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Improved domestic profitability and export competitiveness of selected fruit value chains in the southern Philippines and Australia

Component 3 – Integrated crop management strategies for the productive, profitable and sustainable production of high quality papaya fruit in the southern Philippines and Australia

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Contents

1 Acknowledgment

We wish to thank the growers, extension staff and researchers who were involved in the field, glasshouse and laboratory research into the integrated crop management strategies for papaya in the Philippines and Australia.

2 Executive summary

Integrated crop management strategies for the productive and profitable production of high quality papaya fruit in the southern Philippines and Australia' was a component of ACIAR Project HORT/2007/067, 'Improved domestic profitability and export competitiveness of selected fruit value chains in the southern Philippines and Australia'. The component aimed to identify and address the disease, insect pest and nutrition-related problems associated with the growing of papaya in the southern Philippines and Australia.

Baseline surveys of papaya growers and contractors in Cagayan de Oro City, Misamis Oriental, Bukidnon, Davao del Sur, Davao del Norte and South Cotabato identified constraints to production as being red spider mites, choco spot, bacterial crown rot (BCR) and *Phytophthora* root and fruit rot. A lack of knowledge of the nutrient requirements of papaya was also identified, with little information being available to growers. The diagnostic capacity of pests and diseases by researchers was recognised as being very limited and thus pest and disease management strategies were either non-existent or ineffective.

As component activities progressed, entomologists within the team were able to identify six phytophagous species of mite *Brevipalpus californicus* (Banks), *Eutetranychus africanus* (Tucker), *Tetranychus kanzawai* Kishida, *T, piercie* Mc Gregor, *T. urticae* Koch and an unidentified Tetranychid species associated with papaya. *Tetranychus kanzawai* was found to be the most damaging and abundant phytophagous mite on papaya. A predatory mite *Neoseiulus longispinosus* (Evans) and a predatory beetle *Stethorus pauperculus* were identified on papaya. Mass rearing techniques for these predators were developed.

The diseases choco spot (*Corynespora cassiicola)* and BCR (*Erwinia papayae*) were researched by members of the team. Isolates of *C. cassiicola* were tested for pathogenicity, and trials were conducted to evaluate fungicide efficacy and cultivar resistance. The fungicide propineb applied at 312 g a.i./100 L of water was found to be most effective at controlling choco spot achieving a 114% increase in marketable yield.

Dr. Anthony Young demonstrated the difficulty in recovering and identifying *E. papayae,* the causal agent of BCR. A technique was developed to assist researchers in the successful recovery of the *E. papayae*. By the end of the project, the disease BCR was identified as the greatest concern for growers in the Philippines. It is recommended that further studies be conducted into seed transmission, spread and management of BCR of papaya.

Collaborative research with University of South-eastern Philippines and Del Monte Philippines Inc (DMPI) showed 300 and 450 kg N/ha gave maximum yield of fresh and processing papaya, respectively. Over the range of rates tested (15 to 600 kg/ha), the incidence of fruit stem-end rot increased. DMPI have adopted their findings for production of processing papaya in northern Mindanao. The Merck Reflectoquant® RQflex 10 rapid nutrient (plant sap) test was shown to be a potential plant N monitoring tool. An efficient method of sap extraction was developed that makes the analysis test system adaptable for in-field use where electrical power is not available. A best management practice approach to papaya fertilization was clarified from the literature and applied in N rates research in Australia. Plant response in Stage 1 (transplanting to flowering) suggests that rates above 15.5 kg/ha (during this stage) exceeded plant requirement.

Field trials conducted in Australia showed that copper hydroxide at 375 g a.i./100 L was the most effective in controlling *Phytophthora* fruit rot. In glasshouse experiments, the chemicals dimethomorph and furalaxyl effectively controlled *Phytophthora* root rot. The growing of canola (KBNSR1.3) reduced the severity of root rot in *Phytophthora*-infested soil compared to BQ mulch and a bare fallow.

Eight papers were presented to national conferences and one manuscript written for publication to a science journal. Flyers and handouts were produced and distributed to 54 growers during a grower workshop at Tupi, South Cotabato. A papaya production video titled 'Growing papaya: your guide to getting it right' was produced to assist new and experienced Australian and Philippine growers.

3 Background

Component 3 'Integrated crop management strategies for the productive, profitable and sustainable production of high quality papaya fruit in the southern Philippines and Australia' was a component of ACIAR Program HORT/2007/067, 'Improved domestic profitability and export competitiveness of selected fruit value chains in the southern Philippines and Australia'. The component aimed to identify and address the disease, insect pest and nutrition-related problems associated with the growing of papaya in the southern Philippines.

Papaya is an important crop in the Philippines and is ranked 6th in terms of area planted and 5th in terms of volume produced (165,981 metric tonnes in 2010) and is continually expanding. Commercially grown papaya in the Philippines is based on a number of different cultivars which includes Solo, Cavite Special, Legaspi Special, Morado and the Sinta hybrid. Of the volume of fruit produced, 95% is consumed locally as fresh food and about 5% is exported fresh and dried. Major export markets include Japan, Hong Kong, China, Saudi Arabia, United States, the German Federation and Australia and New Zealand (Coronel 2004). Papaya is grown throughout the Philippines in commercial plantations, backyards and occasionally in mixed cropping systems.

In Mindanao, papaya is climatically well adapted with yields of up to twice the national average (30% of the national production is produced from just 16% of the total national area under papaya). In northern Mindanao, production is mainly focussed on the growing of papaya cultivars for the Del Monte-owned cannery near Cagayan de Oro City. A major expansion by the Dole Company in the production of solo papaya for export and the local market has occurred in southern Mindanao. Similarly, the Sumifru Company has established its production in the South Cotabato region of southern Mindanao. In recent years, pests, diseases and poor plant nutrition have been heavily impacting on production in the Mindanao growing region (PCAARRD ISP Tropical Fruit Industry Strategic S&T Plan, July 2012). Integrated crop management (ICM) is not in general use by growers and contractors for insect, disease and nutrition management and production has been decreasing in recent years.

A component scoping study to the southern Philippines in December 2007 found that many growers and contractors apply heavy calendar-based spray regimes which could be impacting on beneficial insect populations promoting pest flare (D. Astridge, pers. comm.). Spider mites especially the two-spotted mite (*Tetranychus urticae* Koch, Acari: Tetranychidae) have become an increasing concern to the Philippines papaya industry over the past 10 years. These mites damage leaf tissue, which reduces the photosynthetic capacity of the plant, resulting in a loss of plant vigour and yield. Research by Fay et. al. (2001) showed that not only does the high use of pesticides impact on natural biological control but the heavy use of some fungicides such as mancozeb kills natural enemies during critical times in the season. Mite population sampling in Australia identified important predators such as ladybeetles (*Stethorus* spp. and *Halmas ovalis*), predatory mites (Persimilis and Typhlodromas), and lacewing larvae were being adversely effected by the overuse of some pesticides. This was resulting in 'pest flare' and a build up of spider mite populations. Similar conditions were thought to be impacting on beneficial insects in the Philippines causing spider-mites to become a major problem in papaya.

The disease Bacterial crown rot (BCR) is particularly serious in some parts of Mindanao causing 50–90% crop loss in some cases (V. Justo, pers. comm.). Plants affected with BCR are readily distinguished in the field by wilting leaves resulting from infection of the petiole or stem by the bacterium *Erwinia* sp. Water-soaked lesions occur on the petioles and stem eventually causing rots of the petiole and stem particularly during periods of prolonged wet weather. Control measures in the Philippines have centred on the eradication of severely infected plants and the removal of infected petioles and leaves. The disease is caused by *Erwinia papayae*, recently described from the Caribbean (Gardan *et. al*. 2004). BCR has not been recorded in Australia.

Phytophthora fruit and root and stem rot of papaya is also a serious disease during prolonged wet weather. Entire columns of fruit can become infected and the apical portion of the stem can develop water-soaked rots. Seedlings are most susceptible to root rot but during and following prolonged wet weather mature trees will also succumb to the disease. No control measures for *Phytophthora* root rot of papaya are currently practiced in the Philippines. The successful management of *Phytophthora* root rot in Australia is dependent on the integrated use of cultural practices and timely chemical applications. *Phytophthora* fruit rot is managed with crop hygiene and applications of copper fungicide.

The disease choco spot was first recorded in the Philippines on December 2008 causing 80% defoliation on fruit bearing trees in a commercial papaya plantation in Hagonoy, Davao del Sur. Defoliation caused by choco spot can lead to the development of fruit blemishes due to sunburn and severe fruit infections making the fruit unmarketable. Symptoms of choco spot include light brown circular spots up to 5 mm in diameter on leaves, long elliptical lesions (several cm in diameter) on leaf petioles and small, dark, sunken lesions that may develop on fruit

During the component scoping study to Mindanao on December 2007, it was considered that the pest and disease management strategies developed in Australia may also be applicable to growers in the Philippines. Adopting these strategies in the Philippines would help lower pesticide usage resulting in lower chemical residues in the fruit and lower costs of production. This in turn would act as an incentive for growers and contractors to adopt new management systems.

Plant nutrition practices employed by papaya growers in the tropical coast and adjacent hinterland areas of north Queensland are not very precise. Nutrient rates vary considerably amongst growers, principles for determining fertiliser application rates are not well developed, and application methods provide limited scope for controlling nutrient response. Potential deleterious effects to plant and environment are a concern, because high nutrient rates (N, P and K) are commonly applied by growers in an environment characterised by high rainfall (800–3600 mm) with approximately 75% falling from December to April), and soils (Ferrosols, Kandosols and Chromosols) that tend to have high permeability (drainage in the order of 500 mm/hr) and have low cation exchange capacity (<5 $cmol_c$/kg). Such conditions are known to promote plant growth dysfunction (e.g. excessive vegetativeness and vigour, poor fruit quality), and also cause highly charged nutrient flow in drainage water that can result in nutrient wastage, nutrient imbalances, soil acidification, and groundwater contamination leading to wider environmental effects. Many researchers are of the opinion that failure to integrate soil water and nutrient management, and a disregard for the contribution of non-applied nutrients to plant growth, were responsible for problems of this kind.

Of further concern in both countries, is the adverse effects that over-fertilisation might be having on soil biota and the susceptibility of papaya to disease. Plant nutrition has been linked to the predisposition of various plant species and fruits to disease. Little is known about the effect of nutrition on the predisposition of papaya to *Phytophthora* spp. or other diseases or whether current fertiliser practices in Australia or the Philippines are at odds with the management of these diseases.

In Australia, research is required to define improved nutrient management practices for papaya that optimise fruit yield and quality without compromising tree and soil health. There is also scope to reduce N, P and K rates currently being applied by growers, and refine application techniques to improve nutrient response and reduce adverse environmental effects. Recent preliminary research had already indicated the potential for significant reductions of N and K (to about half industry averages) whilst maintaining productivity. Further research was needed to determine the nutrient requirements of the tree for growth and fruit production, and methodologies for determining these requirements. Knowledge of the potential contribution of the soil's nutrient reserves to meet these requirements, and the integration of irrigation and fertiliser practices that optimise nutrient responses was also lacking.

The information gained, was expected to benefit the Australian papaya industry by providing improved cultural systems that eliminate unnecessary pesticide and nutrient applications, and so lower costs of production, maximise production, and reduce environmental impacts, whilst being useful for interpreting opportunities for improving production systems in the Philippines.

Further background on the crop papaya can be found in Appendix 11.3.4

4 Objectives

The overall aim of Component 3 was to increase the profitable and sustainable production of papaya fruit in the Southern Philippines and Australia through the development of sustainable nutrient management systems and integrated crop management (ICM) strategies for the control of major diseases and insect pests. This project had links with Component 1-Analysis of the constraints to selected topical fruit (papaya) supply chains and implementation of improved quality systems for the southern Philippines and Australia and Component 2–Integrated management of *Phytophthora* diseases of durian and jackfruit in the southern Philippines.

The specific objectives of this Component are outlined below:

1. To identify, quantify and study the major pests and diseases of papaya

   1.1 Conduct regional grower/contractor workshops

   1.2 Collect comprehensive biophysical dataset

   1.3 Confirm identity of disease causal organisms

   1.4 Conduct taxonomic survey of beneficial insects

   1.5 Evaluate appropriate fungicides

   1.6 Evaluate economic impact if mites and whiteflies

2. To design and implement IPM strategies for insect pests and diseases

   2.1 Analysis of correlations between diseases and biophysical factors

   2.2 Lab culture pests and diseases

   2.3 Develop pest and disease management strategies

3. To develop and implement sustainable nutrient management practices

   3.1 Review existing literature

   3.2 Hold planning meeting

   3.3 Assess the effects of major plant nutrients

   3.4 Evaluate rapid diagnostic tests

   3.5 Assess nutrient application methods

   3.6 Demonstrate 'best bet' nutritional practices

4. To determine the role of plant nutrition in the integrated management of diseases of papaya

   4.1 Assess the relationship between plant nutrition and disease development

5. To package and disseminate a package of technology (ICM strategies) for papaya

   5.1 Conduct stakeholder planning meetings

   5.2 Develop information resources

   5.3 Implement agreed extension activities

   5.4 Co-ordination of final report

5 Methodology

The activities of Component 3 were conducted at the Bureau of Plant Industry (BPI) Research Centre in Davao (fungicide trial and predatory mite rearing facility), the University of South-east Philippines (USeP) at Tagum (nutrition trials) and grower sites provided by Del Monte (DMPI) in Bukidnon (mite and nutrition trials) and in the Stethorus beetle rearing facility (Camp Phillips). In Australia, nutrition, disease and mite studies were conducted at the Centre for Wet Tropics Agriculture, South Johnstone, North Queensland.

Objective 1. To identify, quantify and study the major pests and diseases of papaya

1.1. Conduct regional grower/contractor workshops

Members of component 2 and 3 took part in a three-day start-up workshop (30 July-1 August 2008) at Del Monte's Camp Phillips in Mindanao. Relevant information on pathogen biology, disease cycles, epidemiology, disease management, exotic pests and diseases and PAR trial establishment and maintenance were presented in lectures. Participants were provided with a training manual and given hands-on experience in pathogen isolation and identification.

Regional grower/contractor workshops were conducted on the 8-13 December 2008 at Cagayan de Oro City, Misamis Oriental, Bukidnon, Davao del Norte and South Cotabato to determine the crop management practices, pest and disease issues, cost of production, soil types, climatic conditions and information sources available to growers. Constraints to papaya production and crop management were identified by growers/contractors. Pest management practices used by growers were also recorded in the grower/contractor survey. During the workshops, collaboration was sought from the growers/contractors for involvement in the research activities.

An in-depth review and planning meeting for stakeholders involved in component 3 activities was held in the Southern Philippines city of Cagayan de Oro on the 1-3 March 2009.

1.2. Collect comprehensive biophysical datasets (insect pests, diseases, soil types, climatic conditions, crop practices) from the survey activity

A written survey of insect pest, disease and nutrition-related issues affecting 19 papaya growers in the regions of Cagayan de Oro City, Misamis Oriental, Bukidnon, Davao del Sur, Tagum City and Davao del Norte was conducted on the 8-13 December 2008. Biophysical datasets on crop production practices, pests and diseases, varieties and soil types were gathered via the survey and group discussion. Insect pests and disease samples were collected during field visits and climatic data was also obtained.

The population dynamics of pest mites and their natural enemies in papaya was investigated at Liboran, Baungon, Bukidnon in an area planted to the processing papaya cultivar 'Cavite'. Population monitoring of mites and damage assessments were conducted from May 2010 to March 2012 using index guides for mite infestation and damage. Field sampling was carried out to identify the mite species associated with papaya in the region and determine the time of the year mite populations are at their lowest and highest density.

Fortnightly assessments were conducted on papaya trees receiving and not receiving the insecticides (abamectin and dimethoate). Stratified random sampling was conducted by taking leaf samples from the top, middle and bottom leaves of each tree. Mites and predatory insects were identified and their populations estimated during each sampling period.

A similar field trial was established at the BPI-DNCRDC Research Station. Red spider mite populations and damage to plants were monitored and weekly assessments were conducted. Rainfall, temperature and relative humidity data was also obtained.

1.3. Confirm identity of insect pests and disease causal organism

Insects, mites, and disease affected plants were collected from the growers' fields every fortnight during surveys and field visits. Insects and mites that were collected from field visits were mounted and sent to specialist taxonomists for identification. Disease samples were forwarded to the plant pathologist at BPI and the bacteriologist at UPLB.

Choco spot. - Parts of infected plants (petioles, leaves and fruits) were collected from grower properties. Infected plant parts were cultured on artificial culture media and pure fungal cultures were maintained on agar slopes. The pathogen was identified under the microscope using morphological characteristics. Pathogenicity tests using healthy young papaya seedlings grown in the greenhouse were conducted to satisfy Koch's postulates.

Bacterial crown rot. - The accurate recovery and identification of isolates from crown rot affected plants is crucial to the success of research into this disease. BCR infected samples of papaya were collected from different regions in the Philippines. Isolates were grown on KB medium and morphological features were recorded. DNA fingerprinting and genetic diversity analyses were conducted using PCR-based methods e.g. PCR-RAPD, PCR-REP, PCR-ERIC, and PCR-BOX.

1.4. Conduct taxonomic survey of beneficial insects

Fortnightly field visits were conducted in papaya growing areas to sample seasonal mite infestation levels. Predatory insects and mites and were collected during these sampling periods and sent to specialist taxonomists for identification.

Objective 2. To develop IPM strategies for major insect pests and diseases based on successful strategies used in other countries/production regions

2.1. Analyse correlations between nutrition, diseases, insects and biophysical factors

Red spider mite populations and damage caused by red spider, beneficial insects and mites and disease incidence were monitored in fertiliser field trials at USeP-Mabini Research Station, Compostela Valley and at Sto. Nino, Manolo Fortich, Bukidnon. Temperature, rainfall and relative humidity data was collected and correlated with disease infection and spider mite infestation.

Data was collected on the population dynamics of spider mites in papaya and analysed to develop a practical grower based monitoring system to be used as a decision support system for grower miticide application.

2.2. Laboratory culture diseases

Samples of Choco spot infected plants were collected from the various papaya growing areas. Disease infected leaves and leaf petioles were cultured on potato dextrose agar (PDA). Spore suspension inoculum was used in the testing of isolates for pathogenicity (to fulfil Koch's postulate), the evaluation of cultivars for susceptibility and in the testing of fungicides for efficacy.

Bacterial cultures were obtained from bacterial crown rot (BCR) infected plants by streaking bacterial ooze from young leaf lesions onto Kings B culture media. Pathogenicity tests were conducted by wound inoculating the crown of healthy papaya seedlings with a suspension of the bacterium. Seed transmission tests were also performed by growing seeds from infected papaya fruit and seeds artificially infested with

Erwinia papayae. Bacterial isolations were also conducted on insects found associated with BCR affected plants to determine if they were capable of transmitting the disease.

2.3. Develop pest and disease management strategies

Seven commercially available fungicides (azoxystrobin, cupric hydroxide, difenoconazole, chlorothalonil, tebuconazole, propineb and mancozeb) were evaluated for the control of choco spot in a field experiment at BPI-DNCRDC Research Station. To ensure a satisfactory research outcome, the trial-site was artificially infested with choco spot by spraying a spore suspension of *C. cassicola* onto the upper and lower surface of leaves of guard plants in the trial. Two weeks after inoculation (6 months after transplanting), the application of fungicides commenced. Nine fortnightly spray applications were made with a knapsack sprayer during the experiment and the spray volume increased from 333 to 430 L/ha as the plants matured. Assessments of the youngest leaf spotted (YLS) with choco spot were conducted during the experiment. The effect of the fungicide treatments on insect and mite populations was also recorded.

Studies of the biology and food consumption of two biological control agents of red spider mite, the predatory mite *Neoselius longispinosus* and the predatory beetle *Stethorus pauperculus* were conducted at DMPI and BPI-DNCRDC. Red spider mites were mass-reared on water hyacinth which is an alternate host plant. These mites were used to feed the predators. Feeding efficiency studies of both predators were conducted. A field trial examining the effect of natural predator populations on red spider mite populations was established at DMPI.

In Australia *Phytophthora*-related diseases are a major constraint to the on-going development of the Australian papaya industry. Cultural and chemical control methods were evaluated as part of an IPM strategy to control these diseases.

Phytophthora fruit rot control. In two field trials, the chemicals copper hydroxide as Kocide, copper oxide as Red Copper, copper hydroxide+metalaxyl-M as Ridomil Gold Plus, dimethomorph as Acrobat., metiram+pyraclostrobin as Aero, potassium phosphonate as Agrifos Supa 600 and chlorothalonil as Bravo WeatherStik were evaluated for efficacy against *Phytophthora* fruit rot of papaya. Both field trials were artificially infested with *P. palmivora*. Seven spray applications of the chemical treatments were made to the foliage and fruit columns. The disease incidence (% fruit infected) was assessed as fruit was harvested.

Phytophthora root rot control. In three glasshouse pot experiments, the plant defence activator acibenzolar-s-methyl was tested at various concentrations for efficacy against *Phytophthora* root rot of young potted papaya seedlings. The roots of seedlings were soaked for 1 hour in 0, 5, 10 and 25 and 50 ppm acibenzolar-s-methyl before being transplanted into either infested or un-infested field soil. One week after transplanting, pots containing the seedlings were drenched with the appropriate chemical concentrations.

In a glasshouse pot trial, the chemicals propamocarb as Previcur at 1.5 mL/L, thiophanate methyl as Banrot at 30 g/L, furalaxyl as Fongarid at 1 g/L, potassium phosphonate as Agrifos Supa 600 at 10 mL/L and dimethomorph as Acrobat at 0.72 g/L were evaluated for efficacy against *Phytophthora* root rot. These treatments were applied to seedlings transplanted to naturally infested field soil.

Biofumigation of *Phytophthora*-infested soil with *Brassica* sp. has been shown to significantly reduce *Phytophthora populations* in soil. In a glasshouse pot trial, sufficient *P. palmivora* infested soil and pasteurised soil were mixed in five-fold dilutions (1/0, 1/5, 1/25 and 0/1 w/w) of infested to un-infested soil. Seed of canola KBNSR1.3 test line and BQ mulch were sown in the appropriate pots and the plants grown for 8 weeks prior to being chopped and incorporated back into the soil and allowed to compost for an additional 6 weeks. Nine-wk-old papaya seedlings were then transplanted to the pots and assessed for root weight and root rot severity.

Objective 3. To design and implement sustainable nutrient management practices

Objective 3 methodology consisted of six main activities; inception meeting, grower surveys, literature review, nitrogen rate and rapid diagnostic research, and commercial collaboration.

3.1 Project inception meeting

The project's inaugural meeting in Davao in July 2008 was used to introduce Australian and Filipino project participants, and resolve operational aspects of the research methodology. Subsequent yearly meetings (2009 to 2012) were organised at trial sites in the Philippines between USeP, UPLB, DMPI and DAFFQ collaborators to review and guide the progress of the research.

3.2 Industry/grower survey

Papaya industries in the Philippines and Australia were surveyed to describe current nutritional practices and clarify RD&E priorities for research. In the Philippines, biophysical and chemical use datasets of the major pests and diseases of papaya were required for Activity 1.2, and this was collected at the same time as the nutritional information. Questionnaire preparation and grower interviews in the Philippines were undertaken jointly by UPLB, USeP, BPI (Davao) and DMPI project staff.

In Australia, nutrition information was collected by postal survey by DAFFQ via Papaya Australia Ltd's grower address database. The majority of growers who received questionnaires were located in the main production region, the wet tropical coast (Mossman to Tully) and adjacent Atherton Tablelands of North Queensland. Survey data were summed and proportions calculated to describe trends, with emphasis on the wet tropical coast and Atherton Tablelands regions. Information on industry nitrogen (N) rates and adoption of best management practices was used to define treatments for N rate research (rate ranges, application methods) and the nature of extension activities.

3.3 Review relevant scientific literature

Review of published literature on aspects of papaya was undertaken in Australia by DAFFQ to understand the culture of papaya and research methodologies (neither the DAFFQ and USeP project teams had prior experience with papaya), and to formulate nitrogen fertilization practices that promote nutrient use efficiency and environmental health in commercial papaya production in a tropical monsoon climate. Literature was sourced mainly through DAFFQ library services and included information on cultural methods, N rate effects, best management nutrient principles (BMP), 'quick test' diagnostics, and fertigation techniques (application of nutrients via irrigation). Best management nutrient principles taken from the review were incorporated in the design of N rates research. Better sap extraction technique, needed to refine 'quick test' diagnostics for papaya, was indentified as priority research.

3.4 Assess the effects of nitrogen

Optimum N rate for growth and yield was evaluated in the Philippines and Australia. In the Philippines, two N rates trials were conducted under rain-fed conditions. The USeP trial (planted July 2009) studied the response of fresh-eating papaya (fresh papaya) at Mabini in southern Mindanao, and was also utilized for student under-graduate studies. The DMPI trial at Manolo Fortich in northern Mindanao (planted May 2010), studied the response of papaya grown for processing (processing papaya). The same six rates were applied in both trials (15−600 kg N/ha/24 month crop cycle; 10 treatment applications applied over 20 months), and included an industry practice (344 kg N/ha/24 month crop cycle; 8 treatment applications applied over 17 months) (Appendix 11.3.1, Table 2).

The influence of N rate on fresh papaya was assessed in Australia by DAFFQ at South Johnstone in North Queensland. The trial was planted in June 2011. Treatments were applied fortnightly by fertigation, and rates applied in the local industry (400−600 kg ha/24 month crop cycle) were within the range of the five rates tested (220−620 kg/ha/24 month crop cycle; Appendix 11.3.4, Table 1). In all trials, growth (plant height and trunk girth), petiole N and fruit yield responses were evaluated.

