Final Report

Nutrient requirements for papaya production

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Nutrient requirements for papaya production (PP20002)

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Content

Summary

This project reviewed the existing scientific evidence base for the nutrient requirements of papaya in commercial production (especially nitrogen and phosphorus) to support the sustainable production of papaya in Australia and identified knowledge gaps which may require further R&D investment.

Current information on the nitrogen (N) and phosphorus (P) requirements of papaya in Australia is based upon RD&E information more than a decade old. The review highlighted that papaya has a tremendous yield potential due to its precocious bearing and indeterminate growth habit with simultaneous vegetative growth, flowering, and fruiting. After a brief juvenile phase, vegetative growth coincides with flower development - an inflorescence emerges continuously in the axil of each leaf, provided climatic and cultural factors are adequate. Based upon published trial data from plant densities of approximately 1,600 plants per hectare, total fruit yields of 128 tonnes/ha from a 2-year crop cycle are not uncommon.

For nitrogen, the review highlighted that papaya is considered a nutritionally heavy feeder. It is an exhaustive crop requiring heavy and continuous supply of nutrients to sustain its high yield potential. Continuous supply of nitrogen through trickle irrigation to meet the demands of the crop as measured by various means such as leaf tissue testing, or petiole nitrate testing was considered to be the current contemporary technique for crop nitrogen management.

Basic nutrient budgeting for nitrogen showed some unaccounted-for nitrogen in the cropping system remained at the end of a 21-24 month cropping cycle.

Knowledge gaps for nitrogen management of papaya were found to exist around defining an industry standard measure and methodology/protocol to manage the optimisation of nitrogen use efficiency of papaya production systems within Australia. Additionally, a knowledge gap exists in defining a universally applicable technique for the application of non-destructive and rapid assessment technology to determine the nitrogen status of papaya crops in a way that allows a nitrogen fertiliser decision process to be undertaken in near real-time.

For phosphorus, the review highlighted that papaya is a relatively light feeder of phosphorus compared to nitrogen and potassium, and that applied phosphorus can quickly become tied up in the soil complex and not readily available for crop uptake.

Basic nutrient budgeting for phosphorus showed significant unaccounted-for phosphorus in the cropping system remained at the end of a 21-24 month cropping cycle.

The literature revealed that papaya plants are dependent on mycorrhizas for their nutrition and benefit greatly from soil mulching and appropriate drainage that facilitate both biotic interactions in the rhizosphere, and phosphorus uptake.

Knowledge gaps for phosphorus management of papaya were found to exist for the role and quantification of biological soil health practices (including mycorrhiza, phosphate solubilising microbes and organic mulches) and their management for increasing the phosphorus use efficiency of papaya. Additionally, the timing and placement of fertiliser to increase papaya phosphorus use efficiency has not been fully explored in the Australian context. Review of the Australian grains R&D on phosphorus use efficiency management via timing and placement management of phosphorus fertiliser may well yield insights into phosphorus management in papaya.

A project factsheet was produced to communicate the findings of the literature review and nutrient budgets developed in this project.

Public summary

Current information on the nitrogen and phosphorus requirements of papaya in Australia is based upon RD&E information more than a decade old. Activities reported in this project include a broad search of the current scientific literature on the nutrient requirements of papaya in commercial production, with a review and analysis of the literature outcomes. The review and analysis of the literature outcomes indicate that there is no one single scientific and commercially accepted protocol for nitrogen crop status measurement and management in Australian papayas and that the role of Arbuscular Mycorrhizal interactions with papaya roots in relation to phosphorus nutrition may require further R&D to clarify its role in the commercial management of papaya phosphorus nutrition.

Basic nutrient budgets were developed for nitrogen and phosphorus in papaya which showed, like most cropping systems in Australia, there were some unaccounted-for nitrogen and significant levels of unaccounted-for phosphorus remaining at the end of a 21-24 month papaya cropping cycle.

A factsheet describing the findings of the literature review and the nutrient budgets was developed to communicate the outcomes of the project.

Keywords

Papaya, nitrogen, phosphorus, knowledge gap, nutrient budget.

