with growing confidence. Ms Una Turaganivalu also presented a poster of her pathogenicity experiment with *Radopholus* at the 17th Biennial Plant Pathology Society Conference. She also attended the 6th

Australasian Soil-borne Diseases Symposium held on the Sunshine Coast from the 9 to 11 August 2010. She again be presented a poster, this time on the role of rotation crops in managing plant-parasitic nematodes on ginger in Fiji. Graham Stirling was the principal conference organiser. Its location on the Sunshine Coast presented an opportunity for local researchers, extension officers and ginger growers to come along. ACIAR project work was represented in five presentations at the Symposium.

The Fijian staff attendance at conferences highlights the importance of establishing and maintaining contact with a network of other professionals. Presentation of their work also demonstrates the importance of conducting their research in such a way that it can be published for the benefit of other professionals and senior decision-makers. Ms Fong and Ms Turaganivalu have made great strides in becoming competent scientists and we have developed confidence in their ability to carry out an independent research program in Fiji.

The project has also been able to supply needed equipment necessary for nematology research as well as securing a room, with shelving installed, so that nematodes can be extracted from samples in a timely manner. Procedures for setting up and taking down samples are working well. During the project repairs were also made to the autoclave and growth cabinet in the Plant Protection Laboratory at Koronivia Research Station, as well as to the glasshouse and soil sterilizer. These have greatly improved the capacity of the staff to conduct research at the station and it was made possible through the project.

During the project the capacity to rear pure cultures of *Radopholus similis* was dramatically improved by the transfer of technology developed by nematologists at QPIF's laboratory complex at Indooroopilly to the Plant Protection Laboratory at Koronivia Research Station. Burrowing nematodes can now be successfully reared on sterilized carrot cultures so that a supply of nematodes is always available for research and teaching. Nematodes, raised in this manner, were used in a pathogenicity experiment described in the previous section and published in an APPS conference proceeding.

In Australia, a notable project development was a demonstrated ability to create the conditions necessary to study Pythium rhizome rot of ginger at our disease nursery site at Maroochy Research Station. Last year we concurred with the findings of Fullerton and Harris (1998) that the *Pythium*/ginger disease system was too difficult to deal with in trial work. The discontinuous distribution of the fungus in the soil, the development of disease 'hot spots' and the particular epidemiological features of the disease (apparently 'turned on or off' by prevailing weather conditions) does not lend itself to experimentation using conventional trial layouts. However this year at Maroochy Research Station, we have demonstrated that it is possible to culture the pathogen and produce inoculum for successful infection of plants (something not practical or welcomed on farms) and we have developed a watering regime that allows the disease to spread in a manner observed during disease epidemics on commercial farms. We can now study the disease under more controlled conditions and examine treatments for disease control with growing confidence.

Finally it was gratifying to witness the initiative taken by one of Australia's leading growers to modify his ginger planter into a double-disc system (demonstrated by the project team in September 2006) that facilitates planting into minimum-tilled beds. The efficiencies gained by this system extend to planting into convention-till beds, as less fuel is needed to pull it through the soil and it also enables the grower a larger window for planting as it is less prone to wet soil sticking to the implement and impeding planting operations. This was an important first step in developing an improved ginger farming system.

8.3 Community impacts – now and in 5 years

We believe the project has delivered impacts benefiting the scientific and extension community in both countries, improving capacity to deliver scientifically sound information

that meets the needs of landholders and that improves livelihoods of communities through more sustainable and profitable ginger production.

A major focus of the project was centred on experimental work conducted on specific farms with outreach to the local farming communities. Field days and workshops attended by growers, extension staff and research scientists have ensured that project findings have been communicated widely and that innovative farmers have rapidly adopted improved cultural practices.

8.3.1 Economic impacts

The project has engendered new interest by DEEDI in the economic development of Australian ginger industry and has resulted in surveys of people involved in the ginger supply chain to ascertain opportunities and challenges facing the industry. A report, *Queensland Ginger Industry: Overview of the market trends and opportunities* has been prepared by QPIF that gives an accurate and up-to-date account of the state of the industry from the perspective of growers, wholesalers and processors.

In Australia, QPIF estimates the current farm gate value of the ginger industry at approximately $15.6 million. Of the 8,000 tonnes harvested annually, 45% goes to the domestic fresh market while 55% is used for processing. It is recognised that the ginger rhizome undergoes substantial value-adding as the commodity is transformed into confectionery products, brewed soft drinks, and therapeutic agents. The value of these products is estimated at over $80 million. Ginger growers and processors are important employers in regional centres and generate export revenue for the country. The producers employ approximately 200 full time staff and 385 casual staff during peak harvesting periods, while the processors employ over 560 staff.

This analysis of the Australian ginger industry complements a similar investigation undertaken by Mr Waisiki Gonemaituba on the Fijian ginger industry. Issues have been identified in both studies which identify strengths of the industry and areas within the supply chain have been selected to focus activities for resolving constraints to supply or for improving demand. A key constraint identified in both studies was that efforts need to be made to reduce losses due to pests and disease.