3.5. Evaluation of rapid diagnostic tests

Research of the Merck Reflectoquant® RQflex 10 rapid nutrient analysis (sap) test (RQflex 10), previously researched as a nutrient monitoring technique in papaya, was undertaken by USeP and DMPI in the Philippines, and by DAFFQ in Australia. USeP and DMPI researchers were trained in test methodology to assist them evaluate the test in their N rate trials. Various mechanical devices were assessed by DAFFQ to improve the current method of petiole sap extraction (maceration of petioles in a food processor followed by sap extraction with a garlic crusher). The efficacy of a developed technique was then tested by evaluating whether petiole sap derived by the technique would differentiate plants treated with different N rates. Sap NO_3^- content, measured by the RQflex 10 and by a commercial laboratory analysis, were also compared to understand whether the RQflex 10 test was a viable alternative to commercial laboratory analysis.

3.6. Evaluate N rates with commercial collaborators

Research of nitrogen nutrition was conducted with DMPI in Bukidnon (described in Sections 3.2, 3.4 and 3.5 above) because the relationship afforded significant opportunity to improve the profitability of papaya growers in the region. The company draws production from 1000 hectares, approximately 85% supplied by contract growers, and has well-organised RD&E capability to manage research and disseminate technical information.

Cultural information was collected from the South Cotabato region (described in Section 3.2 above), and a one day extension workshop was held by USeP and UPLB project staff. Technical information (pest and nutrition management, post-harvest fruit handling) was presented to local papaya growers at the workshop.

Objective 4. To determine the role of plant nutrition in the integrated management of insect pests and diseases of papaya

4.1. Assess the relationship between plant nutrition and pest and disease development

The effect of rates of application of N (ammonium sulphate) on pest and disease incidence and severity in papaya was studied by thesis students in the previously mentioned field trials at USeP and DMPI, Manolo Fortich, Bukidnon. Fortnightly assessments of the 'youngest spotted leaf' (YSL) with choco spot was conducted from the onset of the disease. Red spider mite populations and damage caused by red spider, beneficial insects and mites were also monitored. Fruit was assessed for stem-end rot and other post-harvest diseases and total soluble solids per fruit. Rainfall, temperature and relative humidity was also recorded.

In Australia, four rates of application of nitrogen (110, 170, 255 and 340 kg N/ha) were applied to papaya seedlings growing in 0%, 4%, 20% or 100% *Phytophthora palmivora* infested field soil in the glasshouse. In a second glasshouse experiment, four rates of nitrogen (100, 250, 400 and 600 kg N/ha) were applied to papaya seedlings growing in *Phytophthora palmivora* infested field soil. In each experiment, three fortnightly applications of nitrogen (urea) were made. After five weeks, assessments were made of the days to wilting, dry weight of plant tops, plant height, fresh weight of roots and root rot severity.

Objective 5. To package and disseminate a package of technology (ICM strategies) for papaya

5.1. Conduct stakeholder planning meetings

Several meetings were conducted with growers, contractors and other collaborators. These included the Inception Meeting in Davao in 2008, the Review and Planning Meetings in Cagayan de Oro in March and July 2010 and following that, yearly review meetings at Cagayan de Oro. The barriers to technology dissemination were identified and discussed. The technologies developed from the component activities would eventually be transferred to growers and contractors using an extension program designed at the meetings.

5.2. Develop information resources

Flyers, leaflets, handouts and other extension materials were developed and distributed to growers/contractors and technicians at the regional grower and contractor workshops held in Northern Mindanao in 2009 and South Cotabato in 2011.

5.3. Implement agreed extension activities

Demonstration plots on 'Best practices for integrated pest management in papaya' were conducted on farms contracted by Del Monte in 2010-2011 and on smallholder farms in Tupi, South Cotabato in 2011. Growers were involved in the planning, design and the implementation of the trials to give them ownership of the activity. Growers and collaborators monitored these demonstration sites for pests and diseases. Data and information gathered from these monitoring activities was discussed in scheduled meetings with all the participating growers. Field days were attended by farmers, growers, contractors and local technicians.

Workshops, meetings and training in IPM in papaya were conducted with growers.

Discussions with growers during farm walks field days and workshops held in the six papaya growing regions (10-15 growers attended from each region) provided them with information and knowledge on disease diagnosis, pest identification and pest and disease management.

Co-ordination of final report

Quarterly and annual reports were submitted to ACIAR on time and the final report prepared at the completion of the project.

6 Achievements against activities and outputs/milestones

Objective 1: To identify, quantify and study the major pests and diseases of papaya

no.	activity	outputs/ milestones	completion date	comments
1.1	Conduct regional grower/contractor workshops (P)	Component knowledge gaps identified	December 2009	Grower surveys and workshops in Northern and Southern Mindanao identified red spider mite and Choco spot as the major diseases of papaya. Of lesser importance were fruitflies, whiteflies, scale insects, bacterial crown rot (BCR) and Phytophthora-related diseases. By the end of project, BCR was the greatest concern for growers. A *Phytophthora* workshop and stakeholder meetings were conducted in Cagayan de Oro in 2008-2009. These workshops identified integrated crop management strategies for papaya.
1.2	Collect comprehensive biophysical and chemical use dataset via grower survey (P)	Datasets available providing necessary information for decision making on treatments for pest and disease management	April 2012	A field study into the seasonal abundance of red spider mites conducted in Baungon, Bukidnon in miticide sprayed and unsprayed blocks showed that the predatory mite populations in the unsprayed block produced two population peaks, one in January 2011 and another in April 2011. A relatively low level of mite infestation was recorded from June to September in 2010 and 2011. In the miticide treated block, the population also peaked in April 2011 when the total rainfall recorded for the month was at its lowest suggesting rainfall has a big influence on mite population development in the field. The small predatory black beetle *Stethorus pauperculus* Weise, a voracious feeder of spider mites, was common and more numerous in the unsprayed block. Seasonality data was obtained from Northern and Southern Mindanao (Tupi, South Cotabato) where the major solo papaya production of Dole and Sumifru (for export) and small farmers is located.
1.3	Confirm identity of insect pests and disease causal organisms (P)	Positive identification confirmed of pest and disease causing organisms	December 2011	The choco spot causal organism (*Corynespora cassicola*) was identified. Six species of phytophagous mite were identified by specialist mite taxonomists. The mites were *Brevipalpus californicus* (Banks), *Eutetranychus africanus* (Tucker), *Tetranychus kanzawai* Kishida, *T, piercie* Mc Gregor, *T. urticae* Koch and an unidentified Tetranychid species. Fruitflies, scarring beetles and snails are believed to carry plant pathogens such as *Phytophthora palmivora*. Research showed that a bacterial isolate recovered at Del Monte's Camp Phillip, Northern Mindanao in November 2009 was more likely to represent the causal agent of BCR owing to its phylogenetic proximity to the Caribbean strain (*Erwinia papayae*) of BCR of papaya.

1.4	Conduct taxonomic survey of beneficial insects (P)	Positive identification of important beneficial insects in the Philippines and the impact of pesticides used	December 2011	Three predatory mite species were identified. They were *Neoseilus longispinosus* (Evans), *Amblyseius tamatavensis* Blommers *and A. largoensis* (Muma). The most common pest mite species damaging papaya was *Tetranychus kanzawai* while the two most important predators of mites were the predatory mite *N. longispinosus and* the predatory beetle *Stethorus pauperculus.* Different species of spiders and midge were also observed. There importance in the overall management of pests of papaya is unknown.

PC = partner country, A = Australia

Objective 2: To develop IPM strategies for the major insect pests and diseases of papaya based on successful strategies used in other countries/production regions

no.	activity	outputs/ milestones	completion date	comments
2.1	Analyse correlations between nutrition, diseases, insects, and biophysical factors (P, A)	Datasets available to assist with the development of pest and disease management strategies	December 2012	Glasshouse studies indicate no correlation between high N and Phytophthora root rot (A). Incidence of stem-end rot shown to be enhanced by high nitrogen (P). There was no significant treatment effects between the level of nitrogen applied to the soil and pest spider mite development.
2.2	Laboratory culture diseases (P, A)	Efficacy data available to assist in product registration	April 2010	Confirmation of BCR pathogen as *Erwinia papayae,* choco spot pathogen as *Corynospora cassicola* and Phytophthora root rot caused by *P. palmivora.* Pathogens of concern have been identified An evaluation of commercially available fungicides for choco spot control was conducted in *in vitro* tests. These fungicides were further evaluated in the field. *In Australia in vitro* tests were conducted to provide efficacy data for chemicals used to control damping-off of papaya and Phytophthora fruit rot of papaya.

2.3	Develop pest and disease management strategies (P, A)	Development of pest and disease management strategies	December 2012	Trials completed: • BCR transmission studies (P) • Brown spot resistance and fungicide control (P) • *Phytophthora* fruit rot and root rot studies (A) • Techniques used in the rearing of papaya mites and predatory spp. were developed (P). Samples of bacterial crown rot infected plants were collected from several papaya growing areas in Luzon and Mindanao. The pathogenicity of these isolates was studied but no differences were detected. Seed transmission studies conducted at DMPI showed 1-2% infection in seedlings one month after inoculation. Further work on seed transmission needs to be conducted to confirm these findings. The seven fungicides evaluated for the control of choco spot showed that all the chemicals tested provided a level of control however propineb proved to be the most effective chemical providing a 104% marketable yield increase. Results also showed that dithiocarbamate fungicides were toxic to mite predators such as *S. pauperculus*. In Australia, the chemicals copper hydroxide and metiram+pyraclostrobin effectively controlled *Phytophthora* fruit rot and brown spot (*Corynespora cassicola*). Both chemicals were further evaluated at various rates of application and copper hydroxide proved highly effective at rates of 375 and 450 g a.i/100 L of water. Residue data was obtained. A minor use permit for the use of copper hydroxide at 375 g a.i./100 L will be sought from the Australian Pesticide and Veterinary Medicines Association (APVMA). Results from the three pot experiments showed that the plant defence activator acibenzolar-s-methyl had no effect at reducing the incidence and severity of *Phytophthora* root rot of papaya seedlings when applied as a pre-transplant root soak and drench one week after transplanting. Results from the evaluation of a range of chemicals for the control of root rot showed that drenching infested soil with dimethomorph, furalaxyl and potassium phosphonate significantly reduced the severity of root compared to thiophanate methyl, propamocarb treated soil and the infested control. Results from the evaluation of the green manure crops BQ mulch and canola (KBNSR1.3) showed a significant reduction in root rot in canola-amended pots compared to BQ mulch and a bare fallow in 20% and 100% *Phytophthora*-infested soil. The overall effect demonstrated a reduction in root rot severity in canola-amended pots and an increase in fresh root weight. Bioecological studies on pests and predatory mites and beetles conducted at DMPI and BPI. Mass production techniques were refined to produce more predators for subsequent field releases.

PC = partner country, A = Australia

Objective 3: To design and implement sustainable nutrient management strategies

no.	activity	outputs/ milestones	completion date	comments
3.1	Project inception meeting (P)	Establish links with Australian and Philippine collaborators and coordinate project activities.	2008, 2009–2011	Most of the operational aspects of the research methodology (scope, leadership responsibilities, location, and timelines), described in the project proposal, were formalised at the project's inaugural meeting in Davao in July 2008. In addition, several Australian and Filipino participants of Component 3, who had not previously met, were formally introduced at the meeting (as were introductions made across other Components of the project). Following the inaugural meeting, meetings were held between Australian and Filipino project staff at research sites in Mabini (USeP) and Bukidnon (DMPI) in March and November 2009, August 2010, July 2011 and April 2012 where the progress of the research was reviewed and technical issues resolved. Significant amendments to the initial project plans were made in March 2009. These were; commitments by DMPI to evaluate rapid diagnostics and the effects of N rates on processing papaya (Activities 3.5 and 3.6), and USeP to evaluate the effects of N rates on fresh-eating papaya (Activity 3.4). Asuncion Salabay, who was responsible for USeP's research from the start of the project, resigned from the university in December 2010. Her role was assumed by James Lasquites.
3.2	Industry/grower survey (P and A)	Statement of grower nutritional practices.	2011	In the Philippines, information was collected from 18 interviews with papaya growers in Bukidnon and neighbouring municipalities in the north of Mindanao in December 2008 and from 14 interviews in Tupi and Tampakan in the south in November 2011. Increasing cost of fertilizer inputs was influencing infrequent and irregular applications in northern Mindanao leading to reduced fruit yield and quality. Nitrogen rates reported for the region (commonly 300–400 kg/ha) guided the range assessed in Activity 3.4. In Australia, there was a significant response to the survey posted in March 2010; 20% respondent rate which represented 25% of growers and 45% of the area in the major production region (Appendix 11.3.3). Reported N rates, and verification of the widespread use of fertigation, were incorporated into the design of N rate trial (Activity 3.4). Other survey information highlighted deficiencies in industry nutrient management techniques (particularly soil water monitoring), which were already being addressed by Growcom's extension activities conducted under the Federal Government's Reef Rescue program. To assist adoption of BMP in papaya, DAFFQ project staff supported this program as a participatory assessor in the Reef Rescue Water Quality Incentive Grants program (also part of the Reef Rescue program), which subsidised the purchase of BMP technologies (e.g. fertigation and soil moisture monitoring equipment). This involvement was also an effective forum to clarify and promote relevant BMPs for papaya.

3.3	Review relevant scientific literature (A)	Literature review of aspects of papaya nutrition relevant to Component research.	2011	A BMP approach for papaya fertilization that integrates the principles of optimum rate, matching rate to plant requirement, and nutrient delivery by precise application technique was clarified from the literature (Appendix 11.3.4). The approach was used as a basis for planning the N rates research (Activity 3.4). In addition, a dry matter accumulation model (reported for papaya) was developed from the literature to scale N rate to plant growth. The literature showed that plant sap nutrient 'quick tests' are highly relevant to intensely managed papaya, and while the RQflex 10 has been researched in papaya, the method of extracting sap from petiole index tissue should be improved to make the technique more adaptable to in-field use. This research was including in Activity 3.5.
3.4	Assess the effects of nitrogen (P and A)	Nutrient rates that produce high yield and fruit quality.	2011, 2012	USeP assessed the effect of N rate over a 16 month period (9 month harvest period) (Appendix 11.3.1), while the term of the DMPI research was 22 months (14 month harvest period) (Appendix 11.3.2). The range of N rates tested covered those commonly used in industry (Activity 3.2). DAFFQ assessed the effect of N rate over a 13 month period (6 month harvest period) (Appendix 11.3. 5). The range of N rates tested were determined from reported research results, current rates of local industry (Activity 3.2), and potential reductions by fertigated application reported in the literature (Activity 3.3). Treatments rates were scaled to plant growth according to a dry matter accumulation function derived from Activity 3.3, and applied by fertigation. Plant response was assessed during three phenological stages: Stage 1, planting to flowering; Stage 2, flowering to harvest; and Stage 3, during harvest.
3.5	Evaluation of rapid diagnostics tests (P and A)	Rapid and accurate testing method.	2012	USeP and DMPI researchers were trained in general RQflex 10 test methodology by Merck in mid-2010. Further guidance and technical information relevant to papaya (index tissue sampling, sap extraction, and nitrate measurement) was supplied by DAFFQ to assist them evaluate the test in their N rate trials. The sap extraction efficiency of a number of mechanical devices was assessed by DAFFQ (Appendix 11.3.6). A two-step manual technique was developed consisting of cutting petioles lengthwise, and then removing the sap with a roller press. Efficacy testing of the technique showed that NO_3^- content of sap (obtained by the technique) from plants treated with different N rates was strongly related to rate indicating that the extraction technique was a viable means of supplying sap for the RQflex 10 test. Comparison of sap NO_3^- content measured by RQflex 10 and a commercial laboratory showed that the two measures were highly related and demonstrated the potential of the RQflex 10 test as an alternative to commercial laboratory analysis.
3.6	Evaluate nitrogen rates with commercial collaborators (P)	Extension information describing practices and benefits.	2011	DMPI concluded from their research (Activities 3.4 and 3.5), that 450 kg N/ha for a 24 month crop cycle should be recommended to commercial papaya growers to optimise fruit yield. The RQflex 10 test, which showed greater sensitivity to N rate than total N concentration (measured by Kjehdahl) was also recommended for assessing plant N status. Del Monte grows approximately 1,000 ha of papaya per year (85% of which is produced by contract growers). These technologies will be promoted through their extension network.

P = Philippines, A = Australia, USeP = University of Southeastern Philippines, Del Monte = Del Monte Philippines Inc, DAFFQ = Department of Agriculture Fisheries and Forestry Queensland.

Objective 4: To determine the role of nutrition in the integrated management of diseases of papaya

no.	activity	outputs/ milestones	completion date	Comments
4.1	Assess the relationship between plant nutrition and disease development	Nutrient practices that support disease management	December 2012	The incidence of stem-end rot was shown to be enhanced by high nitrogen applications (P). Assessments at the USeP and Sto. Nino trials showed high N nutrition had no effect on the incidence and severity of choco spot, mites, insect pests and mite predators. Glasshouse studies in Australia showed there were no correlation between high N and the incidence and severity of *Phytophthora* root rot.

Objective 5. To package and disseminate a package of technology (ICM strategies) for papaya

no.	activity	outputs/ milestones	completion date	Comments
5.1	Conduct stakeholder planning meetings (P, A).	Key stakeholders identified, extension programme developed based on agreed list of barriers and drivers to practice change	December 2009	Inception meeting was held in Davao (2008). Review and planning meetings held in Cagayan de Oro, 1-3 March 2009 and July 2010. Yearly review meetings held at CDO.
5.2	Development of information resources	Photos and seasonality datasets completed; drafts prepared for industry input and comments	April 2012	Posters on ‘Papaya insects and mites’ and ‘Choco spot of papaya’ presented at Pest Management Conference in Davao (P) 2010 and Cagayan de Oro 2012 Poster on link between high rates of N and the incidence of stem-end rot (Bohol meeting 2011). Four oral presentations and two posters at the ACIAR-PCAARRD End-of-Program Horticulture Conference.
5.3	Implementation of agreed extension program	Regional workshops completed in selected locations and training provided to stakeholders	April 2012	*Phytophthora* workshop conducted in 2008 (P) Regional grower and contractor workshops (6 papaya regions visited) (P) – N. Mindanao 2009 (10-15 growers in each region) & S. Cotabato 2011 (54 growers). Grower farm walks at trial–sites 2009-2010 (A), attendance at monthly grower meetings.
5.4	Coordination of final report	Final report completed and accepted by ACIAR	April 2013	Completed

7 Key results and discussion

1. Identification, quantification, and study of the major pests and diseases of papaya

Grower surveys conducted at the commencement of the component identified red spider mite and choco spot as the major pest and disease problems in papaya. Of lesser importance were fruitflies, whiteflies, scale insects, bacterial crown rot and *Phytophthora*-related diseases. However as the Component activities progressed, it became apparent that there was a increasing concern amongst growers and contractors of the rapid spread of bacterial crown rot in many of the papaya growing regions. Bacterial crown rot is now found in Luzon (Laguna, Batangas and Quezon) and Northern and Southern Mindanao where larger plantations are found and an expansion of the papaya industry is underway.

Mites and beneficial insect identification Six species of phytophagous mite were identified by specialist mite taxonomists. The mites were *Brevipalpus californicus* (Banks)*, Eutetranychus africanus* (Tucker)*, Tetranychus kanzawai* Kishida*, T, piercie* Mc Gregor*, T. urticae* Koch and an unidentified Tetranychid species. Three predatory mite species were identified. They were *Neoseilus longispinosus* (Evans)*, Amblyseius tamatavensis* Blommers *and A. largoensis* (Muma). The most common pest mite species damaging papaya was *Tetranychus kanzawai* while the two most important predators of mites were the predatory mite *N. longispinosus and* the predatory beetle *Stethorus pauperculus.* Different species of spiders and midge were also observed. Their importance in the overall management of pests of papaya is unknown.

Population dynamics of spider mites in papaya

A field study into the seasonal abundance of red spider mites conducted in Baungon, Bukidnon in miticide sprayed and unsprayed blocks showed that the red spider mite *Tetranychus kanzawai* was present in the trial at the commencement of the experiment. Mite infestations and damage to plants was generally confined and more serious on the bottom leaves than the middle leaves; with the top leaves being seldom infested. Mite population development in the unsprayed block produced two population peaks, one in January 2011 and another in April 2011 (Figure 1). A relatively low level of mite infestation was recorded from June to September in 2010 and 2011. In the miticide treated block, the population also peaked in April 2011 when the total rainfall recorded for the month was at its lowest suggesting rainfall has a big influence on mite population development in the field. The small predatory black beetle *Stethorus pauperculus* Weise, a voracious feeder of spider mites was common and more numerous in the unsprayed block.

Results from this field experiment showed that applications of Abamectin® and Dimethoate® had no effect on the level of mite infestation but had a direct effect in reducing the *Stethorus* beetle population. *Stethorus* beetles were more commonly found on the middle leaves than the bottom leaves. Consequently, a field survey of 15 growers in Iponan, Cagayan de Oro City showed very high beetle populations were reducing pest mites in papaya plantings receiving very low insecticide inputs. These results are shown in figures 1-3.

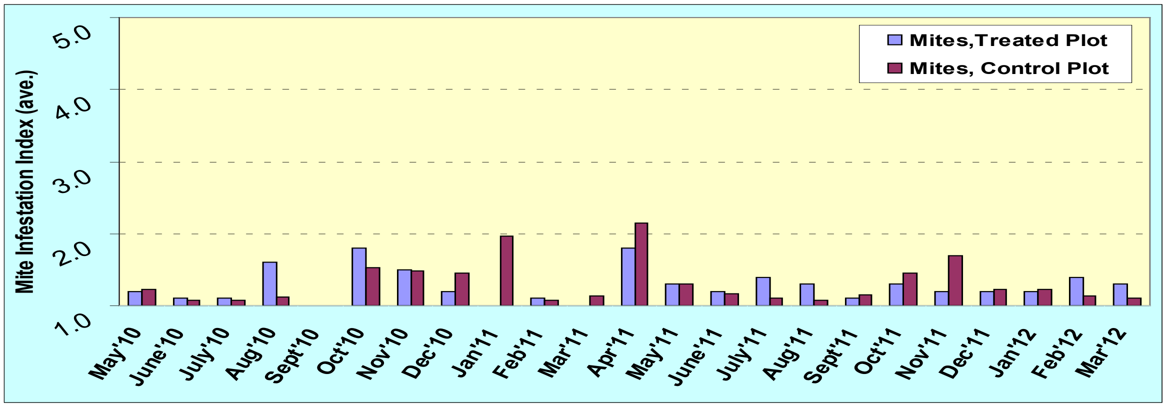

Figure 1. Population dynamics of the red spider mite, *T. kanzawai* on papaya at Liboran, Baungon, Bukidnon (May 2010-March 2012).

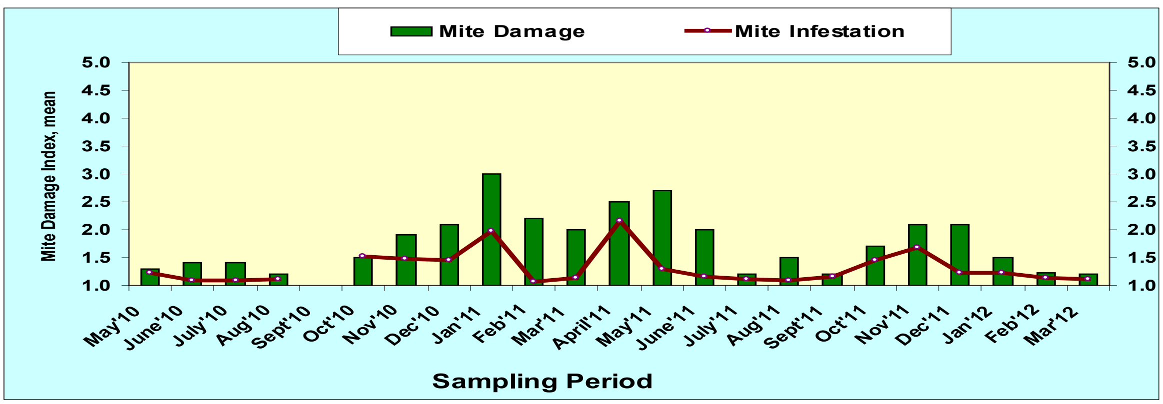

Figure 2. Population development and damage of *T. kanzawai* in papaya at the untreated plot at Liboran, Baungon, Bukidnon (May 2010 - March 2012).

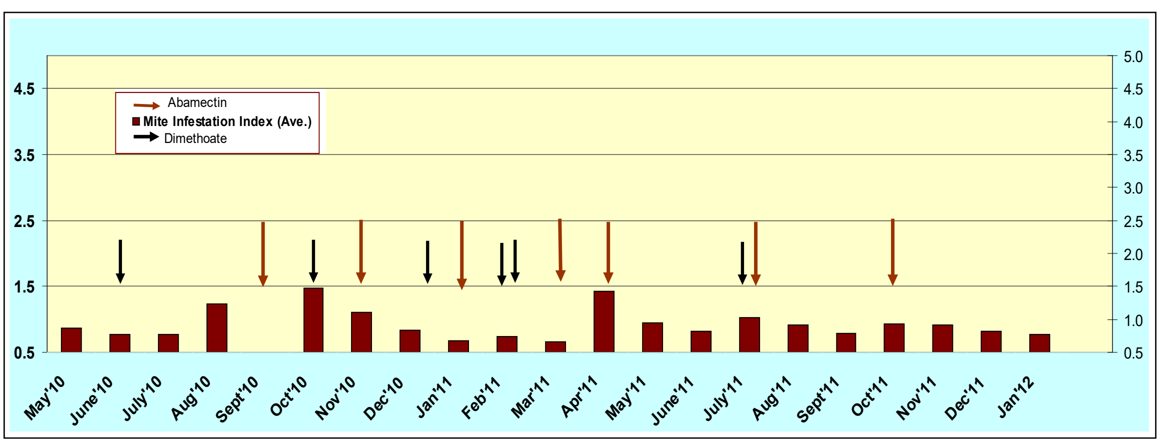

Figure 3. Red mite infestation on the papaya treated with abamectin and dimethoate at Liboran, Baungon, Bukidnon (May 2010 - March 2012).