Introduction

The Industry

The Australian papaya industry is a small but growing tropical fruit industry. Papaya is produced in tropical Australia, particularly Queensland (85%) dominated by Mareeba and Tully, with remaining commercial production occurring in Western Australia (8%) and the Northern Territory (7%). There are over 130 growers in Australia, and production is dominated by several large producers.

In 2018/19, 14,921 tonnes of papaya were produced with a production value of $27.5 million. The volume of papaya production has remained steady over the last 6 years, while value has increased by $7.5 million (38%) since 2012/13. Supply to the domestic market accounts for 99% of the volume of papaya production, with negligible volumes of processing and exported product. Negligible volumes of product are imported to the fresh market.

Two main varieties of papaya are grown: the red-fleshed variety known as “papaya” accounts for approximately 65% of production volume; the yellow-fleshed (rounded) variety known as “pawpaw” accounts for approximately 35% of production volume.

Papaya grows all year round and because of this the industry has the capacity to provide consistent supply of fruit to consumers and year-round income to growers, although supply peaks in the winter months. Papaya grown in Queensland can be transported to all Australian states and territories except Western Australia because of quarantine restrictions.

Project context

The aim of the project was to provide industry with a better understanding of the current global scientific evidence base for the nutrient requirements of papaya in commercial production through a process of systematic literature review. In addition, the project prioritised knowledge gaps for the nutrient requirements of papaya in commercial production for potential R&D investment.

Clarification of the existing scientific evidence base for the nutrient requirements of papaya in commercial production (especially nitrogen (N) and phosphorus (P)) provides support for the sustainable production of papaya.

Regardless of the relatively minor impact of fertiliser costs on the overall gross margin of papaya production in Australia, best practice fertiliser management is becoming the expected norm from the public and government environmental agencies in order to minimise the impact of off-site nutrient run-off on river systems and the Great Barrier Reef.

Methodology

The project methodology included the following activities:

1. Collation and documentation of current commercial papaya nutrition practices, with specific focus on N and P management and the possible scientific evidence supporting such practices.
2. Collation and documentation of current RD&E projects within Australia that specifically focus on papaya N and P management issues.
3. Scientific literature review of contemporary research on papaya crop nutrition with specific focus on N and P management for crop and environmental responses/outcomes.
4. Knowledge gap analysis and documentation of issues and opportunities that may indicate to Hort Innovation areas for further R&D investment.
5. Basic nutrient budgets developed for nitrogen and phosphorus in an Australian papaya cropping system.
6. A project fact sheet developed to communicate the results of the literature review, the identified knowledge gaps, and the results of the nutrient budgets.

Outputs

Project outputs have been:

1. Literature review including bibliography – Appendix 1.
2. Nutrient budgets for nitrogen and phosphorus – Appendix 2.
3. Project fact sheet summarising the literature review and basic nutrient budgets – Appendix 3.
4. Monitoring and evaluation plan – Appendix 4.
5. Project risk register – Appendix 5.

Outcomes

The project outcomes flowing from the outputs documented above include:

1. Hort Innovation and the papaya industry is fully informed of the scientific evidence for the nutrient requirements of commercial papaya production in the Australian context.
2. Knowledge gaps indicating possible R&D priorities for nutrient management in commercial papaya production are identified.

This is in alignment with the Outcome 2.4 (Continue to research and refine agronomic practices to improve productivity, quality, and environmental outcomes) within the Papaya Strategic Investment Plan 2017-2021. Similarly, the results of this project align with Hort Innovation's investment priority of investing in R&D, extension and marketing activities that deliver crop production, pest and disease management sustainability improvements and address the everyday needs of industry.