The study undertaken by Mr Gonemaituba for his Master of Philosophy in Economics at the University of Queensland promises to deliver economic, social and environmental impacts for those associated with the ginger industry in Fiji. Mr Gonemaituba holds a senior position in the Ministry of Agriculture and his findings are important as the ginger industry is one of the key industries identified by the Fijian government in its diversification strategy to accommodate the remnants of the withdrawal of the European Union's sugar preferences. There is considerable pressure on small industries such as ginger to search for ways to operate efficiently and contribute to the economy.

In his study, two types of losses (observed and unobserved) are identified for analysis in a single framework. Observed loss refers to ginger rejected in the field after harvesting and does not reach the exporters' warehouses or processing factory due to sub-standard quality caused by diseases and pests. The unobserved loss, on the other hand, is the unattained increase in ginger output due to technical inefficiency which also includes a measure of soil erosion in a stochastic production function. The study aimed to measure the determinants of observed ginger loss and soil erosion.

Farm revenue was estimated at F$1.97 million for the 2006 season, while export of fresh and processed ginger (plus local sales) totalled F$14.03 million. While the observed loss was estimated to be F$469,732, the total unobserved loss to the ginger industry was a large F$4.6 million or 32% revenue loss for Fiji's ginger industry. With regard to losses caused by diseases, especially *Pythium*, it is recognised that it will fluctuate according to weather conditions, while many of the other pathogens can be controlled by attention to planting material and on-farm management practices. Key recommendations are the need for the establishment of a certified clean seed scheme operated by independent industry

groups and a soil repair strategy combined with a proper crop rotation regime as soil fumigation is not seen as a viable option. In summary, the study highlights some key variables concerning technical efficiency and calls for an integrated package of policies related to use of best farming practices, land tenure and agricultural extension and support services for sustainable agricultural growth.

8.3.2 Social impacts

Social benefits will include the reduction in the amount of pesticide needed (through greater reliance on crop rotations, tillage practices and organic amendments), making agricultural practices safer for producers. There are community expectations that agricultural production will not impact on the safety of farm workers or the surrounding environment, which this project will help to achieve. The empowerment achieved by grower participatory approaches used in the project will enable members to better manage their resources for greater productivity by reducing losses to diseases and pests.

From an Australian perspective, minimum tillage is a new concept for the ginger industry. At the most basic level, reducing the number of tillage operations will reduce fuel usage and save money. However the biggest gains will be made by leaving beds as undisturbed as possible, even while continuously cover cropping, thereby improving soil biology and hopefully creating soils that are more suppressive to soil-borne pathogens. From a rural community's perspective, such practices are meant to make farm enterprises in the district more profitable and sustainable with added benefits of reduced erosion, dust and noise.

8.3.3 Environmental impacts

The project aimed to protect the environment surrounding agricultural production areas by reducing the farming impact on the off-farm environment. To reduce these risks the project aimed to develop more sustainable, yet profitable, management practices. These included optimising the use of organic residues (both green wastes and organic amendments) to develop soils that were better able to suppress soilborne pests and diseases, as well as retain water and nutrients. A major gain, both in Australia and the Pacific islands, is reduced soil erosion and nutrient run-off related to both the use of appropriate plants and to increasing the stability and resilience of soils.

8.4 Communication and dissemination activities

As described in Section 6, project staff presented the results of the first, 2-year phase of research completed in Fiji and Australia at a seminar held at Koronivia Research Station on 13 February 2009. Research staff from the Ministry was present, as were interested SPC plant protection staff and ginger growers. Towards the completion of the project a major workshop was held on 30 July 2010 at a local processor/exporters premises in Navua and was very well attended, drawing the support of the Minister of Agriculture and the Permanent Secretary of Agriculture, together with the Heads of Department and influential local growers. The workshop proved to be a catalyst for gaining the support of private business partners in establishing a clean seed scheme in areas declared free from *R. similis*. It also provided impetus for the printing of information leaflets in the local language and in lauching field days and walks for growers in the major production areas.

In Australia, Field Days organised by the Australian Ginger Growers' Association (AGGA) were held in January for each year of the project and results of project activities were presented through field walks, oral presentations and hand-outs. Project updates have also been provided to growers at quarterly AGGA meetings.

In addition training opportunities, study tours, conference attendance and higher degree studies were undertaken during the course of the project as listed by: name, institution, degree, dates, topic and source of funding.