Diseases

Choco spot, a major foliar disease of papaya was shown to be caused by a fungus *Corynespora cassicola.* Fungal isolates recovered from papaya leaves and petioles and grown on the culture media potato dextrose agar showed the morphological characteristics of *C. cassicola*. The pathogenicity tests conducted fulfilled Koch's postulate and confirmed *C. cassicola* as the causal agent of choco spot.

Research by Dr. Anthony Young, Molecular Biologist/Bacteriologist identified that a bacterial isolate recovered at Del Monte's Camp Phillip, Northern Mindanao in November 2009 was more likely to represent the causal agent of BCR owing to its phylogenetic proximity to the Caribbean strain (*Erwinia papayae*) of Bacterial Crown Rot of papaya. Other isolates taken from collections at DMPI and Visayas University and examined appear to be closely aligned to either a common contaminant *Pantoea agglomerans* or the regular 'soft-rotting' bacteria *E. chrysanthemi* and *E. carotovorum*. These findings raise concerns regarding previous and current research involving the use of these isolates. Dr. Young's research showed that young leaf lesions were required for the successful recovery of the BCR pathogen. More advanced damaged tissues was likely to yield contaminant bacteria only. A Powerpoint presentation was prepared (Appendix 2) which will assist researchers in the successful recovery of the BCR pathogen from infected tissue.

2. Development of IPM strategies for major insect pests and diseases based on successful strategies used in other countries/production regions

Mites and beneficial insects.

Results from the seasonal population dynamics of spider mites resulted in a grower based monitoring system that can be used as a decision support system for miticide application. Surveys also identified important natural enemies of spider mites that have potential use in future biological control programs. Two potential biocontrol agents, a beetle *S. pauperculus* and the predatory mite *N. longispinosus* were identified in field studies as being effective predators against spider mites. *S. pauperculus* was most commonly found in higher numbers in unsprayed trees than in trees sprayed with insecticide. Their capacity to aggregate on mite infestations and disperse when the prey becomes scarce is a positive characteristic of these predators. The predatory mite *N. longispinosus*, although present in Northern Mindanao, was not very common in the study areas.

The study into the possible relationships between nitrogen fertilisation and mite incidence in a papaya field at Sto Nino, Manolo Fortich, Bukidnon showed that nitrogen had no effect on mite incidence and subsequent damage in papaya.

In field trials examining the effects on fungicides on mite predators the results showed that the dithiocarbamate fungicides used were toxic to mite predators such as *S. pauperculus*

The development of IPM strategies for the major insect pests and diseases of papaya is crucial to the ongoing development of the industry. The tools developed for the monitoring and identification of pests and diseases are important in the decision making processes relating to the control of pest and disease. Insect predators have been shown in this research to play an important role in reducing insect pest populations and the damage they cause.

Diseases

The field experiment which evaluated seven fungicides for the control of choco spot showed that all the chemicals tested provided a level of control of choco spot however propineb proved to be the most effective chemical with a 114% increase in marketable yield. These results are given in Table 1.

Table 1. Effect of different fungicides on brown spot of papaya in a field experiment at BPI-DNCRDC, February 2011-February 2012.

Treatment	Rate of application/16 L water	Youngest leaf spotted after[a,b]		Total leaves per plant after[a]		Marketable yield (kg/ha)[a]
		7 sprays	9 sprays	7 sprays	9 sprays	
Propineb	50 g	13.98 a	15.65 a	25.06 abc	28.28 a	30.32 a
Cupric hydroxide	40 g	12.84 a	14.40 ab	26.98 a	27.53 ab	19.23 ab
Chlorothalonil	128 g	12.64 ab	14.29 ab	23.52 cd	25.96 ab	21.61 ab
Azoxystrobin	19 mL	12.35 ab	13.94 ab	26.77 ab	27.42 ab	27.08 ab
Tebuconazole	12 g	11.57 ab	13.97 ab	24.66 abc	26.09 ab	20.61 ab
Mancozeb	128 g	11.31 ab	13.50 bc	24.22 bcd	25.53 bc	14.47 b
Difenoconazole	10 mL	11.29 ab	12.89 bc	23.51 cd	23.17 c	16.31 b
Untreated	-	9.8 c	11.71 c	21.89 d	23.51 c	14.40 b

[a]Means in the same column followed by the same letter do not differ significantly (*P*= 0.05).
[b]YLS rated by counting from the most recent fully expanded leaf to the first leaf with 10 fully developed spots.

Samples of bacterial crown rot infected plants were collected from several papaya growing areas in Luzon and Mindanao. The pathogenicity of these isolates was studied but there were no differences detected between the isolates. Seed transmission studies conducted at DMPI showed 1-2% infection in seedlings one month after inoculation. Further work on seed transmission needs to be conducted to confirm these findings.

The development of IPM strategies for the major insect pests and diseases of papaya is crucial to the ongoing development of the industry. The tools developed for the monitoring and identification of pests and diseases are important in the decision making processes relating to the control of pest and disease. Insect predators have been shown in this research to play an important role in reducing insect pest populations and the damage they cause. Similarly, there needs to be ongoing research into finding sources of resistance to diseases such as bacterial crown rot. Further efficacy studies with the fungicides found to be effective in the control of choco spot need to be completed if a chemical is to be registered for papaya. Plant spacing, sanitation and nutrient management are also among the practices that can help reduce pest damage.

In Australia, results from the field evaluation of seven chemicals for the control of *Phytophthora* fruit rot showed copper hydroxide at 375 g a.i./100 L of water was the most effective treatment with no disease occurring in copper hydroxide treated plots (Table 2).

Table 2. Efficacy of various fungicides on the severity of *Phytophthora* fruit rot in the fruit column and the percentage incidence of *Phytophthora* fruit rot of papaya.

Treatment	Common name	Application rate a.i./100L^{x}	^{AB}Disease severity (12 April)	^{AB}Disease severity (27 April)	(%) infected fruit ^{z}
Untreated control	-	-	1.50 b	1.75 c	16.55 c
Kocide	Copper hydroxide	600	1.00 a	1.00 a	0.00 a
Ridomil Gold Plus	Copper hydroxide + metalaxyl-M	810+67.5	1.05 a	1.00 a	0.27 a
Aero	Metiram + pyraclostrobin	660+60	1.05 a	1.05 a	0.51 a
Bravo Weatherstik	Chlorothalonil	994	1.00 a	1.00 a	0.63 a
Red Copper	Cuprous oxide	990	1.10 a	1.00 a	0.80 a
Agrifos Supa 600	Potassium phosphonate	2%	1.45 b	1.30 ab	8.22 b
Acrobat	Dimethomorph	108	1.50 b	1.55 bc	11.18 bc
l.s.d.	-	-	0.311	0.447	6.920

[A]Treatment means are a scaled index of disease severity where 1, no disease, 2, 1-10% of fruit column affected, 3, 11-20% of fruit column affected, 4, 21-30% of fruit column affected, 5, 31-50% of fruit column affected, 6, >51% of fruit column affected. [B]Means followed by the same letter are not significantly different (P = 0.05).

A number of glasshouse studies were conducted to evaluate chemicals and biofumigation with *Brassica* spp. for the control of *Phytophthora* root rot of papaya seedlings. Results from these studies showed that acibenzolar-s-methyl used as a root soak for 1 hour at 0, 5, 10, 25 and 50 ppm was ineffective at controlling root rot in young papaya seedlings (Table 3). However, a single drench of dimethomorph and furalaxyl at transplanting was shown to give complete control of root rot (Table 4). Results from one of the biofumigation studies showed Canola (KBNSR1.3) was more effective at controlling *Phytophthora* root rot than BQ mulch and a bare fallow (Table 5). A similar result was achieved in other glasshouse studies.

Table 3. Effect of 0, 5,10, and 25 ppm acibenzolar-s-methyl on the root weight and root rot severity, one week after transplanting into un-infested and *Phytophthora* infested soil.

Soil type	Treatment	Application rate	Root wt.(g)[B]	Root rot severity[AB]
Uninfested	Control (Water)	-	3.93 a	1.00 a
Uninfested	Acibenzolar	5	3.18 b	1.00 a
Uninfested	Acibenzolar	10	3.14 b	1.00 a
Uninfested	Acibenzolar	25	2.43 c	1.00 a
Infested	Control (Water)	-	0.53 d	6.90 c
Infested	Acibenzolar	5	0.61 d	6.90 c
Infested	Acibenzolar	10	0.72 d	6.85 c
Infested	Acibenzolar	25	0.56 d	6.55 b
l.s.d (*P*=0.05)			0.392	0.229

[A]Treatment means assessed using a 1-7 scale of increasing root rot severity. [B]Means followed by the same letter are not significantly different.

Table 4. Effect of the fungicides dimethomorph, furalaxyl, potassium phosphonate, thiophanate methyl and propamocarb on the root weight and root rot severity of papaya seedlings, five weeks after transplanting into *Phytophthora* infested soil.

Product Name	Chemical Name	Application rate	Root wt.(g)[B]	Root rot severity[AB]
Acrobat	dimethomorph	0.72 g/L	13.62 a	1.00 a
Fongarid	furalaxyl	1.0 g/l	11.76 a	1.00 a
Agrifos Supa 600	potassium phoshonate	10mL/L	7.24 b	1.70 a
Banrot	thiophanate methyl	30 g/L	2.43 c	5.80 c
Previcur	propamocarb	1.5 mL/L	1.32 c	6.30 cd
Infested control	-	-	0.41 c	6.87 d
l.s.d (*P*=0.05)			3.913	0.993

[A]Treatment means assessed using a 1-7 scale of increasing root rot severity. [B]Means followed by the same letter are not significantly different.

Table 5. Days to wilting, root weight (g) and root rot severity of papaya grown in Phytophthora infested field soil in the glasshouse following green manure crops of canola (KBNSR1.3), BQ mulch and bare fallow.

Treatment	No. days to wilting[B]	Root wt. (g)[B]	Root rot severity[AB]
Canola (KBNSR1.3)	20.8 a	6.65 a	1.3 a
BQ Mulch	19.9 a	5.03 b	2.9 b
Bare fallow	17.4 b	3.92 b	3.8 b

[A]Treatment means assessed using a 1-8 scale of increasing root rot severity. [B]Means followed by the same letter are not significantly different.

3. Design and implementation of sustainable nutrient management practices

Significance of nitrogen rates research in the Philippines

Papaya growth and yield response to six nitrogen rates ranging from 15 to 600 kg/ha/24 months (Table 6), was studied by USeP (fresh papaya) over a 16 month crop life (9 month harvest period), and by DMPI (processing papaya) over 22 months (14 month harvest period). While there were no significant yield differences ($P < 0.05$) for either study over the range of rates assessed, USeP and DMPI reported highest yield at rates equivalent to 300 and 450 kg N/ha/24 months, respectively (Figures 4 and 5). The duration of the USeP study was terminated early because of plant loss due to poor drainage and bacterial crown rot. It is therefore premature to recommend their N rate for fresh papaya production. DMPI report they will recommend 450 kg N/ha for a 24 month crop cycle for processing papaya production. An economic assessment of this strategy would determine whether the additional rate (30% higher than industry) and the extra two additional applications compared to current industry practice (Table 6), are offset by the higher returns derived from a 10% improvement in yield.

Research of N application frequency could improve yield response (and thus nutrient use efficiency) for the rates tested in these studies. The relationship between application rate and yield response described in Appendix 11.3.4 Section 5 suggests that yield plateaus at around 40 g N/plant at application frequencies similar to these studies. Individual application rates were frequently in excess of this, particularly for treatments 450 and 600 kg/ha/24 months (Table 6). Currently, the maximum monthly N rate recommended by PCAARD (2006) is above this rate at 49 g/plant, and equivalent to 1278 kg/ha applied over 20 months as the USeP and DMPI treatments were scheduled.

Improved yield response might also be achieved by using controlled release N (CRN) technologies. These technologies are designed to overcome surplus plant-available nutrients in the soil that might be subject to undesirable transformations resulting in N loss from the production system by volatilization (e.g. nitrate to nitrous oxide) or leaching (e.g. nitrate). Research of treatments to improve nitrogen use efficiency should however, only be undertaken after economic analysis demonstrated that increased application frequency or CRN technologies were potentially cost-effective.

Table 6. Nitrogen rates and application timing of the nitrogen rate trials conducted in the Philippines. Nitrogen rates in **bold type** are rates over 40 g per application.

Nitrogen application timing (MAP[1])	Treatment rate (kg N/ha/24 month crop cycle)					
	15	150	300	450	600	344 (industry standard)
	Nitrogen rate applied (g/plant)[2]					
1	0.22	2.2	4.4	6.7	8.9	11.5
2	0.33	3.3	6.7	10.0	13.3	17.4
3	0.33	3.3	6.7	10.0	13.3	28.9
5	0.89	8.9	17.8	26.7	35.6	34.7
7	1.0	10.0	20.0	30.0	40.0	
8						**40.6**
9	1.1	11.1	22.2	33.3	**44.4**	
11						**40.6**
12	1.7	16.7	33.3	**50.0**	**66.7**	
14						**40.6**
15	2.2	22.2	**44.4**	**66.7**	**88.9**	
17	1.4	14.4	28.9	**43.3**	**57.8**	**40.6**
20	1.9	18.9	37.8	**56.7**	**75.6**	

[1]Months after planting. [2]Density 1667 plants per hectare.

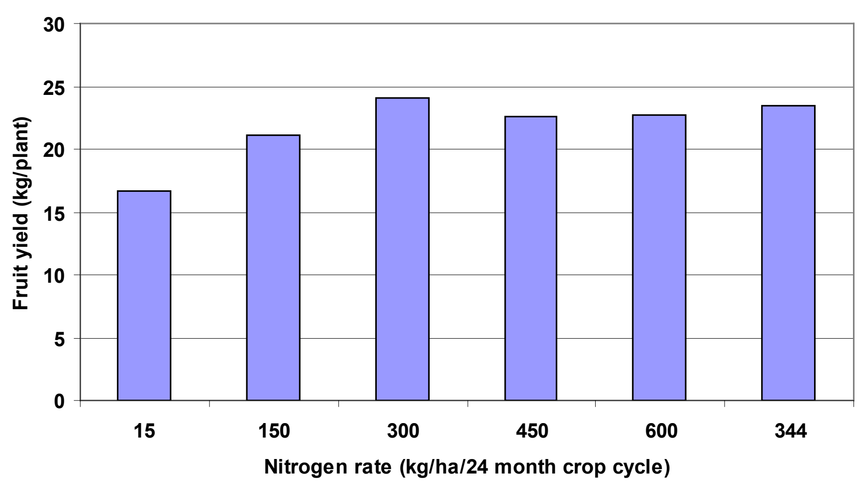

Figure 4. The influence of nitrogen rate on papaya fruit yield described by University of South-eastern Philippines. Yields differences were reported as not significant ($P < 0.05$; Appendix 11.3.1, Table 4).

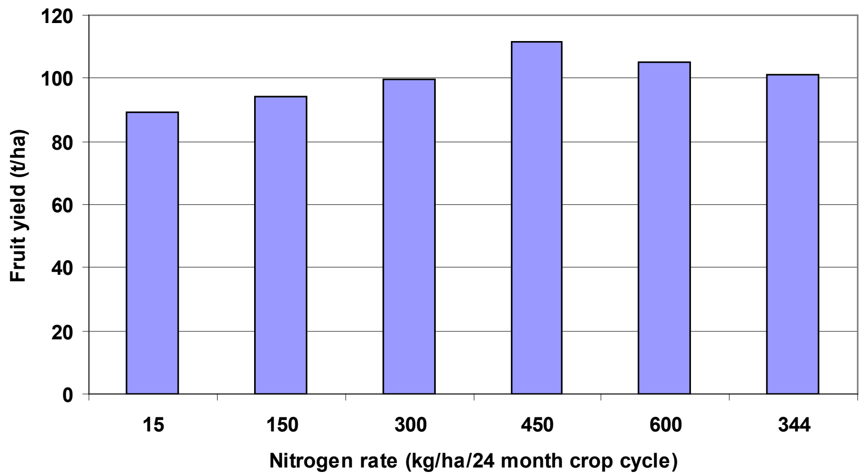

Figure 5. The influence of nitrogen rate on papaya fruit yield described by Del Monte Philippines Inc. Yields differences were reported as not significant ($P < 0.05$; Appendix 11.3.2, Figure 4).

Best management practices for papaya nitrogen fertilization

A best management practice approach to papaya fertilization that integrates the principles of optimum rate, rate synchronized with plant requirement, and nutrient delivery by precise application technique was clarified from the literature (Appendix 11.3.4). The approach is unproven, and limited knowledge about important elements prevents its recommendation for commercial culture (e.g. optimum N rates under fertigated nutrient management, techniques that match rate and plant growth, and rapid diagnostics).

Dry matter accumulation (DM(t)) and cumulative consumption ($Q(t)$) curves provide a scientific basis for matching N rate to plant growth (Bar-Yosef, 1999), however the use of these curves for managing papaya N nutrition is a new approach that has not been reported in the literature. Richards et al. (1998) defined DM and nutrient uptake curves for papaya on the wet tropical coast of North Queensland. A revised form of this function was used in the N rates study in Australia.

Treatment responses suggest that rates applied above 15.5 kg/ha (the lowest rate) during Stage 1 exceeded plant requirement, particularly as 10 kg/ha was potentially available as mineralised N at the beginning of the trial. At 98 days after planting, when plants began developing floral buds, there was no significant differences between treatments for plant height, but the percent of plants with floral buds for the lowest rate was 32% less than the other treatments ($P = 0.051$), which had similar proportions of floral buds. This effect was not evident one week later however, when all treatments had similar ($P = 0.564$) proportions of plants with floral buds and sufficient flowering plants to allow thinning of most planting sites in each treatment. Cumulative N uptake as determined by Richards et al. (1998) for Stage 1 was 6.65 kg/ha.

Suboptimal petiole N concentration (indicating N deficiency) during Stage 2 (Table 7) and associated effects (30% of floral sites not bearing fruit at the highest N rate, and yield response showing no strong evidence of a plateau; Table 8) suggest potential for higher yields. It is not known if rates were limiting during Stage 2, or other factors operated to compromise rate response (e.g. application method, rainfall).

Table 7. Petiole total nitrogen concentration at two sampling times (data extracted from Table 2, Appendix 11.3.5).

Nitrogen rate (kg N/ha/24 months)	Sampling date	
	13/12/2011	13/3/2012
	Total N concentration (%)[1]	
220	0.43 d	0.59 bc
260	0.43 d	0.60 bc
340	0.44 d	0.64 ab
460	0.46 d	0.68 ab
620	0.49 cd	0.76 a

Interaction between treatment and sampling time significant (*P* = 0.047). Means within a sampling date and within treatments across sampling dates not followed by a common letter are significantly different (*P* = 0.05; lsd = 0.14). [1]Adequate concentration 1.3−2.5% (Reuter & Robinson, 1986).

There is economic and environmental justification to research DM(*t*) and Q(*t*) curves for papaya production in North Queensland, particularly for planting dates where Stage 2 coincides with the monsoon season (January to April). A comparison of N rates applied by industry during Stage 2 and that predicted by N uptake (Richards et al., 1998) shows that industry rates could exceeded N uptake by up to 58 kg N/ha during this period (Appendix 11.3.4).

Table 8. The effect of nitrogen rate on agronomic attributes during Stage 2 (data extracted from Table 2, Appendix 11.3.5).

Nitrogen rate (kg N/ha/24 months)	Percent fruiting axils	Total fruit weight (kg/plant)
	P < 0.001	*P* < 0.001
220	23 d	8.5 d
260	31 cd	14.2 cd
340	36 c	16.5 c
460	53 b	29.1 b
620	68 a	45.0 a
5% lsd	8.7	7.3

Means within a column not followed by a common letter are significantly different (*P* = 0.05).

'Quick test' papaya sap analysis

'Quick test' plant nutrient analysis concepts are relevant to crops that are fast growing and intensively managed, which is consistent with the nature and commercial culture of papaya. Research of 'quick test' techniques undertaken in this project was based on the RQflex 10 sap analysis system previously evaluated in papaya by Richards et al. (1998).

Both USep (Appendix 11.3.1) and DMPI (Appendix 11.3.2) tested the system in their N rates trials. The DMPI work was more extensive; RQflex 10 tests were made on several occasions over the duration of the crop, and tests were made at the same time as total N assessments. Unfortunately, the two assessment methods were not compared to understand which of the two was more sensitive in discerning N rate. Mean data for RQflex 10 tests however, describe a consistent trend for each of the 5 testing occasions of increasing NO_3^- concentration with increasing N rate, demonstrating the potential of the test.

'Quick test' technology has potential in the Philippines where plant analytical services are not well developed. The RQflex 10 test procedure is not complicated, and advances in sap extraction technique (described below), means the RQflex 10 system can be use in remote locations, not requiring electrical power. Further development of the system in the Philippines should focus initially on training in sap extraction and test procedures, and then reaffirming the capacity of the test to differentiate plants of different N status under rain-fed culture. The latter work could also define provisional NO_3^- concentration adequacy standards at important phenological stages.

The Australian research focussed on improving the method of sap extraction from petioles (index tissue) because the current technique was cumbersome and potentially less adaptable to in-field use (Appendix 11.3.6). An improved technique was designed that efficiently extracts sufficient volume for the RQflex 10 test, and is highly adaptable to in-field use where electrical power is not available.

Nitrate concentration of sap extracted by the developed technique, as measured by the RQflex 10, discriminated plants growing under different N rate regimes. In addition, good relationships between the RQflex 10 and commercial laboratory analysis indicates that the sap extraction/RQflex 10 system could be used as an alternative to laboratory analysis which has a turnaround time, from field sampling to receipt of test results, of up to 3 weeks.

Improvement of sap extraction and verification that derived sap will discern plants of different N status are important steps in the process of developing the RQflex system as an alternative to total N assessment by dry matter, and for in-field use. Further research is now needed to define adequate NO_3^- concentrations at important phenological stages to allow plant N requirement to be interpreted and managed over the life of the crop.

4. To determine the role of plant nutrition in the integrated management of diseases of papaya

The relationship between plant nutrition and disease development in papaya was assessed during the second year of the crop. A study conducted by a thesis student at the University of South-eastern Philippines investigated if high rates of nitrogen affect the incidence of stem-end rot disease in papaya fruits. Six rates of nitrogen, 15, 150, 300, 344, 450, and 600 kg N/ha were assigned to a randomized complete block design. Five fruit were sampled from five trees per plot at weekly intervals for ten weeks and stored at room temperature. Five days after each harvest, the percentage incidence of stem-end rot and the total soluble solids per fruit per treatment were assessed. Results were analysed using a linear regression analysis. A positive response occurred between the incidence of stem-end rot and increases in the rate of nitrogen. A similar positive relationship occurred between total soluble solids and increasing rates of nitrogen. There was also a positive linear relationship between the incidence of stem-end rot and the total soluble solids or sweetness of papaya fruit. However, there was no linear relationship between the number of marketable fruit and increasing rates of nitrogen. Nitrogen applied at 300 and 344 kg/ha gave the greatest number of marketable fruit. There were no significant differences between the level of nitrogen applied and spider mite population development in this trial.

Results from glasshouse pot trials conducted in Australia showed that high rates of nitrogen did not increase the incidence and severity of *Phytophthora* root rot in papaya seedlings. The results from one of the trials are given in Table 9.

Table 9. Effect of four rates of nitrogen on the number of days to wilting (due to root rot) in 12-wk-old papaya seedlings grown in four dilutions of *Phytophthora* -infested soil.

% infested soil	Rates of nitrogen (g)			
	1.35	2.10	3.15	4.20
0	34.0 a	34.0 a	34.0 a	34.0 a
4	31.8 a	30.8 a	30.4 a	31.8 a
20	29.8 a	30.8 a	32.0 a	30.8 a
100	8.4 d	14.4 c	15.0 c	22.8 b

[B]Means followed by the same letter in columns or rows are not significantly different.

5. To package and disseminate a package of technology (ICM strategies) for papaya

Several planning meetings were held in Davao City and Cagayan de Oro City. Information on papaya production practices was gathered from the baseline surveys and workshops with growers.

The team participated in a workshop on *Phytophthora* diagnosis and management in durian, jackfruit and papaya. Flyers, leaflets, posters, lecture handouts, and Powerpoint presentations on nutrient, pest and disease management were some of the extension materials presented to growers at workshops and field days in Northern Mindanao (10-15 growers attended from each region) and at a forum held at Tupi in South Cotabato (54 growers attended). Information on new papaya growing technologies, identification of insect pests and diagnosis of diseases was shared with growers during field walks and farm visits.

Technical demonstration plots established at DMPI showed that natural populations of beneficial insects such as *Stethorus,* spiders and other natural enemies could keep the pest mite population below damaging levels. Other demonstration plots designed and implemented with the help of growers were conducted at Tupi, South Cotabato to show-case the ‘best bet practices’ of papaya IPM.

8 Impacts

8.1 Scientific impacts – now and in 5 years

The scientific impacts from the research conducted in Component 3 were that;

- the pests, diseases and natural enemies of papaya were properly identified and the partial characterization of bacterial crown rot and its causal organism, *Erwinia papayae* was achieved. Now that *E papayae* has been confirmed as the cause of BCR and a technique has been developed which assures the successful and consistent recovery of the BCR pathogen, future research into the IDM of BCR can be commenced. The confirmed identity of the BCR pathogen is also important to Australian biosecurity as it provides knowledge of recovery methods to use in the event of a BCR incursion.
- significant yield increases could be achieved in controlling the foliar disease ‘choco spot’ with fungicides in the Philippines. This is a new finding for the Philippines and has been well received by growers of ‘Solo’ papaya for export in southern Mindanao.
- optimal yield could be achieved in yellow processing F1 hybrids following the application of 450 kg N/ha over a period of 24 months.
- high N fertilization was shown to increase stem-end rot in red fleshed papaya. This knowledge is new to papaya production in the Philippines and Australia and should help prevent stem-end rot in the cultivar ‘Sunrise Solo’ grown for the fresh market.
- the Reflectoquant RQflex x10 (Merck) meter can be used to monitor petiole NO^3 levels in papaya.
- high N fertilization does not increase mite damage on papaya.
- dithiocarbamate fungicides can be damaging to mite predators. Consequently, there is a need for fungicides which do not harm mite predators so a greater use can be made of beneficial insects.
- the biocontrol agents, *Stethorus* beetles and predatory mites were identified as having potential in controlling pest mites.