Monitoring and evaluation

1 Program logic

Figure 1 Logic model for PP20002

Relevant SIP outcome(s)	**SIP outcome 2.4 - Continue to research and refine agronomic practices to improve productivity, quality and environmental outcomes.**				
End-of-project outcomes	The papaya industry is fully informed of the scientific evidence for the nutrient requirements of commercial papaya production in the Australian context. R&D opportunities for nutrient management in commercial papaya production are identified.				
Intermediate outcomes	Current commercial papaya nutrition practices across Australia documented, with specific focus on N and P management.	Scientific literature review of contemporary research on papaya crop nutrition with specific focus on N and P management for crop and environmental responses. R&D gaps within contemporary papaya projects identified.			
Outputs	Document describing current commercial papaya nutrition practices and RD&E projects within Australia specifically focusing upon N and P.	Scientific literature review of contemporary research on papaya crop nutrition with specific focus on N and P management.	Document describing issues and opportunities that may indicate to Hort Innovation areas for further R&D investment.		
Activities	What you do; i.e. work performed including experiments, field trials, extension events, training, technology development, etc	What you do; i.e. work performed including experiments, field trials, extension events, training, technology development, etc	What you do; i.e. work performed including experiments, field trials, extension events, training, technology development, etc		
Foundational outputs	Current papaya nutritional practices documented. Current papaya nutritional projects identified. Literature review of contemporary scientific information on papaya nutrition. Gap analysis and opportunity identification for future R&D investment in papaya nutrition.				
Foundational activities	Project administration	Baseline data collection	Establishing partnerships	Project planning	Funding

Key evaluation questions

Table 2: Project key evaluation questions

Key evaluation questions	Relevant?	Project-specific questions	Evaluation
Effectiveness			
1. To what extent has the project achieved its expected outcomes?	Yes	To what extent has the project improved knowledge and awareness of contemporary papaya nutrition practices and their environmental impacts?	The project endeavoured to access a broad range of contemporary and historical research reports on papaya nutrition which was synthesised to provide a clear summary of the current knowledge base of papaya nutrition.
Relevance			
2. How relevant was the project to the needs of intended beneficiaries?	Yes	To what extent has the project met the needs of Hort Innovation and industry levy payers?	The project worked closely with Hort Innovation to ensure that outcomes were aligned to industry expectations, while balancing the need for an unbiased and clear report on the reported literature pertaining to the nutrition of papaya in tropical regions of Australia.
Process appropriateness			
3. How well have intended beneficiaries been engaged in the project?	Yes	Have regular project updates been provided through linkage with the industry communication project?	The project conducted an on-line meeting with key growers and industry partners involved in service delivery.
4. To what extent were engagement processes appropriate to the target audience/s of the project?	Yes	Did the project engage with industry levy payers through their preferred communication channel?	An on-line meeting was held with key growers; a factsheet has been completed that will be distributed to all papaya levy payers and other industry stakeholders through the industry communication channels.
Efficiency			
5. What efforts did the project make to improve efficiency?	No		Project team members engaged with Hort Innovation to ensure that project outputs were in line with industry expectations.

Recommendations

Knowledge gaps for nitrogen management of papaya were found to exist around defining an industry standard measure and methodology/protocol to manage the optimisation of nitrogen use efficiency of papaya production systems within Australia. Additionally, a knowledge gap exists in defining a broadly applicable technique for the application of non-destructive and rapid assessment technology to determine the nitrogen status of papaya crops in a way that allows a nitrogen fertiliser decision process to be undertaken in near real time.

Knowledge gaps for phosphorus management of papaya were found to exist for the role and quantification of biological soil health practices (including mycorrhiza, phosphate solubilising microbes and organic mulches) and their management for increasing the phosphorus use efficiency of papaya. Additionally, the timing and placement of fertiliser to increase papaya phosphorus use efficiency has not been fully explored in the Australian context. Review of the Australian grains R&D on phosphorus use efficiency management via timing and placement management of phosphorus fertiliser may well yield insights into phosphorus management in papaya.

Refereed scientific publications

Nil.

References

Refer to Appendix 1 for the full bibliography of the literature review for this project.

Intellectual property, commercialisation, and confidentiality

No project IP, project outputs, commercialisation, or confidentiality issues to report.

Acknowledgements

The author sincerely thanks Yan Diczbalis, Principal Horticulturist at the Department of Agriculture and Fisheries (Queensland) for his generous provision of papaya research reports and reviews of project drafts that added greatly to the depth and coverage of the issues addressed within this project.

Appendices

Appendix 1 – Literature review including bibliography.

Appendix 2 – Nutrient budgets for nitrogen and phosphorus.

Appendix 3 – Grower fact sheet summarising the literature review and basic nutrient budgets.

Appendix 4 – Monitoring and evaluation plan.