- Una Turaganivalu; Biological Crop Protection; 4-22 June 2007; Completed a training program in practical nematology; ACIAR.
- Moti Lal Autar; Department of Primary Industries and Fisheries, Queensland; 4-22 June 2007; Completed a study tour of the Australian ginger industry and met with a number if DPI&F staff involved in plant protection and biosecurity; ACIAR.
- Mereia Fong; 16th Biennial Plant Pathology Society Conference, Adelaide; 20-27 September 2007; Attended conference and completed a workshop in practical plant bacteriology conducted by Dr Ric Cother, NSW Department of Primary Industries; ACIAR.
- Una Turaganivalu; 5th International Congress of Nematology, Brisbane; 13-18 July 2008; Attended conference and presented poster entitled, 'Burrowing nematode (*Radopholus similis*) on ginger in Fiji'; ACIAR.
- Mereia Fong and Una Turaganivalu; Australasian Plant Pathology Society Conference, Newcastle, 29 September-1 October 2009. Attended conference and Una presented poster entitled, 'Pathogenicity of *Radopholus similis* on ginger in Fiji'. ACIAR.
- Una Turaganivalu; 6th Australasian Soilborne Diseases Symposium, Twin Waters, 9-11 August 2010. Attended conference and presented poster entitled, 'The role of rotation crops in managing plant-parasitic nematodes on ginger in Fiji' ACIAR.
- Waisiki Gonemaituba; University of Queensland; Master of Philosophy; June 2006 – September 2008; Awarded degree in 2008; Thesis topic was, 'A study of efficiency, output loss and soil erosion in Fiji's ginger industry' under supervision of Dr Renuka Mahadevan; John Allwright Fellowship, ACIAR.
- Mereia Fong; University of Queensland; Master of Plant Protection; June 2007 – December 2008; Awarded degree in 2008; John Allwright Fellowship, ACIAR.

9 Conclusions and recommendations

Before the project, much of the information on soil-borne pathogens of ginger in Fiji was only to be found in annual reports that were difficult to access and, in many cases, were poorly documented. This project has provided information from extensive farm surveys and from experiments conducted in the field, as well as under more closely controlled conditions in the laboratory and glasshouse. Conclusions and recommendations are based on sound science. Results have been published in peer-reviewed journals and proceedings.

9.1 Conclusions

Our observations in Fiji highlight the importance of Pythium Soft Rot, but also underscore the difficulties involved in developing improved disease management practices. We suspect that there are three major reasons why *Pythium* will always be a threat to ginger production in the hot and wet Fijian environment:

- pathogenicity tests show that the pathogen is capable of destroying ginger rhizomes in 1–2 weeks under ideal moisture and temperature conditions;
- the fact that heavy losses occur on steep, relatively well drained slopes and in soils that dry out following 2–3 days of sunshine suggests that the disease is not necessarily exacerbated by poor drainage and may occur when soils are continually saturated from constant rain; and
- chemical and some cultural methods of control are likely to be too expensive or impractical for Fijian growers with small holdings.

In Australia, its outbreak on two of the oldest farms in the industry serves as a warning that the physical, chemical and biological health of old ginger-growing soils may need to be addressed. The conventional ginger farming system includes practices such as regular and intensive cultivation with a rotary hoe, soil fumigation, lack of crop rotation and high fertiliser inputs; these are all known to deplete soil organic matter and diminish soil health.

Another soil-borne pathogen in Fiji and capable of inflicting severe losses on the ginger crop was the Burrowing nematode (*Radopholus similis*). It was found on infected planting material, on volunteer ginger growing amongst rotation crops and on common weeds. Its ability to move through the soil and quickly multiply on the ginger rhizome resulted in total crop failure in some seed production blocks.

9.2 Recommendations

Chemical control options have so far proven to be largely ineffective in controlling Pythium Soft Rot and likely to be too expensive or impractical for Fijian growers with small holdings. Other strategies such as controlling water-logging and limiting surface water movement by deepening the furrows between beds and increasing the number of cross-row drainage channels have demonstrated effectiveness in limiting spread of the disease. Likewise use of suitable rotation crops and lengthening the period between susceptible ginger crops may limit the build-up of pathogen loads in the soil. However development of more disease suppressive soils is also a viable strategy and the project has demonstrated that ginger-growing soils can be managed in such a way to create microbial communities capable of suppressing Pythium Soft Rot in ginger. Soils amended with poultry manure and sawdust, as well as cropped soils subjected to minimal disturbance were the most suppressive to the disease and the best for harvestable rhizome yield.

Similar to the measures used for *Pythium* control, plant parasitic nematode control also requires the use of clean planting material, the need for adequate crop rotation, as well as the removal of volunteers and weeds that may be acting as hosts for these pathogens. Our research has also shown that timely applications of poultry manure can be very effective in controlling soil infestations of burrowing nematode.

Field experiments have demonstrated that a reduced tillage farming system is a viable option for ginger production in Australia. Based on our results, we recommend establishing raised beds under a controlled traffic system and direct drilling cover crops into the beds. Organic amendments are applied during the rotation phase and residues from rotation crops are retained. The beds are then cultivated prior to planting ginger, with zonal tillage being a possibility that should be investigated. Given the disease pressure that exists in fields used regularly for ginger production, a long break from ginger will be advantageous, and so an extended pasture break is worth considering. However, despite the benefits to soil health, the introduction of these practices can be problematic for farmers. Further work is therefore needed to demonstrate the economic benefits of alternative ginger farming systems, quantify impacts on rhizome yield and quality, and demonstrate that nutrient and soil losses due to erosion can be reduced.

Finally efforts by both the Fijian and Australian industries to produce clean planting should continue to be encouraged and supported to ensure pathogens are not being introduced on ‘seed’ used for planting.

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