8.2 Capacity impacts – now and in 5 years

At the commencement of the Component, none of the Philippine researchers had experience in working with papaya and papaya-related issues. As the component activities progressed, collaborative links were formed between the plant nutritionists, plant pathologists and entomologists and technical skills were developed. Adelfa Lobres, a junior plant pathologist based at BPI, Davao received training in papaya disease diagnostics during a visit to the BPI research facility by Lynton Vawdrey, Principal Plant Pathologist. Anthony Young (Bacteriologist) developed a protocol for the accurate recovery of the *E. papayae* from BCR affected papaya and used this to train plant pathologists involved in the component. A Powerpoint presentation (Appendix 2) on the recovery protocol was used in the training process. The ‘Threat specific contingency plan – Bacterial crown rot (*Erwinia papayae*) developed for the Australian papaya industry (Section 10.2) was written as a result of Lynton Vawdrey experiencing first hand the devastating effects of BCR in the Philippines. The knowledge of this disease outlined in the contingency gives Australian growers and Australian biosecurity the capabilities which enable early detection of BCR thus lessening the risk of an outbreak damaging regional production. Plant nutrition staff at USeP and DMPI received training from Pat O'Farrell, Plant nutritionist in the use of the Reflectoquant RQflex x10 (Merck) meter to monitor petiole NO_3 levels in papaya. Other capacity impacts included;

- training project staff in *Phytophthora* diagnosis and management
- four Bachelor of Science student's completing their thesis on stem end rot, mite infestation, choco spot infection and N nutrition in solo papaya at USeP and one graduate student's thesis on scarring beetles
- developing collaborative links between private growers, LGU's and NGO's (Del Monte Pty Ltd, Sumifru and Tupi Papaya Growers Association of South Cotabato).
- farmers gaining knowledge on the pests, disease, natural enemies' identification and pest and disease management
- farmers learning the importance of nutrition to the growth and yield of papaya enabling them to make informed decisions which will benefit the papaya industry at large.

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

<u>Philippines</u>

The provision of technical assistance to small-holder papaya farmers in Mindanao will increase their production, reduce losses and produce quality papaya fruits which will have economic benefits.

Baseline practices and financial data were collected and 'without technology' gross margins prepared. The 'with technology' gross margins were not finalized as obtaining the data from production people was delayed and there was no economist available to complete the analyses.

<u>Australia</u>

An economic study estimated that when the fallow period was used to control *Phytophthora* in Australian papaya was reduced from 4 years to 3 years and the production cycle was reduced from 7 to 6 years, the changes would be very profitable (see C5 final report),

A C5 (fruit component) economic analysis in 2009 estimated the benefit: cost ratio of the 2003-09 research into *Phytophthora* control was 49:1 and net present value of the research was $28.5m.

Gross margins were prepared in 2009 for papaya production with and without control of *Phytophthora* and they showed gross margins were respectively -$15,912 and +$46,484 /ha respectively for yellow Queensland papaya and -$22,672 and +$18,770 /ha for red solo papaya (see C5 report).

8.3.2 Social impacts

An increase in income from improved yield and reduced inputs will help to improve farmer livelihoods and will have a flow-on effect to the wider community. Increased productivity by larger landholders will increase employment opportunities for rural labourers. Component activities have seen a strengthening of farmer/researcher partnerships in the area of pest and disease management and plant nutrition. There has also been an improvement in communication and trust amongst all stakeholders and a willingness to be involved in further research activities which will benefit small-holder farmers.

8.3.3 Environmental impacts

The project identified and developed the effective use of efficacious fungicides and proper application techniques to reduce health and environmental hazards. The introduction of beneficial insects and their conservation through the judicious use of less toxic pesticides will help to reduce environment impacts. This has the benefit to the consumer of reducing residues in papaya fruit and health and safety problems for the farmer. Improvements in nutrition management such as with the timing and rates of application of nitrogen fertiliser, is evidence of good agricultural practice.

8.4 Communication and dissemination activities

Phytophthora identification and management workshop in 2008

An in-depth review and planning meeting for stakeholders involved in component 3 activities was held at the commencement of the component in Cagayan de Oro on the 1-3 March 2009. Additional component review and planning meetings were held each year.

Grower surveys and workshops in Bukidnon and Misamis Oriental in 2009 (10-15 growers at each workshop) involved the following;

- The preparation and distribution of training materials, flyers and handouts on papaya ICM to smallholder farmers

Grower survey and workshop in Tupi, South Cotabato in 2011 (attended by 54 Tupi growers and contractors) involved the following;

- training in pest and disease identification and nutrient management in papaya
- the distribution of training materials, flyers and handouts on papaya ICM to farmers.

Scientific papers were published and used in oral or poster presentations at meetings, conferences, workshops and other training activities. Posters on ‘Papaya insects and mites’ and ‘Choco spot of papaya’ were presented at the Pest Management Conference in Davao in 2010. A poster on the link between high rates of N and the incidence of stem-end rot was presented at the Bohol meeting in 2011. Four oral presentations and two posters were presented at the ACIAR-PCAARRD End-of-Program Horticulture Conference in Cebu. Two oral and 5 poster presentations were made at national conferences.

A papaya production video for titled ‘Growing papaya, your guide to getting it right’ was produced for the benefit of new and experienced growers in Australia and the Philippines. As at the 14 May 2013, there had been 2900 views of the YouTube video http://youtu.be/0dIP-xmtehM.

8.4.1 List of reports, publications and workshop presentations

A list of publications is given in section 10.2 of this report.

9 Conclusions and recommendations

9.1 Conclusions

Red spider mites, choco spot, BCR and *Phytophthora*-related diseases were the production constraints identified by growers and contractors during the baseline survey conducted in Northern and Southern Mindanao. However by the end of the project, the disease BCR had become the greatest concern for growers.

Of the six phytophagous mites collected and identified, *Tetranychus kanzawai* is the most destructive to papaya. It is abundant in all the papaya growing areas of Mindanao. Two predatory species, *Stethorus pauperculus* beetles and the predatory mite *Neoseilus longispinosus* were identified. Both species can be raised under artificial conditions and potentially used in an IPM program for red spider mite control.

The causal organism of choco spot was identified as *Corynespora cassicola* and bacterial crown rot was identified as *Erwinia papayae*. Propineb was shown to be the most effective fungicide against choco spot out of the seven commercial products evaluated providing growers with a 114% increase in marketable yield.

Preliminary studies with BCR showed contaminant bacteria were mistakenly being used in research activities. A protocol was developed which will enable researchers to consistently recover *E. papaya* from BCR affected plants. Some evidence was obtained to show BCR can be transmitted in/on papaya seed.

In Australia, the control of *Phytophthora* root rot is largely dependent on the use of mounds, pre-transplant applications of metalaxyl-M and post-transplant applications of potassium phosphonate. Results from this recent research has shown the chemical dimethomorph to be as effective as metalaxyl-M as a pre-transplant treatment. In addition to this, the growing and incorporation of the biofumigant crop Canola KBNSR1.3 reduced the severity of *Phytophthora* root rot in papaya seedlings. Growers will be encouraged to plant canola in *Phytophthora*-infested ground during the cool winter months prior to transplanting papaya.

The data obtained in the effective control of *Phytophthora* fruit rot with copper hydroxide will be used in a minor-use permit application to the APVMA.

Research by USeP and DMPI showed that 300 and 450 kg N/ha gave maximum yield of fresh and processing papaya, respectively. The USeP findings should not be recommended yet because the research was terminated prematurely due to water-logging and disease influence on plant growth. DMPI will adopt their findings for production of processing papaya in northern Mindanao. Further research in the Philippines of application frequency and CRN technologies could improve yield response to these rates.

A best management practice approach to papaya fertilization was clarified from the literature and applied in N rates research in Australia. Plant response in Stage 1 (planting to flowering) suggests that rates above 15.5 kg/ha (during this stage) exceeded plant requirement. The yield response asymptote was not described by the research, and it is not known whether this was due to the range of rates tested or other factors.

‘The Merck Reflectoquant® RQflex 10 rapid nutrient (plant sap) test was shown, in both the Philippines and Australia, to be a potential plant N monitoring tool. An efficient method of sap extraction was developed that makes the analysis test system adaptable for in-field use where electrical power is not available.

In the Philippines, no relationship was found between N rate and the incidence and severity of choco spot and red spider mite damage in either fresh or processing papaya. However, the incidence of stem-end rot was shown to increase with increasing rates of N. In glasshouse studies in Australia, no relationship was found between N rates and the incidence and severity of *Phytophthora* root rot.

9.2 Recommendations

1. Bacterial crown rot has spread rapidly in the papaya producing regions of Mindanao and has caused significant losses for many smallholder farmers. Thus successful recovery and study of the BCR pathogen is critical to the development of a successful management strategy for this disease. Scientists in the southern Philippines would benefit greatly from training in plant disease diagnostics.

2. That further research be conducted into benefits of releasing mite and beneficial insects for the management of pest mites. Due to the successful mass rearing of the mite predators *Stethorus pauperculus* (predatory beetle) and *Neoseiulus longispinosus* (predatory mite) further research into control the red spider mite should involve the release of these predators and the monitoring of predator and pest mite populations on grower properties in various papaya growing regions.

3. That the Fertilizer and Pesticide Authority be encouraged to seek registration of propineb for choco spot control. Further research needs to be conducted by researchers at BPI, Davao and the relevant chemical company to obtain data for the Fertilizer and Pesticide Authority for the registration of propineb for choco spot control.

4. Growers in Australia will be encouraged to plant canola in Phytophthora-infested ground during the cool winter months prior to plant papaya as part of the integrated disease management of Phytophthora fruit rot.

5. A minor-use permit be obtained for copper hydroxide use in Australia.

6. DMPI report that they will recommend 450 kg N/ha for a 24 month crop cycle for processing papaya production. An economic assessment of this strategy would determine whether the additional rate (30% higher than industry) is offset by the higher returns derived from a 10% improvement in yield.

7. Further research be undertaken to evaluate improved N use efficiency in the Philippines eg. by more frequent applications or by using CRN technologies. In Australia, further research is required to develop practical methodologies to scale overall crop rate to temporal plant requirement.

8. Further refinement of Merck Reflectoquant® RQflex 10 ‘quick’ plant analysis technology for monitoring plant N status.

‘Further development of the system in the Philippines should focus initially on training in sap extraction and test procedures, and then reaffirming the capacity of the test to differentiate plants of different N status under rain-fed culture. The latter work could also define provisional NO_3^- concentration adequacy standards at important phenological stages.

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10.2 List of publications produced by this project

The Philippines

Scientific publications

Arcelo, Mercedes M, Valeriana Justo, Gorgonio Quimio and David Astridge (2013). Population dynamics of red spider mites Tetranychus kanzawai on 'Solo' papaya in Southern Mindanao. Pp. 72-78 In. Oakeshott J. and Hall D. (eds) 2013. Smallholder HOPES—horticulture, people and soil. Proceedings of the ACIAR–PCAARRD Southern Philippines Fruits and Vegetables Program meeting, 3 July 2012, Cebu, Philippines. ACIAR Proceedings 139. Australian Centre for International Agricultural Research: Canberra. 298 pp.

Balendres M, Dela Cueva F, Justo V. (2011). Revisiting papaya diseases: the case of bacterial crown rot in the Philippines. Proceedings of Annual Conference for the Philippine Fruit Association, Cebu City.

Balendres MA, de la Cueva F and Justo V. (2012). Characterization of *Erwinia* sp. causing bacterial crown rot disease of papaya in Southern Philippines. Submitted to the *Journal of Plant Pathology* (Italian Society of Plant Pathology) for review.

Herradura, Ma. Lorna E., Adelfa N. Lobres, Cyril B. Montiel and Lynton L. Vawdrey (2013). Recovery and pathogenicity of Corynespora cassiicola in papaya and field evaluation of fungicides for its control. pp 65-71. In. Oakeshott J. and Hall D. (eds), 2013. Smallholder HOPES—horticulture, people and soil. Proceedings of the ACIAR–PCAARRD Southern Philippines Fruits and Vegetables Program meeting, 3 July 2012, Cebu, Philippines. ACIAR Proceedings 139. Australian Centre for International Agricultural Research: Canberra. 298 pp.

Quimio, Gorgonio M., Valeriana P. Justo, Fernando N. Banuag and David P. Astridge (2013). Seasonal dynamics of mites infesting papaya in Northern Mindanao pp. 79-88. In. Oakeshott J. and Hall D. (eds) 2013. Smallholder HOPES—horticulture, people and soil. Proceedings of the ACIAR–PCAARRD Southern Philippines Fruits and Vegetables Program meeting, 3 July 2012, Cebu, Philippines. ACIAR Proceedings 139. Australian Centre for International Agricultural Research: Canberra. 298 pp

Velos, Jessica R. Lilethee U. Malabug and Luther John R. Manuel (2013). Sustainable nutrient management strategies for papaya production in the southern Philippines: nitrogen fertilisation program. pp 59-64. In. Oakeshott J. and Hall D. (eds) 2013. Smallholder HOPES—horticulture, people and soil. Proceedings of the ACIAR–PCAARRD Southern Philippines Fruits and Vegetables Program meeting, 3 July 2012, Cebu, Philippines. ACIAR Proceedings 139. Australian Centre for International Agricultural Research: Canberra. 298 pp

Conferences

Oral presentations:

Arcelo M, Justo V, Quimio G. (2012). Population dynamics of red spider mite *Tetranychus kanzawai* Kishida on Solo papaya in Southern Mindanao. End-of-program Horticulture Conference, Cebu, Philippines.

Balendres MA, de la Cueva F and Justo V. (2011). Revisiting papaya diseases – the case of bacterial crown rot in the Philippines. Proceedings of the Annual Conference for the Philippine Fruit Association. Cebu City.

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11 Appendixes

11.1 Appendix 1: Mites and beneficial insects

Mite Infestation Index (MII) was used at the end of each fortnightly sampling period to estimate the level of mite infestation to 3 leaf positions within the canopy. These included; (1) the first fully expanded leaf from the top, (2) the middle leaf and (3) the bottom leaf positions on each papaya plant.

1- clean, no mites withn 2” circumference

2- 10 mites within 2” circumference

3- 11-20 mites

4- 21 to 50 mites

5- >50 mites

Mite Damage Index (MDI):

1 – clean, no damage

2 – slight damage, water-soaking and pin head spot chlorosis

3 – moderate damage, corky latex oozing, spot chlorosis

5 – severe damage, shot holes, latex oozing, bigger necrotic tissues

11.2 Appendix 2: Plant disease

11.2.1 Powerpoint presentation of the 'Methodology for the successful recovery of the bacterial crown rot pathogen *Erwinia papayae*

Easy Guide
to Isolating
Plant Pathogenic Bacteria

Anthony Young
Agri-science, Queensland
Department of **Employment, Economic Development** and **Innovation**

anthony.young@deedi.qld.gov.au

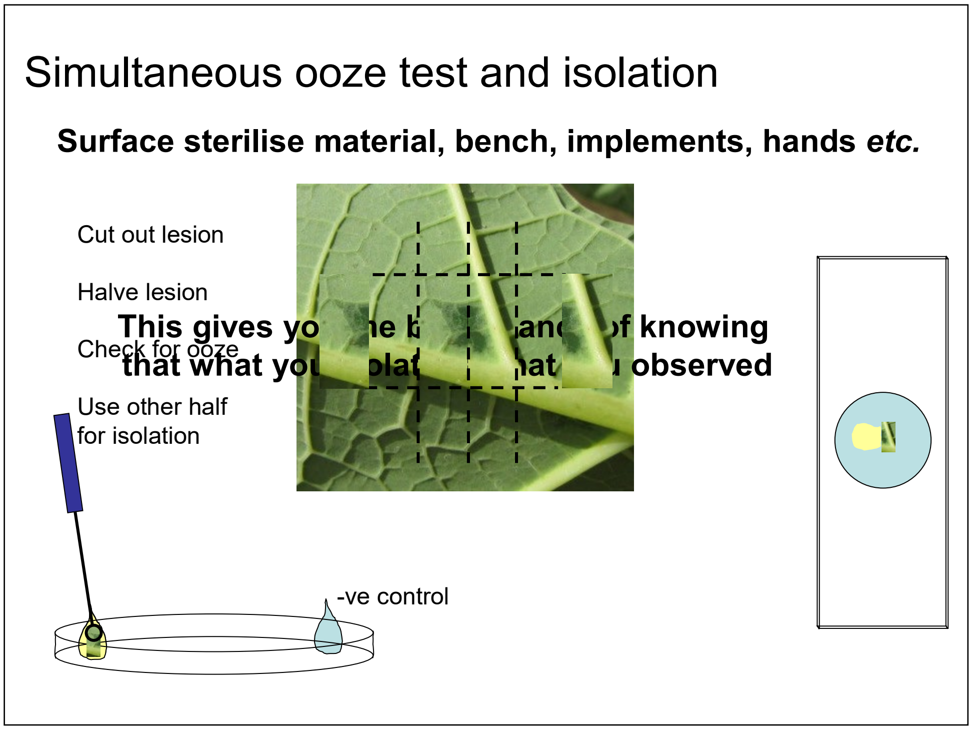
How to isolate *Erwinia papayae*

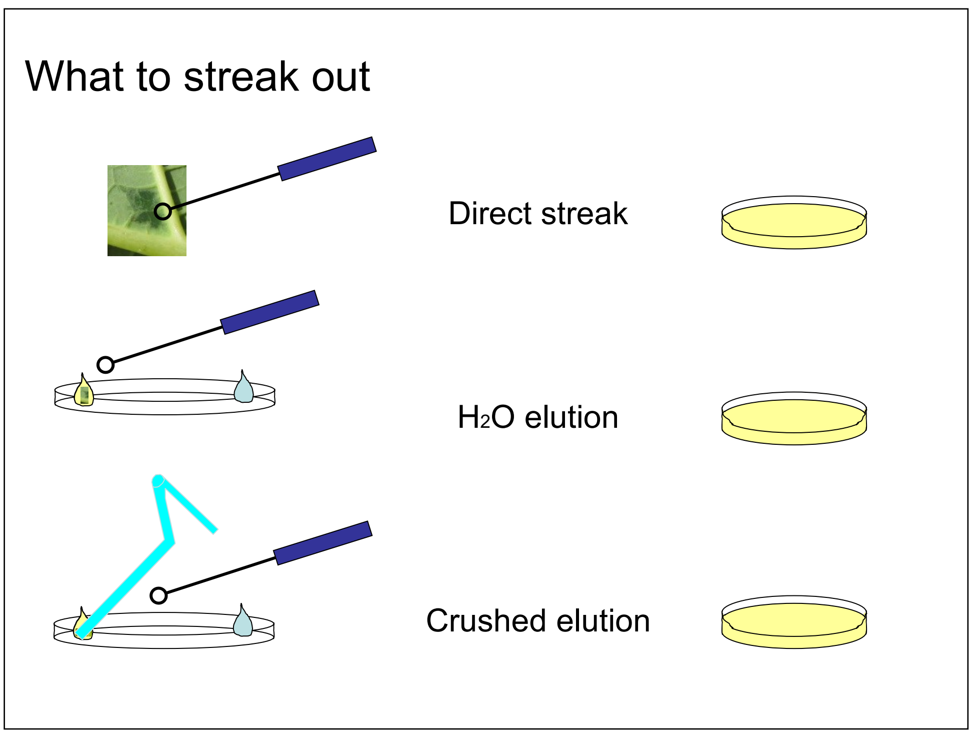
Select newly-infected material

Too late: many opportunistic bacteria and saprophytes present

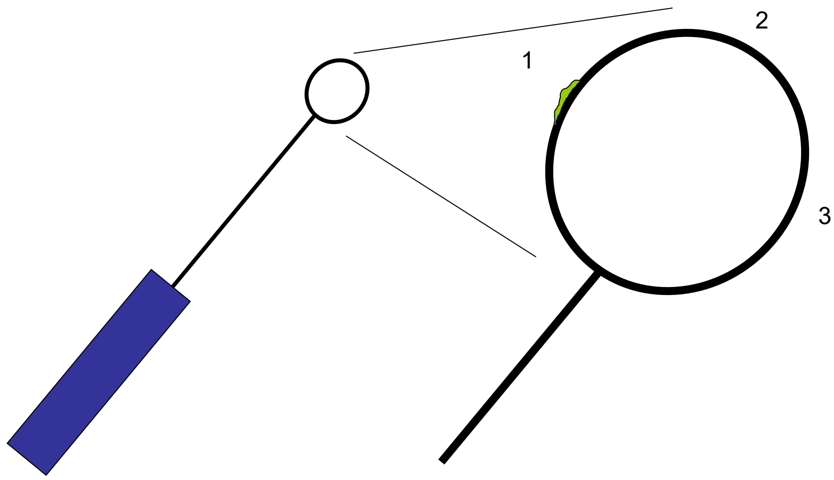
Okay: but other bacteria may have invaded the tissue

Perfect: fresh lesion only contains causal agent, no time for others


Simultaneous ooze test and isolation
Surface sterilise material, bench, implements, hands *etc.*
Cut out lesion
Halve lesion
Check for ooze
Use other half
for isolation
-ve control

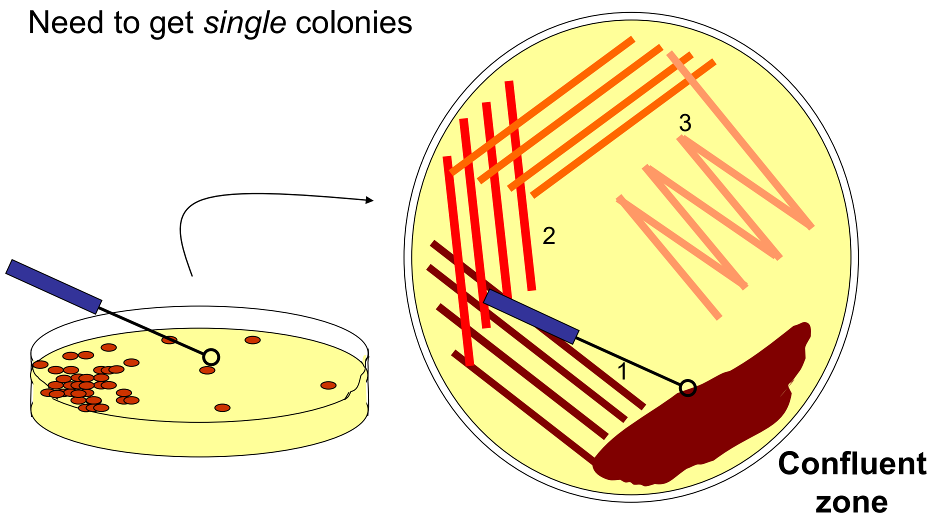

What to streak out
Direct streak
H_2O elution
Crushed elution

Fast 12+ streak



Streaking

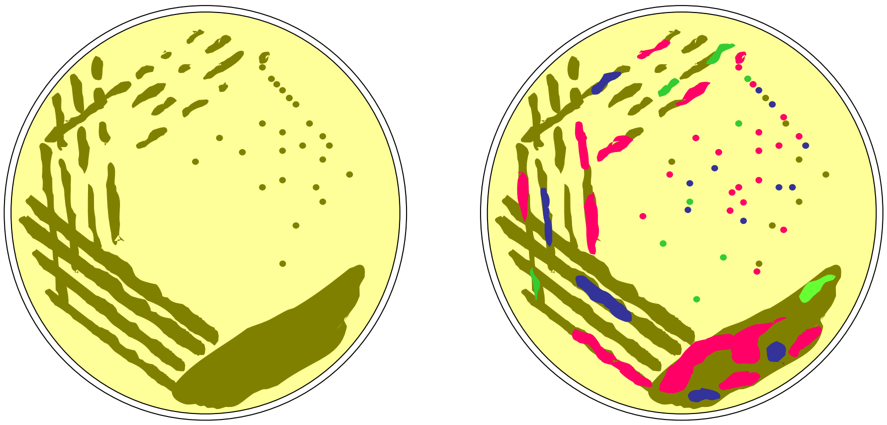
Need to get *single* colonies



Good or bad isolation?

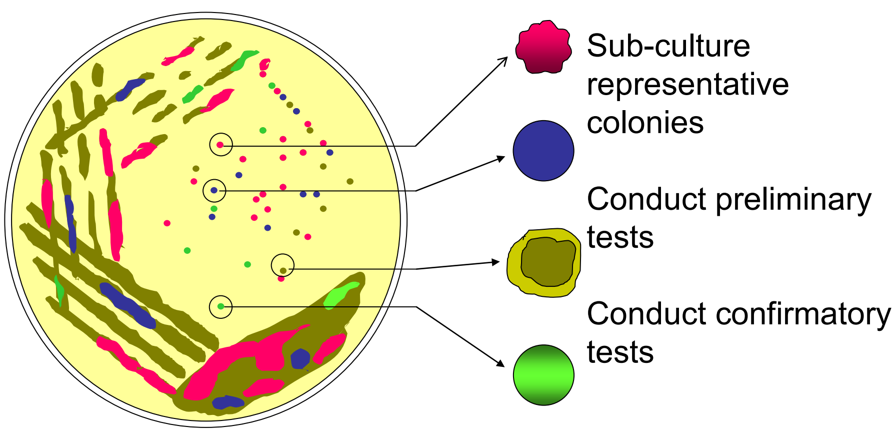
Relatively uniform culture indicates target is isolated

Mixed culture often means poor isolation

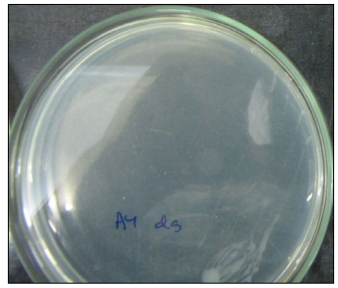


Always streak single colonies

Examine colonies with *stereomicroscope*
- -incidental light
- -transmitted light



Properties of *Erwinia papayae*



Poorly described bacterium

Need to take great care with ID

Watery and grey on nutrient agar

Not clearly defined colonies
-small, slow-growing (2-4 days)

Does not cause potato soft rot

Gram negative

Highly pathogenic to papaya

11.3 Appendix 3: Plant nutrition

11.3.1 Sustainable production of high quality papaya fruit in the Southern Philippines through nitrogen management

A report of progress of nitrogen rates research at the University of Southeastern Philippines, Mabini Campus.

Ma. Asuncion L. Salibay and Rosalino B. Recto, University of Southeastern Philippines.

1. Introduction

Papaya is one of the most important economically and nutritious fruit in the country. Philippines has a total area of 9,125 hectares planted to papaya and produced 164,233 metric tons/yr. The bulk of production is located in Southern Philippines particularly SOCCSKSARGEN, Northern Mindanao and Davao Region which produced 101,000 metric tons in 2007 (BAS, 2007). The fruit is one of the country's major fruit export crops of which Japan is the major market for fresh fruit. Papaya is also utilized as dried fruit and exported mainly to Hong Kong and Australia. China, Saudi Arabia, United States, Germany and New Zealand are also export markets of papaya. Papaine, a proteolytic enzyme that is extracted from green papaya is also used for food preparations, nutraceuticals and cosmetic industries and now shows economic potential for both local and export markets (PCARRD, 2006).

Solo, Cavite Special, Legaspi Special, Morado, Sinta and the Sinta hybrid are the most common cultivars used in the country. Papaya is grown throughout the country primarily by small-scale farmers with a farm size ranging from 0.25 to 3 hectares. It is also grown in commercial plantations, of which the largest plantations are managed and owned by Del Monte, Dole and Sumifru.

Papaya grows rapidly in the first six months after planting, hence it needs proper nutrition at the right amount and the right time. Adequate and efficient manuring and fertilization of young and mature papaya tree is essential to maintain the health of the fruit and to obtain high yields. It responds positively to nitrogen (N), phosphorus (P) and potassium (K) application as well as to micronutrients particularly boron. Since papaya grows vigorously and continuously, it has a continuous demand for nutrients. Commercial papaya plantations rely on the use of inorganic fertilizers to obtain high yields. However, over-application of inorganic fertilizers can damage the soil as well as affect the fruit. Although, the fertilizer recommendation for papaya has already been established, there are still some parts in the region that produce low yields. Hence, there is a need to determine the appropriate fertilizer rate for optimum production of papaya.

Research began in mid-2009 to design and implement sustainable N management strategies to improve the yield and quality of Solo papaya. This report describes progress of the research to December 2010 (approximately 16 months after planting).

2. Objectives

The research had two objectives: to determine appropriate rates of N to optimize growth, yield and fruit quality of papaya, and to determine the reliability of rapid diagnostic tests for assessing plant nitrogen status and plant tissue nutrient standards for N fertilization.

3. Methodology

The experimental site was located at the University of Southeastern Philippines, Mabini Campus, Mampising, Mabini, Compostela Valley Provence. The site has an annual rainfall of 2,000–2,300 mm/year and an average temperature of 24–32°C. Assessment of soil (10–15 samples) collected at 0-15 cm and 15-30 cm depths prior to the start of the experiment described the soil of the experimental site as clay loam based on particle size analysis (Table 1), and having a pH and organic matter content of 5.85 and 0.75%, respectively.

Table 1. Particle size analysis (%) and textural class of soil sampled from the experimental area prior to the start of the experiment.

Sample	Silt	Sand	Clay	Textural class
1	48,6	20	31,4	Sandy Clay Loam
2	46,6	22	31,4	Sandy Clay Loam
3	42,6	26	31,4	Clay loam

Table 2. Treatments of the nitrogen rate experiment designed for a 24 month crop cycle.

MAP[1]	Treatment (N rate, kg/ha)					
	15	150	300	450	600	344[2]
1	0,3	3	6	9	12	15,5
2	0,45	4,5	9	13,5	18	23,5
3	0,45	4,5	9	13,5	18	39,1
5	1,2	12	24	36	48	46,8
7	1,35	13,5	27	40,5	54	
8						54,8
9	1,5	15	30	45	60	
11						54,8
12	2,25	22,5	45	67,5	90	
14						54,8
15	3	30	60	90	120	
17	1,95	19,5	39	58,5	78	54,8
20	2,55	25,5	51	76,5	102	

[1]Months after planting. [2]Control (industry practice).

The experimental design was a randomized complete block consisting of 6 treatments with 5 replications, for a total of 30 plots. A fresh eating (yellow fleshed) bisexual variety called Solo 'Capoho' was used for the experiment. The plants were planted in single rows at a distance of

2 m intra-row, 3 m inter-row (1667 plants/ha). Planting dates for the five replicates of the experiment were influenced by weather conditions and the timing of land preparation. Replicates 1 and 2 were planted on July 31, replicate 3 on August 11, replicated 4 on August 29, and replicate 5 on November 30.

Treatments (Table 2) were designed for a 24 month crop cycle and were applied at various months after planting (MAP). The application of treatments 15, 150, 300, 450, and 600 kg N/ha was scheduled over 20 months, with 48% of the total rate for the crop applied during the first 12 months. The control (industry practice), 344 kg N/ha, was scheduled over 17 months, with 65% of the total rate for the crop applied in the first 12 months.

Data gathered and assessments

Data were recorded from 10 permanent sample plants in each plot as follows.

- Soil physical and chemical properties.
- Petiole nutrient concentrations.
- Plant height, stem girth, and height of the first fruit (6 and 12 MAP).
- Yield (fruit number, weight and grade).
- Fruit quality for fresh fruit (brix, acid and pulp colour).
- Disease incidence (tree and fruit).

Height to first fruit was taken by measuring the height from the ground to the lowest hanging fruits.

Soil samples were collected at 12 MAP for measurement of nitrate, pH, organic matter content, and P and K concentration. Leaf petiole samples were collected at specific plant ages for nutrient analysis – N concentration (at 8, 10, and 15 MAP) and N, P,K, calcium (Ca), magnesium (Mg), zinc (Zn), copper (Cu), Iron (Fe) boron (B) and manganese (Mn) (at 6 and 12 MAP).

A comparison of the Reflectoquant® RQflex 10 (a rapid sap nitrate analysis test) with conventional analysis of petiole N concentration was planned to determine the reliability of the test. However, the capacity of the test to differentiate N rate treatments was tested in the laboratory to gain experience with the test procedure and the method of collecting sap samples.

Uniform application of inputs and care and maintenance were implemented in the field except for N treatments. Ammonium sulfate (21% N) was the main source of N, while muriate of potash was the main source of K at a rate of 700 kg K/ha. Zinc sulfate and Inkabor® were applied to supply Zn and B.

Data were analysed using analysis of variance, and differences between treatment means were evaluated using the Honest Significance Difference test (Tukey). Replicate 5 was damaged by root rot and excluded from the analysis.

4. Results and discussion

4.1 Growth of Solo Papaya

Plants are currently at fruiting stage. Despite the large range in treatment N rates, there were no statistical differences between treatments for plant height, stem girth and height of the first fruit measured at 6 and 12 MAP (Table 3). However, distinct fruit gapping is observed now in the plants with receiving the lowest N rate.

Table 3. Growth measurements (cm) recorded from N treatments 6 and 12 months after planting (MAP).

Nitrogen rate (kg/ha)	Plant height		Trunk girth		Height of first fruit	
	6 MAP ns	12 MAP ns	6 MAP ns	12 MAP ns	6 MAP ns	12 MAP ns
15	135,18	212,08	24,52	31,40	88,89	135,43
150	137,75	216,73	24,21	30,93	84,96	138,70
300	147,10	228,29	25,91	32,75	83,31	143,98
450	136,78	205,90	24,07	31,65	78,04	131,80
600	138,38	217,50	26,19	32,18	72,03	137,03
344	141,45	209,35	26,53	31,72	71,30	136,09

4.2 Yield of Solo Papaya

Two plants were harvested during the first harvest on March 25, 2010. The mean weight of fruits/tree (yield) and mean number of fruits/tree harvested for each month April to December 2010 are presented in Tables 4 and 5, respectively. Statistically differences between treatments for yield were observed for some harvest months, however the response was inconsistent and did not reflect N rate. During the first four months of harvesting, highest yield was observed in plants receiving 344 kg N/ha. This was due to higher amount of N fertilizer that was applied during the early stage of the plant's growth as practiced by the industry growing papaya. Plants applied with the highest rate of N at 600 kg N/ha did not produce the highest yield. Lowest yield was consistently recorded for the 15 kg N/ha treatment. Mean monthly fruit weight/tree followed a similar trend to mean fruit number/tree.

There were no statistical differences among treatments for cumulative yield for the period harvested. Highest yield was recorded for the 300 kg N/ha treatment, and the lowest for the 15 kg N/ha treatment.

Table 4. Mean fruit weight (kg) of N treatments.

Nitrogen rate (kg/ha)	Month of harvest April ns	May	*	June ns	July ns	Aug	*	Sept ns	Oct ns	Nov	**	Dec	**	Total ns
15	0,65	1,37	b	3,37	2,98	2,64	b	2,99	1,99	1,65	c	0,99	b	16,63
150	1,92	2,62	ab	4,30	3,67	2,92	ab	4,54	2,30	1,81	bc	1,54	ab	21,11
300	1,56	2,95	ab	4,13	3,63	3,02	ab	5,60	2,63	3,85	a	1,16	b	24,04
450	1,85	3,36	ab	3,69	2,88	3,72	a	4,73	2,20	2,86	ab	2,51	a	22,62
600	1,57	2,84	ab	4,46	3,58	3,32	ab	5,21	2,38	2,03	bc	1,76	ab	22,76
344	2,06	3,79	a	5,76	4,09	3,01	ab	4,34	2,34	2,36	bc	1,48	ab	23,41

*** Significant at 5% level of significance using HSD.**

Table 5. Mean number of fruits of N treatments.

Nitrogen rate (kg/ha)	Month of harvest April ns	May ns	June	*	July ns	Aug ns	Sept	*	Oct ns	Nov	**	Dec ns	Total
15	1,50	2,50	5,13	b	5,28	4,80	5,88	b	3,55	3,35	b	1,90	33,51
150	3,75	4,22	6,78	ab	6,55	5,44	8,35	ab	4,03	3,45	b	2,83	43,51
300	3,10	4,81	6,21	ab	6,13	5,24	10,56	a	4,71	7,00	a	1,95	48,94
450	3,05	5,94	5,87	b	5,17	6,46	8,93	ab	4,00	5,48	ab	6,83	50,95
600	2,39	4,62	7,53	ab	6,23	5,74	9,93	ab	4,20	4,10	b	3,15	47,88
344	3,10	5,77	9,44	a	7,10	5,66	8,44	ab	4,39	4,35	b	2,70	50,94

*** significant at 5% level of significance using HSD**

4.3 Leaf nitrogen

The analysis of the leaf petiole concentration at different growth stages is shown in Table 6. The influence of the different N rates is not clearly seen on petiole N concentrations since no consistent trends were observed. Significant differences among treatments for petiole N concentration were only recorded at 8 and 12 months after planting. However, the N concentration for the different treatments for these sampling times did not reflect the amount of N that was being applied to the plants. As can be observed, plants that were applied the lowest amount of N at 15 kg N/ha sometimes have higher N in the petioles than plants applied with higher rates of N. The application of 344 kg N/ha, which is the practice of the industry showed the highest levels of N in the petioles at 8 and 12 MAP.

Table 6. Petiole nitrogen concentration (%) of nitrogen treatments, measured at 5 sampling times (months after planting).

Nitrogen rate (kg/ha)	Month of sampling				
	6 MAP ns	8 MAP	10 MAP ns	12 MAP	15 MAP ns
15	0,66	0,84 b	1,07	0,79 ab	0,81
150	0,83	0,92 ab	1,07	0,82 ab	0,85
300	0,68	0,82 b	1,17	0,72 b	0,77
450	0,69	0,90 ab	1,18	0,79 ab	0,80
600	0,72	0,94 ab	1,25	0,88 ab	0,79
344	0,65	1,11 a	1,12	1,08 a	0,86
CV (%)	28,64	11,10	11,66	18,41	10,71

Richards et al. (1998) established preliminary adequate petiole N concentrations for papaya plants at different growth stages (Table 7). Petiole N adequacy ranges have also been reported by Bowen (1992) at 1.37–1.46%, Awada and Long (1969 and 1971) at 1.14–1.28, and Robinson (1986) at 1.3–2.5%.

Table 7. Preliminary adequate petiole nitrogen concentrations (%) at different growth stages (Richards et al., 1998).

Growth Stage	Nitrogen concentration
Flowering Onset	0.9
Harvest Start	1.1–1.2
Harvest plus 2 months	1.6–1.7
Harvest plus 6 months	1.1–1.2

Comparing the data from the trial and the data established by different nutritionist, the project generated lower petiole N values at different growth stages. At the start of harvest (8 MAP), only plants applied with 344 kg N/ha (1.11%) had reached the adequate concentrations set by Richards et al. (1998). It can also be noted that N concentrations were highest at 10 MAP for all treatments compared with the other sampling times, which is consistent with the data of Richards et al. (1998). Petiole N concentrations fell following 10 MAP and this might be due to the decreasing frequency of N application and also due to crop removal in the form of harvest.

4.4 *Soil nitrate as nitrogen*

Table 8 shows the concentration of nitrate as nitrogen in the soil 12 MAP, and it was not affected significantly by the different rates of N applied. Soils applied with lowest N rate had the lowest concentration of nitrate, while the highest amount of nitrate was found in soils applied with 344 kg N/ha.

Table 8. Soil nitrate as nitrogen of nitrogen treatments measured 12 months after planting (MAP).

Nitrogen rate (kg/ha)	Nitrate as Nitrogen ^{ns} (mg/kg)
15	13,9
150	14,85
300	14,65
450	29,6
600	33,6
344	42,45
CV (%)	54,09

4.5 *Rapid nitrogen test*

Preliminary results of petiole nitrate concentration as evaluated by the Reflectoquant® RQflex 10 are presented in Table 9. Concentrations were not affected significantly by the different rates of N applied in the field. However, plants applied with the 15 kg N/ha had the lowest concentration and the highest was observed from plants applied with 344 kg N/ha. Concentrations recorded for the 600 kg N/ha treatment were lower than the 300 and 450 kg N/ha treatments. Further work will be done to improve the method of the sap extraction and nitrate testing to establish the reliability of the instrument for assessing N in the papaya tissues.

Table 9. Petiole nitrate concentration of nitrogen treatments as evaluated by the Reflectoquant® RQflex 10.

Nitrogen rate (kg/ha)	Nitrate as Nitrogen ^{ns}
15	12,25
150	17,33
300	30,63
450	30,50
600	21,50
344	46,25
CV (%)	59,85

4.6. Leaf phosphorus and potassium

Richards et al. (1998) and Awada and Long (1969 and 1971b) established a critical P of 0.21% in petioles and critical K at 3.65%, while Robinson (1986) established adequate P at 0.2–0.4% and K as 3–6%. In addition, Richards et al. (1998) established preliminary adequacy concentrations for K at different growth stages (Table 10).

Table 10. Preliminary adequate petiole potassium concentrations at different growth stages (Richards et al., 1998).

Growth Stages	Petiole K (%)
Flowering Onset	3.5
Harvest Start	4.0–4.2
Harvest plus 2 months	4.0–4.2
Harvest plus 6 months	3.5–4.0

Uniform phosphorus and potassium rates were implemented over the whole study area. Petiole P concentration for all treatments was at or above optimum concentrations at 6 and 12 MAP, and at both sampling times, concentrations among N rates were not significantly different (Table 11). Despite the high K application rate (700 kg K/ha the whole crop duration), petiole K concentration was below optimum for all N treatments at both sampling times. Differences in concentration among N treatments at both sampling times were not significant.

Table 11. Petiole phosphorus and potassium concentrations (%) of nitrogen treatments, measured at 6 and 12 months after planting (MAP).

Nitrogen rate (kg/ha)	Phosphorus		Potassium	
	6 MAP ns	12 MAP ns	6 MAP ns	12 MAP ns
15	0,25	0,42	1,52	3,19
150	0,27	0,33	1,76	2,94
300	0,30	0,44	1,35	2,79
450	0,24	0,44	1,58	2,49
600	0,25	0,39	1,42	2,54
344	0,22	0,38	1,28	2,32
CV (%)	16,63	9,85	18,02	16,17

4.7. Leaf calcium, magnesium and zinc

Robinson (1986) reported an adequate petiole Ca concentration of 1–2.5% and Mg concentration of 0.5–1.5%, while Bowen (1992) reported 0.24% as optimum for Ca and 0.56% for Mg. There were no significant differences among N treatments for petiole Ca and Mg concentrations measured at 6 and 12 MAP (Table 12). Calcium concentration was within the adequacy range at both sampling times, while Mg was only within the adequacy range at 12 MAP.

Table 12. Petiole calcium and magnesium concentrations (%) of nitrogen treatments, measured at 6 and 12 months after planting (MAP).

Nitrogen rate (kg/ha)	Calcium				Magnesium			
	6 MAP	ns	12 MAP	ns	6 MAP	ns	12 MAP	ns
15	1,40		1,36		0,50		0,74	
150	1,36		1,31		0,48		0,77	
300	1,36		1,19		0,48		0,73	
450	1,28		1,19		0,44		0,74	
600	1,11		1,48		0,44		0,78	
344	1,10		1,36		0,47		0,82	
CV (%)	11,89		11,73		17,56		6,76	

No adequacy ranges for Zn, B, Cu, Fe and Mn in papaya petiole exist to draw comparison with concentrations measured for the N treatments (Table 13). Uniform Zn and B were regularly applied to the trial, and no significant differences were observed among N treatments for concentrations of these micronutrients measured at 6 and 12 MAP. Of the other micronutrients measured, only Fe showed significant variation among N treatments, however concentrations were inconsistent with N rate.

Table 13. Petiole micronutrient concentrations (ppm) of nitrogen treatments, measured at 6 and 12 months after planting (MAP).

Nitrogen rate (kg/ha)	Zinc				Boron		Copper		Iron		Manganese	
	6 MAP	ns	12 MAP	ns	12 MAP	ns	6 MAP	ns	6 MAP	*	6 MAP	ns
15	11,31		18,00		25,72		3,41		19,01	b	35,20	
150	11,68		17,75		25,72		3,50		33,91	a	45,89	
300	16,34		16,50		24,84		3,49		29,04	ab	42,05	
450	13,28		16,75		23,82		3,09		23,54	ab	44,89	
600	10,84		21,25		24,55		3,03		25,38	ab	41,95	
344	12,35		16,50		22,50		3,16		28,63	ab	48,35	
CV (%)	42,14		19,74		6,88		8,94		21,04		17,63	

4.8. Soil analysis of the site

Pre-plant soil pH and organic matter of the area was 5.85 and 0.75%, respectively. At 12 MAP, there were no statistical differences among N treatments for these attributes (Table 14). There were also no statistical differences among N treatments for soil available P or exchangeable K measured at the same time.

Table 14. Soil attributes of N treatments measured 12 months after planting (MAP).

Nitrogen rate (kg/ha)	pH [ns]	Organic matter (%) [ns]	Phosphorus (ppm) [ns]	Potassium (ppm) [ns]
15	6,05	1,00	13,0	440,0
150	5,95	1,10	14,5	370,0
300	6.00	1,40	14,0	426,5
450	6,05	1,10	16,5	350,0
600	5,75	1,20	14,0	417,5
344	5,65	1,25	15,5	422,5
CV (%)	3,25	22,33	17,55	21,64

4.9. Total soluble solids

While lowest at the lowest N rate, flesh total soluble solids (a measure of the sugar content and sweetness) were not significantly influenced by N treatments (Table 15).

Table 15. Total soluble solids (°Brix) of N treatments.

Nitrogen rate (kg/ha)	Total soluble solids [ns]
15	10.75
150	11.17
300	11.18
450	11.21
600	11.10
344	11.16
CV (%)	2.80

4.10. Problems encountered and ongoing activities

Despite the installation of props to support plants, plants within replicate 5 of the trial were affected by root rot and lodging following heavy rains and strong winds. Very few permanent sample plants in this replicate remained, and thus it was excluded from the data analysis.

Fruit gapping was observed in plants.

Fruit stem end rot and ‘choco’ spot diseases that affect the quality of the fruit were considered the main problems in the trial. However, regular application of fungicides helped to reduce the affect of ‘choco’ spots.

Studies of the effect of N rate and different control measures on stem end rot incidence were conducted by USeP students. The students also monitored total soluble solids and other fruit quality characteristic, however, this information was not available for inclusion in this report.

11.3.2 Sustainable nutrient management strategies for papaya production in Southern Philippines – nitrogen fertilization program

A report of nitrogen rates research at Del Monte Philippines Inc, written for publication by ACIAR.

Jessica R. Velos, Lilethee U. Malabug and Luther John R. Manuel[1] DMPI, Camp Phillips, Bukidnon

***Abstract*. Yellow processing type papaya hybrids were tested in Bgy. Sto. Niño, Manolo Fortich, Bukidnon under 15, 150, 300, 450 and 600 kg N/ha nitrogen fertilization scheme applied periodically from 1 to 22 MAP. Total yield of yellow papaya hybrids was highest when nitrogen rate was applied 450 kg N/ha since fruit production per tree was highest at this rate. Fruit production as well as total yield declined when nitrogen was applied at 600 kg/ha. Average fruit weight, brix, fruit flesh thickness and percent cavity were all unaffected by varying nitrogen rates. Petiole NO3-N, determined using Merck Reflectoquant® *RQflex 10* at 0.09% (900mg/L) was considered detrimental to papaya while 0.02-0.04% was considered limiting.**

Introduction

The increasing cost of farm inputs specifically fertilizers and pesticides have led some papaya growers to neglect or follow the regular fertilization and proper pesticide applications. These lapses in farm management practices caused a decline in their yield and profitability and at the same time resulted in poor yield and fruit quality. Hence, proper nutrient management and control of pest and diseases to achieve the desired yield and fruit quality of papaya is needed to augment and help the papaya industry.

This trial, conducted in collaboration with the Australian Center for Agricultural Research (ACIAR) and the University of Southeastern Philippines, aim to establish the best rate of nitrogen fertilizers to maximize the yield of papaya (yellow, canning type) and establish leaf nitrogen level as indicator of the crop's nitrogen status. At the same time, the results of this trial can hasten the capability of farmers to become effective papaya farmers that can detect and correct nitrogen deficiencies at any given time.

Materials and Methods

Technical Description of Experimental Site:

The experiment was conducted in papaya grower's farm in Barangay Sto. Niño, Manolo Fortich, Bukidnon (Longitude: 124° 50' 52.83"; Latitude: 8° 23' 20.54") during the period of May, 2010 to May 2012. Experiment area had an average annual rainfall of 2,032 mm evenly distributed throughout the year. Soil of grower's farm, taken 24 cm. depth prior to planting had clayey soil texture with initial pH of 5.70 that resulted from a 20MT lime application 3months before planting; phosphorus, 15 ppm; potassium, 155 ppm; calcium, 823 ppm and magnesium, 151 ppm.

Experiment Procedure:

Field Planting and Establishment. In May, 2010, 300 seedlings of hybrid, yellow fleshed canning type papaya were planted at 3m. between beds x 2m. between hills spacing, equivalent to 0.22 hectares. Five papaya seedlings constituted one treatment. The nitrogen rates used in this trial were: 15, 150, 300, 344, 450 and 600 kg N/ha. The 344 kg N/ha represented farmer's practice. Fertilizer application started one month after planting using ammonium sulfate (21% N) as nitrogen source and potassium chloride (60% K_2O) as potassium source. During the scheduled fertilizer application (Table 1), the required amounts of ammonium sulfate and potassium chloride were applied separately in band around each papaya seedling using calibrated plastic containers and 15cm. away from the papaya base to prevent fertilizer burn.

Flowering started 3 months after planting. It was at this time when thinning was started, leaving 1 hermaphrodite seedling per hill. In the absence of hermaphrodite trees, female trees were left to maintain plant population. The height of individual papaya trees within each treatment along with corresponding trunk girth was measured per quarter quarter starting at 3 MAP to monitor its growth. Plant height was measured from the ground to the shoot apex using a meter stick while trunk girth was measured 15cm. from the base using a caliper. Other cultural management practices of the trial area such as manual weed control, chemical pest control, soil conservation and drainage maintenance were done by the farmer/grower according to his practice.

Table 1. Nitrogen rate scheduled according to plant age (months after planting; MAP), and total rate applied over the duration of the trial.

Kg N/ha	Total Amount of Nitrogen Applied by Crop Age, Kg/ha					
	4 MAP	8 MAP	12 MAP	15 MAP	19 MAP	21 MAP
15	1.2	3.8	7.5	10.5	12.5	15.0
150	12.0	37.5	75.0	105.0	124.5	150.0
300	24.0	75.0	150.0	210.0	249.0	300.0
344	78.0	180.0	289.0	344.0	344.0	344.0
450	36.0	112.0	225.0	315.0	374.0	450.0
600	48.0	150.0	300.0	420.0	498.0	600.0

Fruit Harvesting, Preparation and Evaluation. Harvesting of papaya fruits was done once per week starting at 6MAP. At 8 MAP when fruiting was at its peak, harvest frequency was increased to twice weekly at 3 days interval. During each harvest period, 50% color break (Fig. 1) papaya fruits were picked from individual trees within the treatment and weighed correspondingly. At 12 MAP, harvesting reverted to once per week frequency because of reduced fruit load. During each harvest, one fruit was collected from any of the 5 trees within each treatment plot, and taken to the analytical laboratory for measurements of cavity, flesh thickness, flesh color, and quality assessment like fruit brix and nitrate-N content. During processing, each fruit sample was immersed in plastic container filled with water up to its rim. The displaced water collected in a catchment was measured using a graduated cylinder. The fruit was then sliced into half and deseeded. Subsequently, the cavity of papaya was placed with water, again measured using a graduated cylinder. Percent cavity was computed based on volume of water contained in the fruit cavity against volume of water displaced by the entire fruit. Flesh thickness was measured by placing a ruler on the span of the flesh. Flesh color on the other hand was rated using the yellow color chart of the International Society for Horticultural Science (ISHS; Fig 1). For fruit brix a 3cm. thick section of the fruit flesh was sliced lengthwise, peeled, cubed, and pureed using a blender. Sap was extracted successively using cheese cloth, and read using a refractometer.

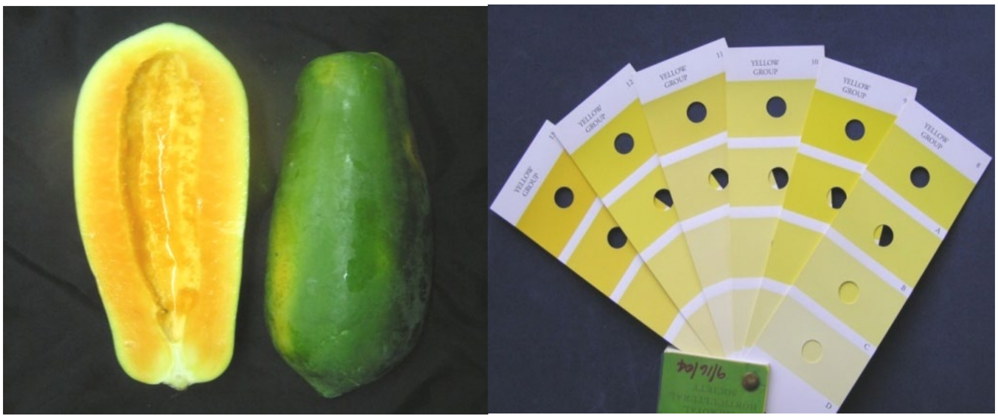


Fig. 1. Appearance of yellow papaya fruit at 50% color break and evaluated for flesh color rating using ISHS Color Chart.

Leaf Sample Preparation and Analysis. For total nitrogen and petiole NO3-N analysis, the youngest, recently mature leaf subtending a freshly opened flower was taken from one representative tree per treatment at 4, 9, 14, 17 and 20 MAP, collected from the experiment location from 0600-0700 hours. The leaves were then taken to the laboratory, washed with tap water and air dried. When leaf samples have dried, a 15cm. portion at the middle part of the petiole was cut and sliced thinly. Then 10g from thinly sliced petioles was macerated using mortar and pestle, gradually adding distilled water until 100mL of sap solution was accumulated in a volumetric flask. Then 10mL sap solution volume was transferred to a beaker where the two-band indicator nitrate strips (Reflectoquant®, 5-225mg/L NO_3^- range) was immersed for 5 seconds, inserted into the *Merck Reflectoquant®RQflex 10* meter for 15 seconds until the reading was displayed in the monitor (Fig. 2). The readings displayed from the monitor were multiplied by 10 to account for the dilution

Fig. 2. Papaya petiole sap for nitrate analysis using *Merck*

of petiole sap. The rest of the petiole samples were analyzed following Kjehdahl method of total nitrogen analysis, using Kjeltec auto distiller 2200.

Results and Discussion

Soil pH of the trial area did not decline as a result of the nitrogen application rates and remained within the range of 6.0-6.3, irrespective of treatments. The stability of soil pH 1 year after planting was attributed to the high calcium concentration of the location which greatly buffered the acidifying effect of high nitrogen application. Other soil nutrients were not affected significantly by nitrogen application, except for phosphorus which increased significantly with increasing nitrogen application rates up to 225 kg N/ha. (Table 2).

Table 2. Soil pH and soil P, K, Ca and Mg levels as affected by nitrogen application one year after planting.

Kg N/ha	pH	Phosphorus (ppm)	Potassium (ppm)	Calcium (ppm)	Magnesium (ppm)
At planting	5.7	15	155	822	150
15	6.0 *a*	9 *b*	106 *a*	1,538 *a*	151 *a*
150	6.3 *a*	10 *b*	101 *a*	1,596 *a*	125 *a*
300	6.2 *a*	11 *b*	142 *a*	1,401 *a*	139 *a*
344	6.1 *a*	12 *ab*	186 *a*	1,493 *a*	144 *a*
450	6.4 *a*	20 *a*	121 *a*	1,749 *a*	137 *a*
600	6.1 *a*	15 *ab*	192 *a*	1,297 *a*	147 *a*

In a column, means not followed by a common letter are significantly different ($P < 0.05$).

Plant height and trunk girth did not vary significantly between treatments in all crop stages measured. With emphasis on the 15 Kg N/ha treatment, papaya trees in this treatment grew just as the same with those that received >150 kg N/ha (Fig. 3). These results suggest that papaya invested more in building up its structure and biomass.

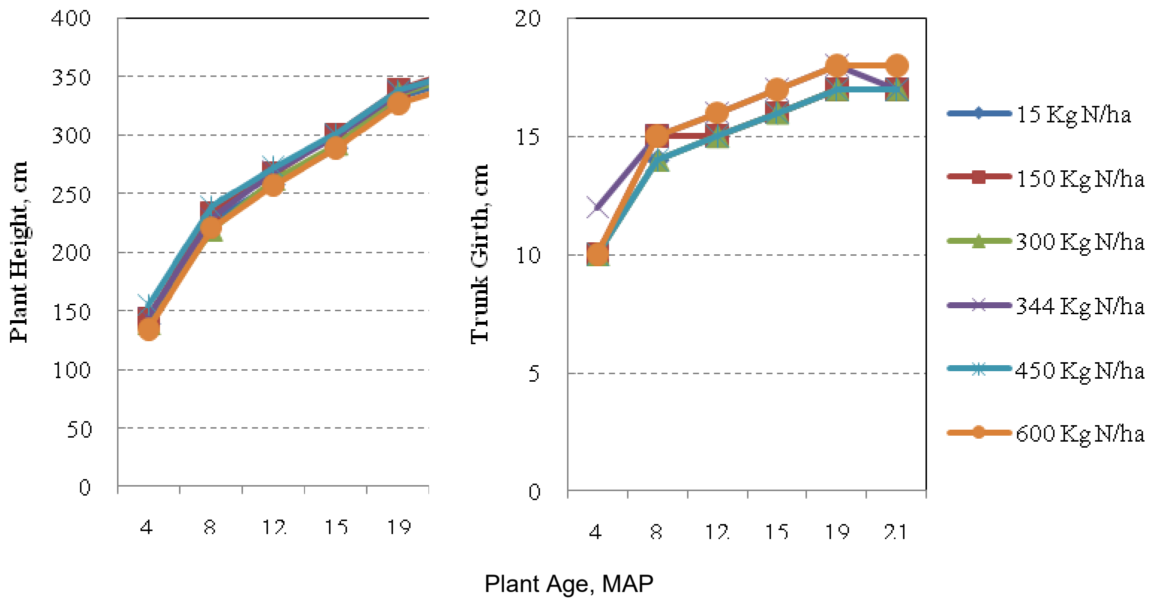


Fig. 3. Plant height and trunk girth of yellow, processing type papaya hybrid as affected by increasing nitrogen fertilization rates.

The most noticeable effect of increasing nitrogen fertilization on yellow papaya hybrid was on fruit production. Though statistically insignificant, increasing nitrogen fertilization correspondingly increased fruit production up to 450 kg N/ha only. It was at this rate where fruit production peaked to an average of 76 fruits per tree (Fig. 4.) Beyond this rate, fruit production declined and correspondingly, total yield declined. In contrast, fruit production was lowest when nitrogen was applied <300 kg N/ha, with total fruits ranging 61-62 pieces per tree. The difference of 15 fruits accounted for the yield difference between these rates equivalent to 30 MTH. Other parameters like average fruit weight (AFW), fruit brix and NO3-N content, percent fruit cavity, flesh thickness and flesh color were not affected significantly by varying nitrogen rates.

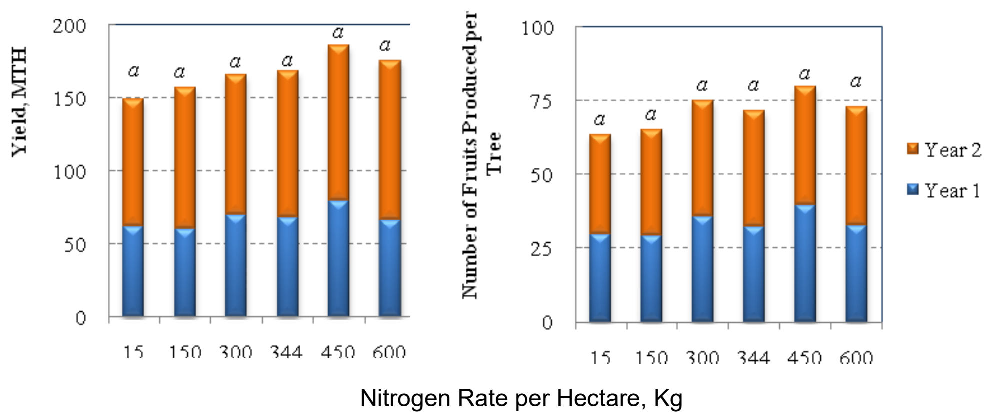


Fig. 4. Yield and average number of fruits produced per tree of yellow hybrid papaya as affected by various levels of nitrogen fertilization.

One of the objectives of this trial was to establish a procedure that can assess the nitrogen status of papaya at certain growth stage. The petiole NO3-N analysis through the use of nitrate strips and analyzed using the Merck Reflectoquant® *RQflex10* proved to be a better method than the Kjehdahl total nitrogen analysis, at least for this trial. With this procedure, a more definite trend was obtained since a consequent increase in petiole NO3-N concentration was obtained as a result of increasing nitrogen application (Table 3). Starting at 9 MAP up to 20 MAP, petiole NO3-N differed significantly between 15-150 kg N/ha and 450-600 kg N/ha. Incremental increase in petiole NO3-N was negligible when nitrogen was applied from 450 to 600 Kg/ha. Presumably, the 600 kg N/ha which resulted in 0.09% NO3-N in the petiole might be a detrimental concentration already. Such NO3-N level in the petiole may have an impact on the physiological functions of papaya on its entirety. Accordingly, high nitrate contents are of limited use for nitrogen metabolism in plants and only stored nearly exclusively in the vacuole and its release from the vacuole into the cytoplasm can become a rate limiting step for the utilization of nitrate in growth processes (Marschner, 1995). Moreover, NO3- assimilation requires additional energy to convert it into $NH4^+$ form, hence growth maybe more limited in high NO3- conditions (Bloom *et al.,* 1992). Such physiological phenomenon might also be applicable with papaya and more plant energy may have been diverted to convert NO3- to $NH4^+$ form instead of producing more flowers that will ultimately develop into fruits. This event could explain the decline in yield starting at 11 MAP (Fig. 5) In contrast, petiole NO3-N levels of 0.02-0.04% is considered a limiting level.

Table 3. Nitrate content of papaya petiole using Kjehdahl method and Merck Reflectoquant ® RQflex 10 in response to nitrogen fertilization.

Kg N/ha	**Papaya Petiole Total, %**					**Papaya Petiole NO3-N, %**				
	4	9	14	17	20	4	9	14	17	20
	(MAP)					(MAP)				
15	-	5.5 *a*	4.3 *c*	4.3 *c*	4.4 *a*	0.04 *a*	0.04 *b*	0.03 *b*	0.02 *b*	0.02 *c*
150	-	5.2 *a*	4.6 *bc*	4.1 *abc*	4.5 *a*	0.06 *a*	0.06 *ab*	0.04 *b*	0.03 *ab*	0.04 *bc*
300	-	5.4 *a*	5.1 *ab*	5.0 *bc*	4.8 *a*	0.11 *a*	0.07 *ab*	0.05 *ab*	0.04 *ab*	0.05 *abc*
344	-	5.5 *a*	5.6 *abc*	4.7 *abc*	4.0 *a*	0.16 *a*	0.09 *a*	0.07 *ab*	0.05 *a*	0.04 *abc*
450	-	5.2 *a*	5.4 *a*	5.2 *a*	4.9 *a*	0.11 *a*	0.08 *ab*	0.09 *a*	0.06 *a*	0.07 *ab*
600	-	5.5 *a*	5.3 *a*	4.8 *ab*	4.4 *a*	0.12 *a*	0.09 *a*	0.09 *a*	0.06 *a*	0.08 *a*

In a column, means not followed by a common letter are significantly different (P < 0.05).

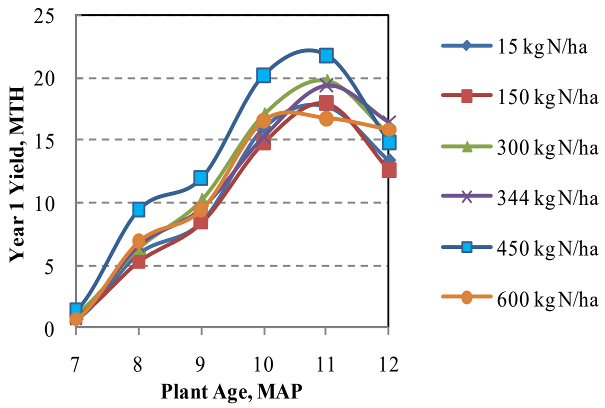


Fig. 5. Monthly yield performance of yellow hybrid papaya as affected by varying levels of nitrogen fertilization.

Conclusion

Nitrogen application rate at 450 kg/ha for a 24-month cycle of papaya is recommended to commercial papaya growers to optimize fruit production and yield. Whenever possible, petiole NO3-N should be analyzed using the Merck Reflectoquant® *RQflex10* since this instrument was more sensitive in measuring variations in levels of nitrogen application rates.

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11.3.3 Characterisation of fertilizer practices in the wet tropical coast and Atherton Tablelands region of North Queensland with emphasis on nitrogen use

Patrick O'Farrell and Paula Ibell, QDAFF.

1. Introduction

Information about grower fertilizer practices was required to understand RD&E priorities to design and implement sustainable nutrient management strategies for papaya. This was obtained by questionnaires posted to growers in March 2010 via Papaya Australia Ltd postal address database. Data were sought on a number of key practices including factors influencing fertilizer rate decisions, application techniques and record keeping (Table 1).

At the time of the survey, most the papaya production in Australia occurred in North Queensland on the wet tropical coast mainly between Mossman and Tully, and an adjacent hinterland broadly referred to as the Atherton Tablelands. At the time of the survey, there were approximately 60 growers cultivating 300 hectares of papaya in the region (G Kath, Pers. comm.). Production was equally spread between the coast and tablelands.

Table 1. Information sought in the postal questionnaire.

Question	Information sought
1	How do you decide how much fertilizer to apply? [external advice; own experience; fact sheets/Agrilink; other farmers; plant appearance]
2	Do you use soil and plant tests to determine fertilizer requirements? [yes; no; sometimes]
3	Do you have a target amount of N, P and K over the life of the crop? [yes; no]
4	What are your target amounts of N, P and K over the life of the crop?
5	Do you irrigate? [yes, dripper; yes, mini-sprinkler; no]
6	Do you routinely check your irrigation system to ensure that drippers or sprinklers are working properly? [yes; no]
7	Do you measure soil moisture to know when to irrigate? [yes, routinely; yes, sometimes; no]
8	Do you apply fertilizer through the irrigation (fertigate)? [yes; no]
9	Does anything prevent you from fertigating any time of year (e.g. pump site floods, limited water)? [yes; no]. If yes, what?
10	Please tick the records you keep. [fertilizer inputs; soil/leaf test results; irrigations; yield; rainfall]

2. Data analysis and interpretation

Questionnaire data were summed and proportions calculated to describe trends. Responses were received from Atherton Tablelands (AT), wet tropical coast (WTC), central Queensland (C Qld), southeast Queensland (SE Qld), the Northern Territory and Western Australia. The overall response (number of respondents and area reported) was initially described, and then trends for the WTC and AT regions described in detail. One respondent in the WTC region, whose fertilizer practice was based on organic materials, was not included in the latter analysis.

3. Results

3.1. Questionnaire response and total production area reported

Twenty percent of the 110 questionnaires posted were returned from current growers. An additional four were received from respondents who no longer cultivated papaya. Most respondents were from the WTC and AT regions (68% of the total), and their collective production area was 92% of the total reported (Figures 1a and b).

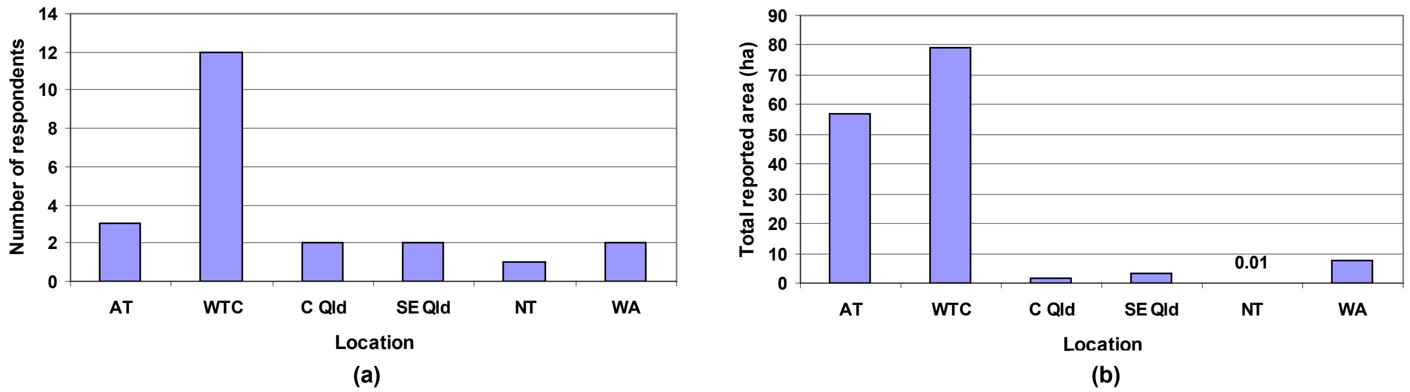


Figure 1. (a) number of respondents, and (b) area reported according to location.

3.2. Nutrient management practices in the wet tropical coast and Atherton Tablelands regions

The number of respondents for the WTC and AT regions combined (WTC/AT) represented 25% of the growers in the region, and the total production area reported by the survey represented half of the total production area of the region (Figure 3). The area reported for these regions individually (as a proportion of their total growing area), was higher for the WTC compared with the AT region (53% *cf* 38%). Importantly, the WTC region drains into the Coral Sea and agricultural activities of the region that affect nutrient loss (via erosion and deep drainage) are believed to influence the health of the Great Barrier Reef.

The production area of farms in the WTC/AT region, ranged from 1.3 to 30 hectares, with most being less than 5 hectares (Figure 4a). The combined production area of three of the respondents was 62% of the total production area reported for the region. Data for planting density was supplied by 10 respondents. Most were in the range 1500 to < 2000 plants per hectare (Figure 4b).

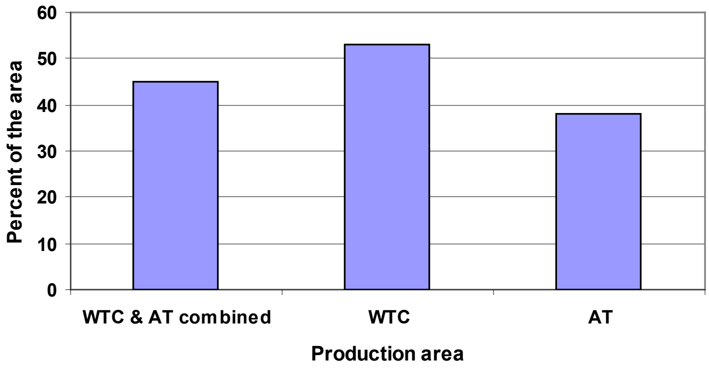


Figure 3. Significance of the reported for the wet tropical coast (WTC) and Atherton Tablelands (AT) production areas.

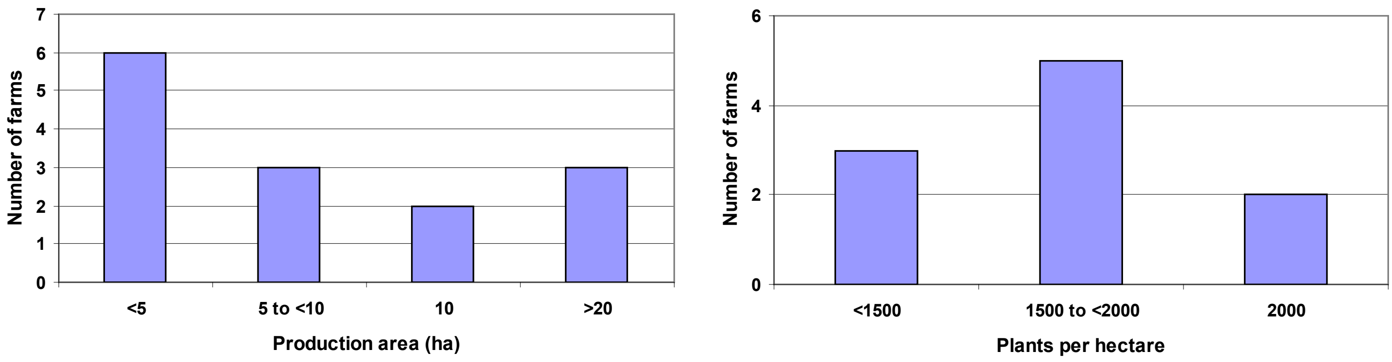


Figure 4. Distribution: (a) of production area, (b) plant density reported for the wet tropical coast and Atherton Tablelands regions combined.

3.3. *Factors influencing fertilizer decisions*

Most respondents relied on their own experience when deciding fertilizer application rates (Figure 5). Plant appearance was significant in guiding their decision, while only half sought external advice (e.g. from a consultant). Information from other growers, generally, did not feature strongly in decision making. Less than half the respondents used soil and leaf nutrient tests (43%), while an equal proportion used these tests sometimes. Fertilizer rates (for N, P and K) of half the growers were guided by a planned 'sufficiency' (or target) rate.

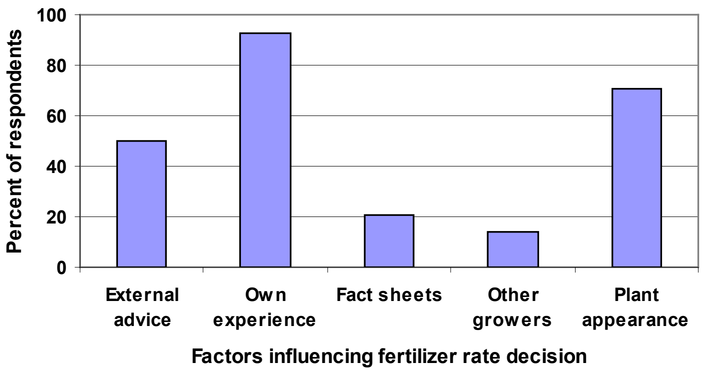


Figure 5. Factors influencing nutrient management decisions in the wet tropical coast and Atherton Tablelands regions combined.

3.4. Nitrogen application rates

Only 57% of respondents supplied nutrient rate information. Four supplied sufficient information to interpret annual application rate. Three of these had the largest production areas (> 20 hectares; Figure 4a).

Nitrogen rates ranged from 160 to 310 kg N/ha/yr (Table 2), and are consistent with those obtained from growers in the region subsequent to this survey (S Lindsay, Pers comm.). Significantly, these rates are lower than those reported by Richards et al. (1995) who found almost 40% of growers in the region applied in excess of 350 kg N/ha/year (11% applied > 650 kg N/ha/year).

Table 2. Nitrogen rates reported by four respondents.

Respondent	Region	Production area (ha)	Number of plants/ha	Nitrogen rate (kg/ha/year)
1	AT	25	1500	200
4	WTC	30	2000	300
7	AT	30	1840	160
19	WTC	1.3	900	310

3.5. Irrigation and fertigation practices

All 14 respondents in the WTC/AT region used irrigation, with equal proportions using drip and mini-sprinkler systems (Table 3). All expect 3 (who were in the WTC region), applied nutrients by fertigation (i.e. via irrigation); 90% of those who fertigated routinely checked that their irrigation systems were working properly, while 55% routinely monitored soil moisture status to understand drainage depth of applied irrigation water and nutrient in relation to the depth of the root-zone of plants. All respondents who use drip irrigation also fertigated.

For the WTC region only, that has a high rainfall monsoon climate (Appendix 11.1.2; Figure 1), 8 of the 11 respondents used fertigation. This represented 86% of the total area reported. All respondents who fertigated did routine irrigation checks, but only half routinely monitored soil moisture (32% of the total reported area). All respondents who routinely monitored soil moisture also did routine irrigation checks. Seven of the respondents who fertigated reported they were prevented from using fertigation all year because of high rainfall. The total area of these respondents represented 85% of the area reported to be fertigated (68 ha).

Table 3. Irrigation and fertigation practices in the wet tropical coast (WTC) and Atherton Tablelands (AT) regions.

Practice	WTC region (number of growers)	AT region (number of growers)
Irrigation (total 14 growers)[1]		
By mini-sprinklers	6	1
By drip	5	2
Fertigation (total 11 growers)[1]		
By mini-sprinklers	3	1
By drip	5	2
Routinely check irrigation	8	2
Routinely monitor soil moisture	4	1
Prevented sometimes	7	1

[1]Total for WTC and AT regions combined.

3.6. Farm management records

Fertilizer inputs were the most commonly kept records (Figure 6). This possibly reflects quality assurance requirements (G Kath, Pers. comm.) more than an interest to keep information that could guide future fertilization decisions, or use it to understand the reason for plant growth/productivity anomalies that might occur. There was low interest by respondents in keeping irrigation, yield and rainfall records that might also be used for these purposes. The number of respondents who kept soil and leaf nutrient test results correlates directly with the number who used them regularly (see Section 3.2).

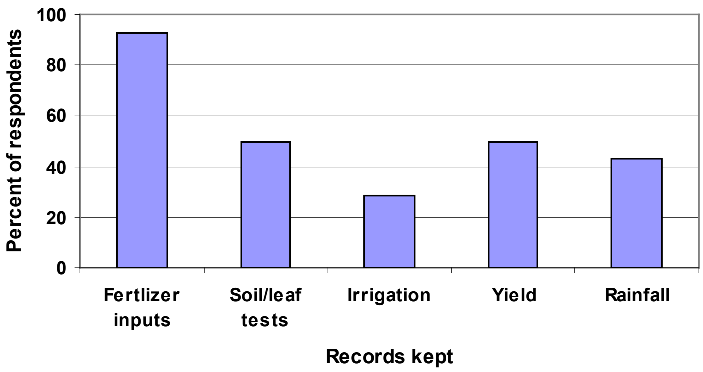


Figure 6. Records kept by respondents in the wet tropical coast and Atherton Tablelands regions combined.

4. Implications for Objective 3

- There was a significant response to the questionnaire (20% respondent rate). For the WTC/AT region combined, this represented 25% of the growers in the region, and 45% of the production area.

- The use of soil and leaf nutrient tests and external advice (e.g. consultant) is not high, and are possibly related. Personal experience and plant appearance were significant in fertilizer application rate decisions.
- Nitrogen rates ranged from 160 to 310 kg/ha/yr. While few respondents supplied N rate information, the response represented 30% of the production area in the WTC/AT region at the time of the survey.
- Fertigation is widely used in the WTC/AT region, but cannot be used all year in the WTC region because of high rainfall. This has implications for nutrient management during the monsoon season when leaching risk is high.
- Only 50% of respondents in the WTC who fertigated, routinely monitored soil moisture to understand irrigation drainage depth. Communication of best-practice irrigation/fertigation practices to papaya growers is being undertaken by Growcom (www.growcom.com.au).

11.3.4 Understanding sustainable nutrient management of papaya (*Carica papaya* L) in the wet tropics of North Queensland with emphasis on nitrogen fertilization: a review of the literature

Patrick O'Farrell and Paula Ibell, QDAFF.

1. Introduction

Most of the Australian production occurs on the wet tropical coast between Mossman and Tully (latitude 16° 28'S to 17° 55'S; longitude 145° 41'E), and to the west an adjacent elevated hinterland (elevation ~500 m) broadly referred to as the Atherton Tablelands. The environmental landscape features high rainfall (75% occurring December–April; Figure 1), highly permeable soils with low cation exchange (3−10 $cmol_c$/kg), and undulating terrain.

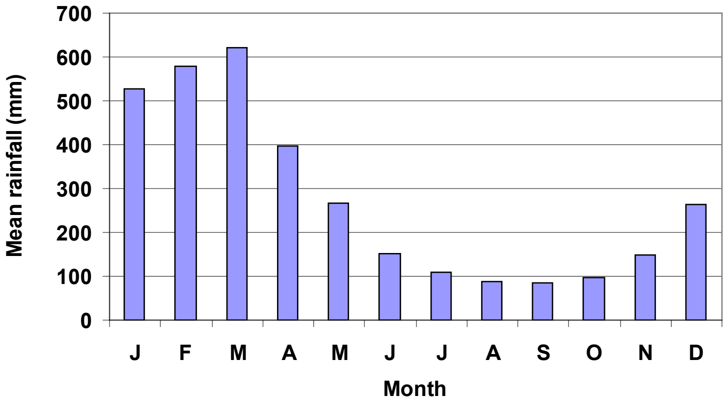


Figure 1. Rainfall (total annual 3335 mm) for South Johnstone (17°37'S, 146°E).

The region is adjacent to the Great Barrier Reef, a World Heritage marine park with significant conservation and economic value. Over the last decade, declining quality of catchment runoff (sediment, nutrients and pesticides) due to agricultural activities has been recognised as a major threat to the ecosystem (Great Barrier Reef Marine Park Authority, 2009). This has led to government regulation of farming practices (Great Barrier Reef Protection Amendment Act 2009), and initiatives to assist farmers to improve water quality leaving the farm including repair of degraded land, construction of erosion control works, and adoption of best practice management technologies (Reef Rescue program).

The purpose of this review is to clarify what is known about sustainable nutrient management in papaya, evaluate information that might refine current knowledge, and identify RD&E opportunities to advance understandings of improved practices.

2. Papaya growth and development

Papaya (*Carica papaya* L) is a giant herb (Marlo and Campbell, 1986), atypically herbaceous because of its size that can reach 9 m (Campostrini and Glenn, 2007). It is a tropical species, and while opinions differ, its probable origin is the lowlands of Central America and southern Mexico, possibly West Indies (Caribbean) (Crane, 2008).

Papaya is classified as a plant with C_3 metabolism (Campostrini and Glenn, 2007). The plant is fast-growing (Malo and Campbell, 1986), and leaf development rates of up to 3 per week have been reported (Awada and Ikeda, 1957). While it can live to 20 years (Crane, 2008), commercial lifespan in North Queensland rarely exceeds 2 years (Ross et al., 2000). Favourable conditions for growth include fertile well drained soils (medium or sandy clay in texture), temperatures 22 to 26°C, relative air humidity 60 to 85%, and rainfall 1,800 to 2,000 mm (well distributed throughout the year), and shelter from high winds (Oliveira et al., 2007).

Papaya phenology has three distinct development stages (Figure 3); initial growth (field planting to flowering), flowering and fruit formation, and production (harvest) (Oliveira et al, 2007). The duration of first and second stages in North Queensland is typically 4 and 5 months, respectively (Ross et al., 2000), while the harvest stage may be as long as 16 months depending on plant health. During the second and third stages vegetative and reproductive growth occurs synchronously. Fruit of various maturities extend up the column to the developing flowers; the most flowers located about 17−20 axils from the apex of the plant (O'Farrell and Ibell, unpublished data).

Under commercial culture in North Queensland, constant nutrient and irrigation supply is common during stages 2 and 3 to achieve economic yields. In this circumstance, manifestation of stress symptoms occur within 4 weeks if the supply is interrupted (chlorotic leaves, reduced crown size, and flower and fruit drop), or if rainfall produces waterlogged soil conditions that favour hypoxia, NO_3^- leaching, and *Phytophthora palmivora* root rot.

3. Nutrient best management principles

Intensive high-yield agriculture is dependent on fertilizer, especially industrially produced ammonium and nitrate (NO_3^-) (Tilman et al., 2002). Unfortunately nitrogen fertilization has led to pollution of groundwater (by NO_3^-) and green house gas emissions (by N_2O) that can adversely affect ecosystems and human health.

The purpose of nutrient best practice management (BMP) is to ensure plant nutrients are used efficiently and effectively to benefit society without adversely affecting the environment (Roberts, 2010). The emphasis given to economic, social and environmental outcome depends on the circumstance; greater emphasis on environmental outcomes might apply to a sensitive ecosystem than to an agricultural industry where economic viability is important.

Various codes of practice for nutrient management exist, for example the 'THE SIX EASY STEPS' approach used in the sugar industry in Australia (BSES Limited, 2010), and the Code of Practice for Nutrient Management used in New Zealand (Fertilizer Association, 2012). A broad range of technologies are employed to overcome adverse in-situ and off-site effects. In addition to those described in the following sections, genotypes with high nutrient use efficiencies (increased yield per unit of added N) (Tilman et al., 2002), and synthesised slow-release N fertilizers (Guertal, 2009) may also be relevant.

Roberts (2010) proposed that the correct (nutrient) product applied at the right rate, time and placement were the four principles of nutrient stewardship. In effect, fertilizer products are matched to soil properties and crop needs, rates are matched to realistic yield targets, temporal nutrient availability is synchronized with crop demand, and nutrients are strategically placed in the root-zone to maximise nutrient use efficiency. The concept recognizes that BMPs are site and crop specific.

4. Sustainable nitrogen management practices for papaya in North Queensland

Nutrient BMP guidelines for papaya in North Queensland have received some consideration since the mid-1990s. Richard et al. (1998) hypothesised a sustainable management system that integrated N rate, techniques that match N to plant requirement, and precise application methodology, while the recent Reef Rescue Water Quality Incentive Grants scheme (to improve water quality leaving papaya farms) for managing nutrients, sediment and pesticides was based on an ABCD framework (Terrain Natural Resource Management, 2013).

The ABCD framework classifies farming practices, with increasing sophistication, from D (unacceptable practices) to A (practices expected to exceed BMP). Best practices include: soil conservation measures (diversion drains, contour planting, vegetative inter-rows, minimum cultivation to prepare planting mounds); objective soil moisture monitoring, irrigation rates suited to soil type and crop need; irrigation distribution uniformity 80−85%; and fertilizer targeted to the planting mound, applied in small amounts and taking weather forecasts into account.

The integrated approach of Richards et al. (1998) consisted of:

1. pre-plant soil analysis (to determine lime requirement for pH adjustment, and N and P requirement);
2. a fertilizer (target) rate for the life of the crop (340 kg N/ha/2 year crop), apportioned in synchrony with plant growth according to nutrient uptake;
3. nutrient sap testing every 2 weeks to finetune applications;
4. frequent applications every 1−2 weeks applied by fertigation (i.e. applied via irrigation);
5. and sound management of other aspects of plant health so that nutrient uptake is not compromised (pest/disease/irrigation).

Using fertigation, Richards et al. (1998) suggested it may be possible to reduce the target rate by possibly 30% because of greater application efficiencies compared with broadcast application that was used in their research to establish the target rate. This approach conforms in principle with that of Roberts (2010); however it has never been validated by empirical research. Further, elements of the approach are not well understood; these are, target rates for nutrient applied by fertigation, techniques to match nutrient applications to plant growth, and the effectiveness of sap tests as a tool to guide nutrient management.

5. Nitrogen rate by fertigation

The adaption of fertigation (application of soluble nutrients to crops via irrigation) to commercial cropping systems has opened up possibilities for precisely matching application rates to crops requirements, thus enhancing nutrient use efficiency and reducing leaching of nutrients into groundwater (Bar-Yosef, 1999). Nitrogen rate reductions of 30−50% have been demonstrated in sugar cane (Ng Kee Kwong et al., 1999), pecan (Worley et al., 1995) and tomato (Singandhupe et al., 2002), and decreased NO_3^- loading into ground water in orange (Alva et al., 1998).

The response of papaya to N has been researched under non-fertigated conditions; as surface applications (broadcast) under either rain-fed or irrigation culture (Table 1). Various vegetative and reproductive responses to N rate are reported; for example, increased growth rate (trunk circumference; Awada and Long, 1971), increase petiole N concentration (Allan et al., 2000), reduce time to flowering (Reddy and Kohli, 1989), increased fruit number, and promotion of fruit biomass in relation to non-fruit biomass (Reddy and Kohli, 1989).

For five studies, the effect of N rate on fruit yield was reviewed by comparing rate per application/plant and relative yield (yield relative to maximum yield). Depending on the study, N was applied every 4, 8 or 10 weeks in equal amounts over the duration that treatments were applied. The data, while limited, show maximum yield response occurring at lower application rates the lower the application interval. Maximum yield response for the 8 week frequency occurred around 40 g/application (Table 1, Figure 2).

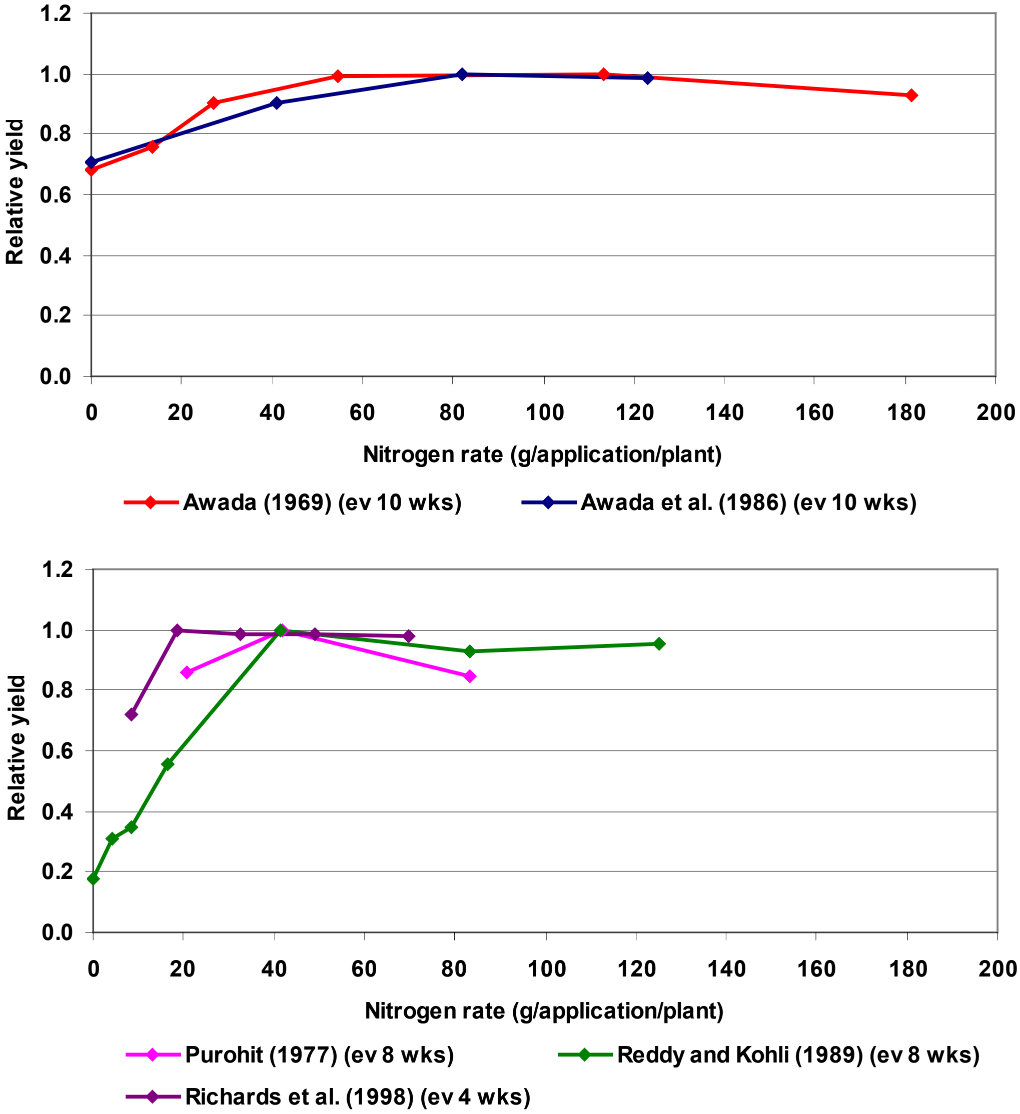


Figure 2. Papaya response to nitrogen rate applied at three frequencies (every 4, 8 and 10 weeks).

Table 1. Information for nitrogen rates derived from the literature and North Queensland papaya industry.

Reference	Plants per hectare	Water management	Harvest period (months)	When treatments started	N treatment rates (g/plant)	Application method & frequency	Yield at highest response (kg/plant)	Rate at highest yield response (g/application)	Comments
Allen et al., (2000)	4444	Spray irrigation	2	Planting	5.6, 13.6, 21.2, 28.8	Broadcast weekly over 12 months			Plants grown in 85 L pots in a polyethylene greenhouse. There was a negative NK interaction for yield.
Purohit (1977)	1736	Irrigated (form not stated)	18	2 months after planting	20.8, 41.7, 83.3	Applied every 2 months over 2 years.	64.6	41.7	Application method not stated (possibly broadcast).
Awada (1969)	1389	Rain-fed	19	Flowering	0, 13.6, 27.2, 54.4, 113.4, 181.4	Applied in 15 cm deep holes, 60−120 cm from trunk, and every 10 weeks.	96.0	113.4	
Awada and Long (1971)	Not stated	Rain-fed	12	Flowering	0, 41, 81.9	Broadcast every 6 weeks.			Applied N increased yield over nil N ($p<0.05$), but applied N treatments were not significantly different.
Awada and Ikeda (1957)	1197	Irrigated (form not stated)	9	Flowering	0, 2.3, 9	Applied in 15 cm deep holes, 45 cm from trunk, and every 3 months.			Yield did not respond to applied N.
Reddy and Kohli (1989)	3086	Irrigated (form not stated)	12	Not stated	0, 4.2, 8.3, 16.6, 41.6, 83.3, 125	Applied every 2 months.	18.4	41.6	Application method not stated.

Table 1 (cont.). Information for nitrogen rates derived from the literature and North Queensland papaya industry.

Reference	Plants per hectare	Water management	Harvest period (months)	Start of treatments	N rates (g/plant/mth)	Application method & frequency	Yield at highest response (kg/plant)	Rate at highest yield response (g/plant/mth)	Comments
Awada et al., (1986)	1582	Drip irrigation	12	12 month old plants	0, 41, 82, 123	Broadcast every 10 weeks.	15.9	82	Applied N increased yield over nil N ($p<0.05$), but applied N treatments were not significantly different. Yield of the 35.5 rate 10% higher than the 17.8 rate.
Richards et al., (1998)	1667	Sprinkler irrigation	10	Flowering	8.3, 18.7, 32.5, 49.2, 69.8	Broadcast monthly	76.1	18.7	Treatments started in Jan 1996, and rates were reduced in Jul 1996. Highest yield was recorded at the 18.7 rate, which was reduced to 7.2 g/plant/month in Jul 1996.
Local industry	1840	Drip irrigation		Flowering	15.9	Fertigated			Reported in Appendix 11.3.3.
Local industry	2000	Drip irrigation		Flowering	12.5	Fertigated			Reported in Appendix 11.3.3.

Jeyakumar et al. (2010) demonstrated a 25% yield improvement over conventional nutrient application techniques (broadcast/flooding) when the same N rate was applied by fertigation (via drip irrigation). For the fertigation treatments however, they did not find that N rate could be reduced; there was a 15% reduction in yield (from 74 kg/plant) when the maximum rate was reduced by 25% (from 25 to 18.8 g/plant/month).

In a similar study at the same plant density (3086 plants/ha), Sadarunnisa et al. (2010) recorded a 33% increase over the conventional technique, but also found improved nutrient use efficiency with fertigation; for the fertigated treatments, yield was not reduced from 102.6 kg/plant ($P < 0.05$) when rate was reduced by 25% (possibly from 20.8 to 15.6 g/plant/month). There was insufficient information provided by these workers to understand clearly what N rates and the period of harvest were.

The available information does not confirm NUE benefits in papaya from fertigation. While both Jeyakumar et al. (2010) and Sadarunnisa et al. (2010) found improved NUE with fertigation over conventional application techniques, their results are conflicting. Further, the fertigated rate at maximum yield response of the former researchers is still comparable to non-fertigated rates listed in Table 1. In contrast, the fertigated rates of two growers in North Queensland that produce economic yields are below non-fertigated rates, suggesting that improved NUE is possible in papaya with fertigation.

Merely applying nutrients by fertigation does not necessarily guarantee improved NUE, because irrigation/fertigation system type, design and management (operation and maintenance), that affect nutrient leaching (Burt et al., 1995), will affect the proportion of applied nutrient that is available for plant uptake. Nutrient leaching can be substantially reduced by minimising deep percolation and controlling the concentration of leachable nutrient in the soil, and these factors are influenced by distribution uniformity of irrigation water and applied nutrient, irrigation scheduling, rainfall, and the amount and form of chemical applied.

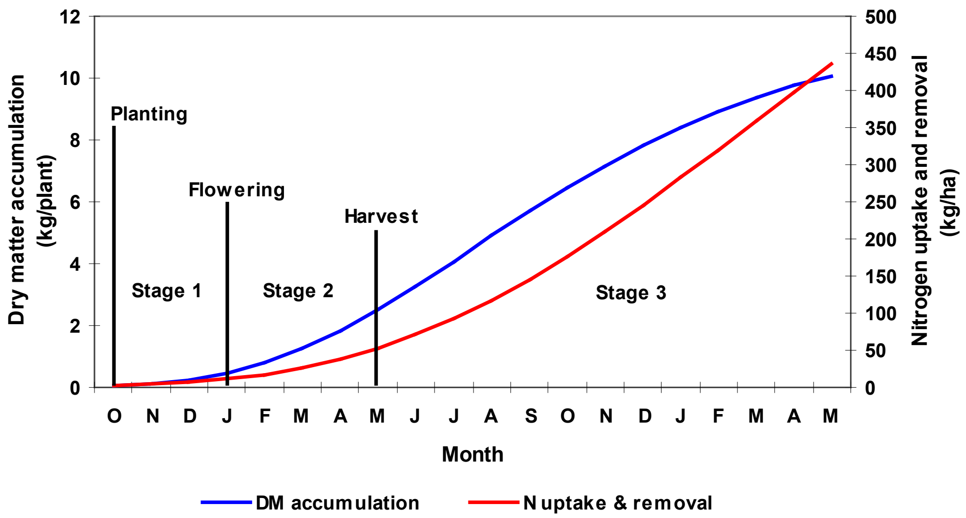
Fertigation is common in North Queensland production systems; however its use during the monsoon season when leaching potential is high is restricted by excess rainfall (presumably saturated soil conditions) and inundation of pumping sites (Appendix 11.3.3). It is not known whether fertigation injection point and block size, which affect minimum fertigation time (delivery time to furthest emitter, flushing of the system), and emitter discharge rate (in relation to soil infiltration rate) also limit the capacity to fertigate during wet conditions. Irrespective, alternative application methods might be relevant during high rainfall conditions when fertigation cannot be used (e.g. slow release forms).

6. Synchronizing nitrogen rate to plant requirement

Bar-Yosef (1999) theorised that yield and fruit quality were determined by dry matter (DM) production and partitioning among plant organs, and nutrient concentration (NC) in plant organs as a function of time. He proposed that the product $DM(t) \times NC(t)$ defines a cumulative consumption function $Q(t)$. The $DM(t)$ and $Q(t)$ curves that produce maximum yield and fruit quality under given climatic conditions are termed the objective (target) DM and nutrient uptake curves. They are determined empirically by measuring DM, NC, and fruit yield and quality over time and under a range of fertigation and climatic conditions.

Richards et al. (1998) defined DM and nutrient uptake curves for papaya on the wet tropical coast of North Queensland (Figure 3). They provide a scientific basis for supplying the nutrient needs of papaya during the different phenological stages. Whole plant biomass and NC were measured 7 times over a 21 month growth period starting from an October planting date. Data were from plants receiving, at various times, N rates equivalent to 8.3−69.8 g/plant/month. This research was not extensive. It provides limited understanding of seasonal influence on DM accumulation and nutrient uptake, as plant growth from only one time in the planting season (March to November) was considered.

Further, N rates were reduced 6 months after flowering, the reduced rates correlating with a decrease in DM accumulation (Figure 4).



Equations for curves (C Wright, Pers. comm.):

DM = Cexp(-exp(-B*age+M)), where B = 0.1862, M = 2.116, and C = 11.905.

NU&R = Cexp(-exp(-B*(age-M))), where B = 0.1076, M = 18.96, and C = 970.

Figure 3. Dry matter accumulation and nitrogen uptake and removal determined by Richards et al. (1998), showing phenological stages.

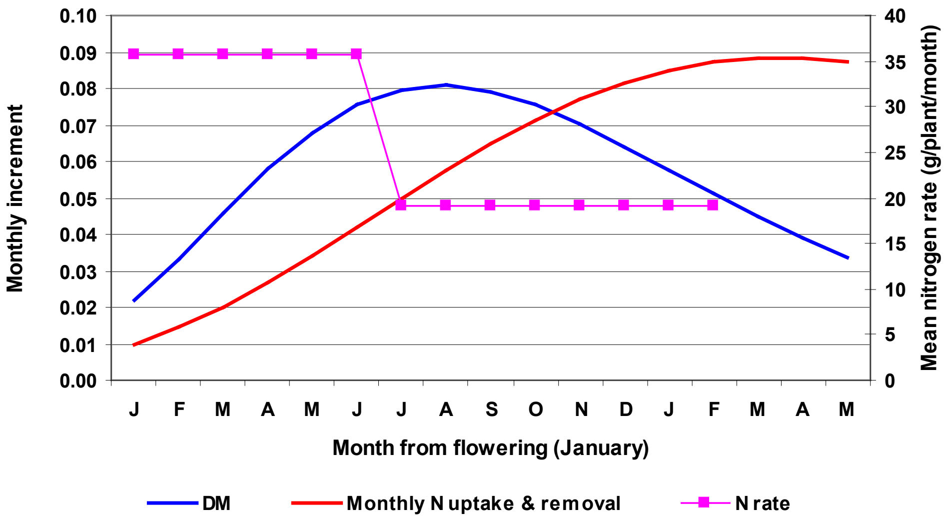


Figure 4. Relationship between nitrogen rate and dry matter accumulation and nitrogen uptake and removal increment (Richards et al., 1998).

The N uptake model of Richards et al. (1998) suggests that, in principle, growers could reduce N inputs by moderating practices during Stage 2 (flowering to the start of harvest) so that rate is aligned with plant requirement. It is not uncommon for local growers to increase N rate to a maximum monthly rate from the time plants flower, the maximum maintained for the productive life of the crop. For the industry rates stated in Table 1 and equivalent density (1666 plants/ha), up to 58 kg N/ha ($88/ha costed at $700/t urea) over that predicted by the model is applied during Stage 2. The environmental significance of oversupply during this period depends on the time of planting which influences the timing of Stage 2 in relation to seasonal climate. For the October planting that was modelled by Richards et al. (1998), Stage 2 coincides with the monsoon season when the risk of N leaching loss is high.

7. Rapid diagnostics (plant sap 'quick tests')

The concept of sap testing has existed for over 70 years, however there has been resurgence in interest with the release of reliable tests and calibration data for NO_3^- and other analytes (Hanson and Shelley, 1993). Sap testing is most applicable for short duration crops that grow quickly and are intensively managed, and is best used as a monitoring tool; interpretations based on trends rather than one-off readings. Trends should be compared with researched optimum concentrations at defined growth stages.

Traditionally, local papaya growers have used petiole dry matter analysis by commercial laboratories to guide fertilization. Index tissue and optimum concentrations are well accepted (Ross et al., 2000). The method is inconsistent with nature of papaya that grows rapidly and is highly responsive to and environmental influences (cultural or otherwise). Turnaround time from field sampling of petioles to receipt/interpretation of test results can be up to 3 weeks (G Kath, Pers. comm.). In addition, tests are costly ($60+/sample, depending on sample number) and discourage frequent and regular plant assessment.

Regular sap monitoring (e.g. in-field 'quick tests') could potentially improve the responsiveness of growers to plant nutrient needs and thus achieve positive production and environmental outcomes. Richards et al. (1998) demonstrated the potential of 'quick test' technology in papaya. In their work to adapt the Reflectoquant® RQflex 10 (RQflex), they showed that the test could differentiate N rates, and found petiole sap and soil NO_3^- concentration as measured by the RQflex were well correlated with laboratory analysis. They determined a provisional adequate concentration of 1630 mg NO_3^-/L in the index petiole (petioles of the youngest fully expanded leaves subtending the most recently opened flowers; Ross et al., 2000).

The RQflex technique consists of a portable reflectometer and NO_3^- test strips with two reactive zones. Nitrate absorbed onto the reactive zones when immersed into a sap solution, is reduced to nitrite, and subsequent reactions produce a red-violet azo dye, the intensity of which is proportional to the concentration to nitrate in the sap. The strip is then inserted into a reflectometer that quantifies nitrate concentration. The technique is highly relevant for nutrient management of papaya; the test is quick (< 10 mins) and low cost (~$1.00/test strip), soil and plant NO_3^- can be monitored, and it can be used to optimise fertigation times (measuring nutrient flow rates). In addition, the technique can quantify P and K concentration. The instrument can be purchased locally for $1515.00.

Refining the sap extraction method would improve the usefulness of the technique. Richards et al. (1998) extracted sap by firstly macerating petioles in a domestic electric food processor. Sap was then squeezed from the macerated material with a garlic crusher. The need for electrical power precludes use of the technique as an 'on-the-spot' monitoring tool.

8. Implications for Objective 3

- A BMP approach to nutrient management in papaya that integrates N rate, matching N rate and plant requirement, and precise application techniques has been hypothesised and agrees with approaches theorised by other researchers.
- The approach is unproven, and limited knowledge about important elements prevents its recommendation for commercial culture (N rates under fertigated

nutrient management, DM(*t*) and *Q*(*t*) curves that optimise fruit yield and quality, and rapid diagnostics).

- DM(*t*) and *Q*(*t*) curves provide a scientific basis for matching N rate to plant growth.
- Modelled savings in N during Stage 2 of phenology provides economic and environmental justification for refining DM(*t*) and *Q*(*t*) curves, particularly for planting dates where this stage coincides with the monsoon season.
- Sap 'quick tests' are highly relevant to intensively managed papaya. Improving the method of sap extraction would make the technique more adaptable for in-field use.
- Fertigation is widespread in the North Queensland papaya industry, and offers potential NUEs. Future N rate research should therefore be based solely on this form of nutrient application.
- Fertigation is prevented by rainfall during the monsoon season. Alternative N application methods might enable growers to supply N to plants during periods when fertigation cannot be used.

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11.3.5 Optimising nitrogen rate for papaya (*Carica papaya* L) under fertigation in the wet tropics of North Queensland

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1. Introduction

A best management practice approach for papaya fertilization that integrates the principles of optimum rate, synchronizing rate and plant requirement, and nutrient delivery by precise application technique was clarified from the literature (Appendix 11.3.4). The approach is unproven, and limited knowledge about important elements prevents its recommendation for commercial culture (e.g. N rates under fertigated nutrient management and techniques that match rate and plant growth).

Fertigation (application of soluble nutrients to crops via irrigation) has opened up possibilities for precisely matching application rates to crops requirements, thus enhancing nutrient use efficiency and reducing leaching of nutrients into groundwater (Bar-Yosef, 1999). The application method is widespread in the North Queensland papaya industry (Appendix 11.3.3). While nutrient rate reductions of up to 30% are generally considered possible, research has never substantiated optimum rates by fertigation in papaya in North Queensland.

Dry matter (DM(*t*)) and cumulative consumption (*Q*(*t*)) curves provide a scientific basis for matching N rate to plant growth (Bar-Yosef, 1999), however the use of these curves for managing papaya N nutrition is a new approach that has not been reported in the literature. Richards et al. (1998) defined DM and nutrient uptake curves for papaya on the wet tropical coast of North Queensland (Appendix 11.3.4). Their research was not extensive.

The research reported here investigates the response of papaya to five nitrogen rates (N) applied by fertigation, and scaled to plant growth according to dry matter accumulation.

2. Materials and Methods

2.1. Location and crop management

The trial site was located at South Johnstone (17°37'S, 146°E) on a gentle easterly draining slope. The soil is a Haplic, Dystrophic Brown Dermosol (Isbell, 1996). Soil chemical properties (0−40 cm), measured prior to the application of pre-plant basal treatments, were: pH (1:5 water); EC, 0.09 dS/m; 6.4; phosphorus (Cowell), 32 mg/kg; and calcium, potassium, magnesium, and sodium, 4.5, 0.49, 1.1, and 0.04 Meq/100 g, respectively. Calculated mineral N in the top 40 cm of soil of the planting mound was 10 kg/ha.

Planting mounds (4 m apart, centre-to-centre) were aligned east-west, and were 70 cm high and 1.8 m broad at the base when formed. A lime/dolomite blend was broadcast and cultivated into the soil prior to mound formation. Phosphorus, potassium, zinc and boron fertilizers were incorporated into the top of the mounds prior to planting. The trial was planted on 23/6/2011. Four plants (hermaphrodite variety *cv* RB1) were planted at each planting site that were 1.4 m apart within the row (effective planting density 1786 plants/ha).

Most plants had flower buds on 29/9/2011 (98 days after planting; DAP). Planting sites were thinned to one hermaphrodite plant starting on 5/10/2011. This was completed on 24/10/2011 (123 DAP). Harvesting began on 16/2/2012 (238 DAP), and was completed on 25/7/2012 (398 DAP). Fruit were harvested at 'colour break' stage (just starting to yellow). Each plant was irrigated by a 30 L/hr micro-sprinkler that distributed water to the width of the mound. Fertilizers were injected into the irrigation via venturi, observing required injection and flushing times to ensure even distribution of nutrients over the trial area.

2.2. *Nitrogen treatments*

Treatment N rates were based on the range from 220 to 620 kg/ha/24 month crop cycle (Table 1). Rates were guided by the recommendation of Richards et al. (1998), whose rate research was based on broadcast/irrigation application, and those applied in the local industry. Rates were scaled to plant growth according to a revised form of the dry matter function of Richards et al (1998), which constrained nutrient application to a constant rate once maximum dry matter increment was reached (Figure 1). Treatments were applied fortnightly as urea by hand (*in-solution*) from planting to flowering, and then either by hand or fertigated, depending on soil moisture and weather conditions, for the remainder of the trial. Fortnightly rates were increased on 26/3/2012 (277 DAP).

Table 1. Elemental nitrogen (N) rates applied during Stage 1 (planting to flowering), Stage 2 (flowering to harvest) and Stage 3 (during harvest. Days after planting (DAP) describe the conclusion of Stages 1 and 2, and initial and revised rates during Stage 3.

Nominal N rate (kg/ha/24 months)	N rate (kg/ha)		
	Stage 1 98 DAP	Stage 2 238 DAP	Stage 3 277 DAP
220	15.5	59.6	132.2
260	18.4	70.4	171.1
340	24.0	92.1	209.4
460	32.5	124.6	248.7
620	43.8	167.9	290.7

2.3. *Agronomic measurements*

Vegetative, floral and fruit yield responses were assessed. The 10th leaf from the apex (L10 axil) of plants was tagged on 22/2/2012 (244 DAP) six days after the start of harvest (Stage 3). The L10 axil position approximates the fruiting column (or yield) existing on plants at the end of Stage 2 standardised across treatments. Fruiting attributes (number of fruiting axils and fruit weight) were assessed to the 10th axil position. Various numbers of plants were lost from treatments plots over the course of the trial due to disease, and only those existing at the final harvest were included in yield assessments.

The following attributes were measured:

- Plant height (measured from the ground to the apex of the plant) at 98 DAP (a week before the start of thinning), height to first floral bud, and height to first fruit.
- The number of plants at each planting site with floral buds prior to plant thinning.
- Date of thinning, fruit set and first harvest.
- Total number of axils and number of axils with fruit, from first floral bud to the L10 axil.
- Individual fruit weight from weekly harvests.

Petiole samples were collected according to standard procedures on 13/12/2011, 13/3/2012, and 19/6/2012 and 31/7/2012 (Figure 1) for measurement of total N concentration (by Kjehdahl method).

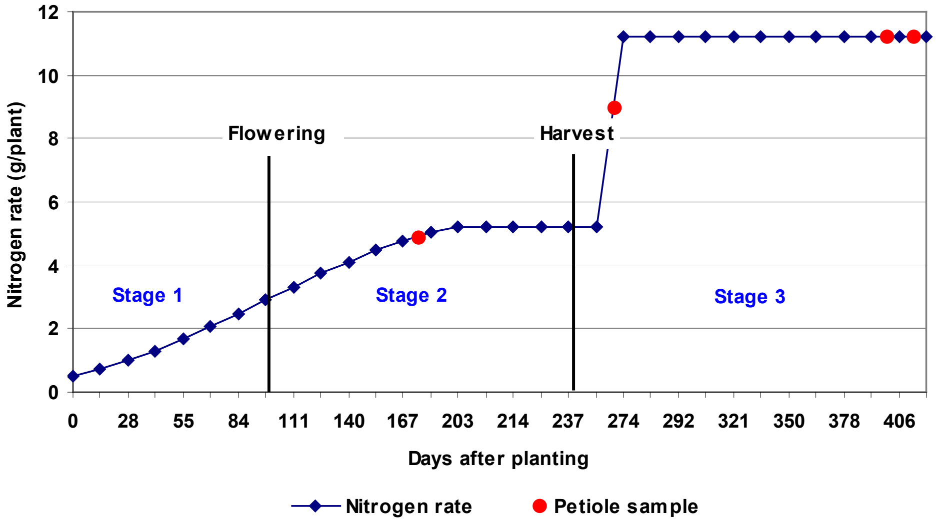

Figure 1. The pattern of fortnightly nitrogen application, planting to flowering (Stage 1), flowering to harvest (Stage 2) and during harvest (Stage 3). Red circles show the timing of petiole total nitrogen concentration assessment.

2.4. Statistical analysis

Analysis of variance (ANOVA) was used to analysis the continuous variables, while both ANOVA and a generalised linear mixed model (GLM) assuming a binomial distribution and logit link function were used to analysis the proportion of fruiting axils. Where a significant treatment effect was found, pairwise comparisons are made using the 95% LSD.

3. Results

3.1. Plant nitrogen concentration

Total N concentration reflected N rate at each sampling time (Table 2). For the first three samplings, concentrations increased (P = 0.047) with sampling time for all treatments. Higher concentrations for the last two sampling times were associated with increased N rate from 26/3/2012. For the first two samplings, total N of all treatments was below optimum concentrations (1.3−2.5%; Reuter & Robinson, 1986), and was only at optimum for the last two samplings at the highest rate. Nitrogen concentration was never at the optimum concentration for rates 11.2 g/plant/fortnight and lower during Stage 3.

Table 2. Petiole total nitrogen concentration at four sampling times (Figure 1).

Nitrogen rate (kg/ha/24 months)	Sampling date							
	13/12/2011		13/3/2012		19/6/2012		31/7/2012	
	Total N concentration (%)							
220	0.43	h	0.59	fg	1.00	d	1.04	cd
260	0.43	h	0.60	fg	0.99	d	1.10	cd
340	0.44	h	0.64	ef	1.06	cd	1.13	bc
460	0.46	h	0.68	ef	1.23	ab	1.32	a
620	0.49	gh	0.76	e	1.35	a	1.33	a

Interaction between treatment and sampling time significant (P = 0.047). Means within a sampling date and within treatments across sampling dates not followed by a common letter are significantly different (P = 0.05; lsd = 0.14).

3.2. Nitrogen effects on agronomic attributes

3.2.1. Planting to flowering (Stage 1)

Plant height at the end of Stage 1 (98 DAP) was not affected (P = 0.226) by treatments (mean 91 cm). At the same time, the percent of plants with floral buds for the lowest N rate was 32% lower (P = 0.051) than the other treatments (which had similar proportions of floral buds; mean 63.5%). This effect was not evident one week later when all treatments had similar (P = 0.564) proportions of plants with floral buds (mean 93%), and sufficient flowering plants to allow thinning of most planting sites in each treatment. As a result, the time from planting to thinning was similar (P = 0.296) for all treatments (mean 105 DAP).

3.2.2. Flowering to harvest (Stage 2)

First harvestable fruit was higher on the trunk of plants receiving the lowest N rate (Table 3). This response was related to greater numbers of non-fruiting axils from the axil of first floral bud to the axil of first fruit, as height to first floral bud was similar (P = 0.686) for all treatments (mean 95 cm). Number of non-fruiting axils was inversely related to time to fruit set and harvest.

Table 3. The effect of nitrogen rate on agronomic attributes during Stage 2.

Nitrogen rate (kg/ha/24 months)	Height to first fruit (cm)		Number of non-fruiting axils		Days to fruit set		Days to harvest	
	P = 0.013		*P* = 0.003		*P* < 0.001		*P* < 0.001	
220	113	a	6.6	a	148	a	265	a
260	109	b	4.1	bc	140	b	256	bc
340	110	ab	4.4	b	140	b	259	b
460	107	b	2.6	bc	135	b	252	cd
620	107	b	2.2	c	134	b	249	d
5% lsd	3.5		2.2		6.1		5.6	

Means within a column not followed by a common letter are significantly different (*P* = 0.05).

3.2.3. Harvest (Stage 3)

All attributes measured (total number of axils from the first floral axil to the L10 axil, and the proportion of which bore fruit; total fruit weight and number of fruit per plant; and mean fruit weight) increased with increasing rate (Table 4). At the highest rate, 30% of axils (floral sites) did not bear fruit. Total fruit weight increased in a linear fashion, the response showing no strong evidence of a plateau.

Table 4. The effect of nitrogen rate on agronomic attributes during Stage 2.

Nitrogen rate (kg N/ha/24 months)	Total axils per plant		Percent fruiting axils		Total fruit weight (kg/plant)		Mean fruit weight (g)		Total fruit per plant	
	P < 0.001		*P* < 0.001		*P* < 0.001		*P* < 0.001		*P* < 0.001	
220	53.6	c	23	d	8.5	d	691	c	11.6	d
260	56.2	b	31	cd	14.2	cd	777	b	17.3	cd
340	56.9	b	36	c	16.5	c	795	b	20.9	c
460	59.6	a	53	b	29.1	b	858	b	33.5	b
620	61.6	a	68	a	45.0	a	969	a	46.3	a
5% lsd	2.1		8.7		7.3		81		6.9	

Means within a column not followed by a common letter are significantly different (*P* = 0.05).

4. Implications for Objective 3

- Dry matter and cumulative consumption curves (DM(*t*) and *Q*(*t*) curves) provide a scientific basis for matching N rate to plant growth (Bar-Yosef, 1999).
- The use of these curves for managing papaya N nutrition is a new approach that has not been reported in the literature.
- Richards et al. (1998) defined DM and nutrient uptake curves for papaya on the wet tropical coast of North Queensland, however their research was not extensive.

A revised form of the dry matter function of Richards et al. (1998) was used in this study.

- Treatment responses suggest that rates applied above 15.5 kg/ha (the lowest rate) during Stage 1 exceeded plant requirement, particularly as 10 kg/ha was potentially available as mineralised N at the beginning of the trial. Cumulative N uptake as determined by Richards et al. (1998) for Stage 1 was 6.65 kg/ha.
- Suboptimal petiole N concentration (indicating N deficiency) during Stage 2 and associated effects (30% of floral sites not bearing fruit at the highest N rate, and yield response showing no strong evidence of a plateau) suggest potential for higher yields. It is not known if rates were limiting or other factors compromised rate effects (e.g. application method, rainfall).
- There is economic and environmental justification for research to refine DM(t) and $Q(t)$ curves for papaya production in North Queensland, particularly for planting dates where this Stage 2 coincides with the monsoon season. Total N rate of industry during Stage 2 (the maximum monthly rate is applied from flowering) and that predicted by N uptake determined by Richards et al. (1998) were compared in Appendix 11.3.4, Section 6, and showed that industry rates might exceeded N uptake by up to 58 kg N/ha during this period.

References

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11.3.6 Development of quick test' methodologies for determining papaya nitrogen status

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1. Introduction

'Quick test' plant nutrient analysis concepts are relevant to crops that are fast growing and intensively managed, which is consistent with the nature and commercial culture of papaya (Appendix 11.3.4). Richards et al (1998) showed that the portable Reflectoquant® RQflex 10 sap analysis technique (RQflex 10) might be useful for guiding papaya nutrient management. Their method of sap extraction however, is cumbersome (maceration of petioles in a food processor followed by sap removal with a garlic crusher). Further, it requires electrical power, and thus is potentially less adaptable to in-field use than a manual technique.

2. Scope of the research

The sap extraction efficiency of various mechanical devices was assessed which led to the development of a two-step manual technique. The technique was then tested to understand whether the NO_3^- content of petiole sap derived by the technique would differentiate plants treated with different N rates. Sap NO_3^- content, measured by the RQflex 10 and by commercial laboratory analysis, were compared on two occasions.

3. Sap extraction development

The developed technique involves firstly, cutting petioles length-wise with a splitter (Figure 1), and then removing the sap with a roller press (Figure 2). Reducing petioles to halves improves feed rate through the press (compared with whole petioles). Petioles are fed through the press with the cut surface inverted. The technique is quick, and the equipment is easily cleaned between separate samples. Gap width between the rollers is adjustable to accommodate different petiole sizes and influence sap yield; decreasing gap width increases sap yield (Table 1). Four petioles will yield sap volumes in excess of the 2 mL required for the RQflex 10 NO_3^- test.

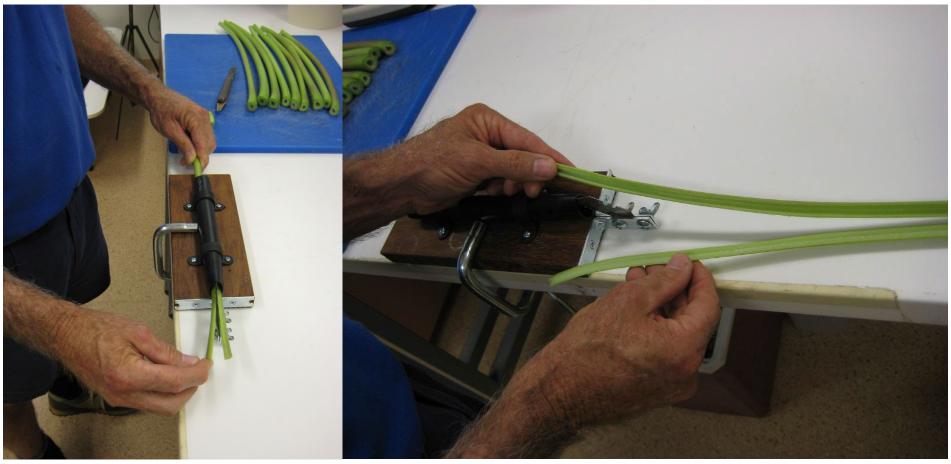

Figure 1. Petiole splitter for reducing whole petioles to halves.

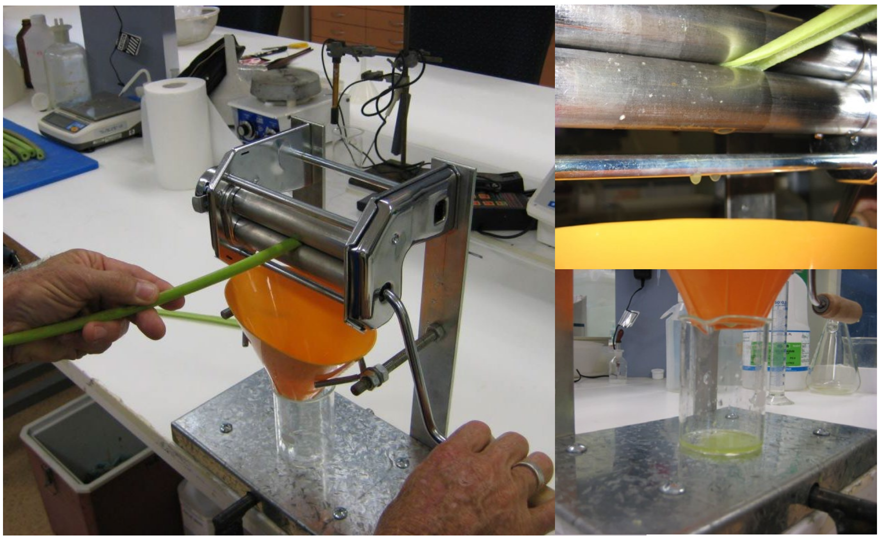

Figure 2. Roller press for removing sap from petioles.

Table 1. Sap yield of (9 half) petioles subjected to multiple pressings and different roller gap widths.

Sample	Roller gap (mm)	Pressing sequence	Sap yield (mL)	Total sap yield (mL)
1	1.30	1st press	5.0	
	0.86	2nd press	5.0	10.0
2	0.86	1st press	5.0	
	0.38	2nd press	10.0	15.0

4. Assessment of sap derived from the developed extraction technique

4.1. Materials and Methods

Petiole samples were collected according to standard procedures on 13/3/2012 and 19/6/2012, from the five treatments of the N rates trial. Sap was extracted from the samples using the developed technique, and was analysed for NO_3^- content by the RQflex 10 and by a commercial laboratory. For each N rate treatment, the same sap was used for both tests. To obtain sufficient sap, multiple pressings of each sample were made, firstly at 1.3 mm roller gap width, and then at 0.86 mm. Analytical procedures recommended by Merck (2009) for the RQflex 10 were followed. Measurements were based on 2 mL of sap and, when required, sap was diluted with distilled water to reduce NO_3^- concentration to within the range of the test strips (5−225 mg/L). Diluted samples were well mix before immersing the test strip, and measured NO_3^- concentration was multiplied by the relevant dilution factor to give the undiluted concentration. Three separate measurements were made on each sample.

4.2. Statistical Methods

The 13/3/2012 RQflex 10 data contained missing values (mainly for the lowest N rate) resulting from sap NO_3^- concentration being below the level of detection of the instrument (< 5 mg/L). These values were estimated from available data using the method of Taylor (1973). This procedure required a log10 transformation, and following estimation of missing data, the data for this sampling date (and also the 19/6/2012 sampling) were analysed using ANOVA. Where a significant treatment effect was found, pairwise comparisons are made using the 95% LSD.

4.2. Results

Extracted sap yields were usually in the range of 15 to 30 mL/sample, for (half) petiole numbers ranging from 4 to 9. For both sampling times, the test effectively discriminated N rate (Table 2), and was highly related to commercial laboratory analysis of NO_3^- concentration (Table 3).

Table 2. Petiole sap nitrate concentration (mg/L) as measured by the RQflex 10 for different nitrogen rates at two sampling times. Data in parenthesis are back-transformed means.

13/3/2012 sample				19/6/2012 sample		
Nitrogen rate (g/plant/fortnight)	Sap nitrate concentration			Nitrogen rate (g/plant/fortnight)	Sap nitrate concentration	
	P < 0.001				P < 0.001	
3.4	-0.512	a	(3.3)	7.1	110	a
4.0	-0.711	a	(5.2)	9.2	242	ab
5.2	-1.032	b	(10.8)	11.2	557	b
7.1	-1.515	c	(32.8)	13.2	1594	c
9.5	-1.917	d	(82.7)	15.3	1998	d
5% lsd	0.213				371	

Means within a column not followed by a common letter are significantly different (P = 0.05). Least significant difference value for the 13/3/2012 sampling relates to transformed data.

Table 3. Correlation coefficients (r) for relationships between nitrate (NO_3^-) concentration as measured by RQflex 10, and nitrogen rate and commercial laboratory nitrate analysis at two sampling times.

	Sampling date	
	13/3/2012	19/6/2012
	r values for the relationships with RQflex 10 measured NO_3^- concentration	
Nitrogen rate	0.893	0.902
Laboratory analysis	0.890	0.978

4. Implications for Objective 3

- The developed sap extraction technique efficiently extracts sufficient volume for the RQflex 10 test, and is adaptable to in-field use where electrical power is not readily available.
- Nitrate concentration of sap extracted by the technique, as measured by the RQflex 10, will discriminate plants growing under different N rate regimes.
- Good relationships between the RQflex 10 and commercial laboratory analysis indicated that the sap extraction/RQflex 10 system could be used as an alternative to laboratory analysis which currently takes up to 3 weeks from field sampling to receipt of test results.

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