Appendix 5 - Project risk register.

PP20002 - Nutrient requirements for papaya production

Literature Search and Knowledge Gap Analysis

Dianne Fullelove & Associates P/L – March 2021

Report as part of Milestone 102 of project PP20002.

Hort Innovation Strategic levy investment | PAPAYA FUND

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

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Introduction

Background

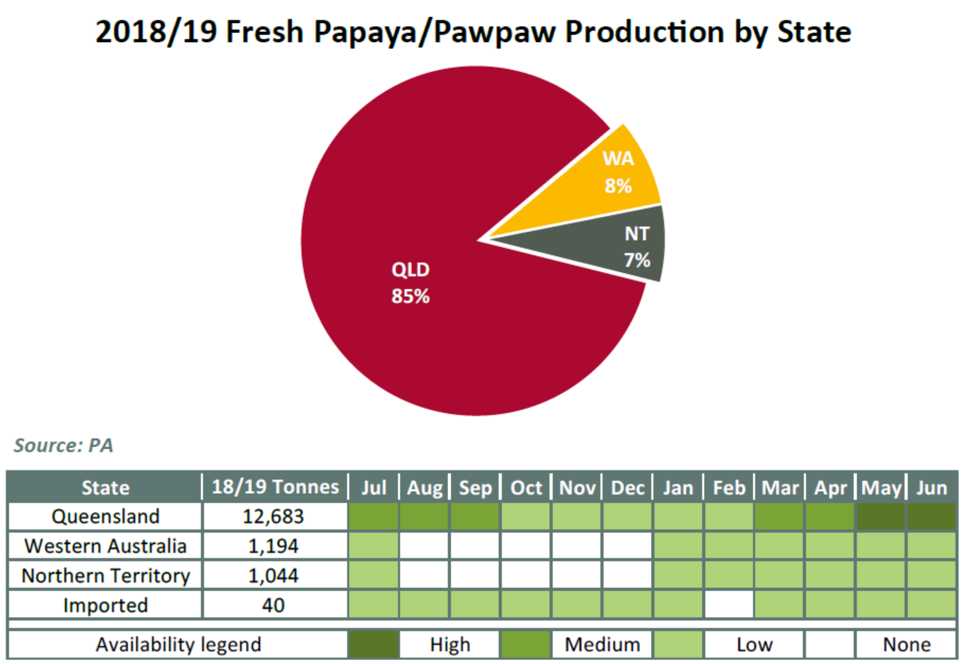
This review will clarify the existing scientific evidence base for the nutrient requirements of Papaya in commercial production (especially Nitrogen (N) and Phosphorus (P) to support the sustainable production of Papaya in Australia and identify any knowledge gaps which may require further R&D investment.

Current information on the N and P requirements of Papaya in Australia is based upon possibly out-dated RD&E information sources. The opportunity exists to review the current scientific literature on the nutrient requirements of Papaya in commercial production to either validate current practices or identify knowledge gaps in the Australian production system to indicate if there is a need for RD&E to boost Australian Papaya crop nutrition management to meet or exceed world's best practice.

Contemporary Australian Context

The Australian Papaya industry is a small but growing tropical fruit industry. Papaya is produced in tropical Australia, particularly Queensland (85%) dominated by Mareeba and Tully, with remaining commercial production occurring in Western Australia (8%) and the Northern Territory (7%) [1 – p. 170]. There are over 130 growers in Australia, but production is dominated by several large producers.

In 2018/19, 14,921 tonnes of Papaya was produced with a production value of $27.5 million [1 – p.168]. The volume of Papaya production has remained steady over the last 6 years, while value has increased by $7.5 million (38%) since 2012/13. 99% of the volume of Papaya production is supplied to the domestic market, with negligible volumes of processing and exported product. Negligible volumes of product are imported to the fresh market.



State	18/19 Tonnes	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Queensland	12,683												
Western Australia	1,194												
Northern Territory	1,044												
Imported	40												
Availability legend			High		Medium			Low			None		

Figure 1. Australian Papaya production by state. [1 - p. 170]

The FAO ranks Australia as 42nd in world Papaya production based upon a production of 6,370 tonnes in 2019. On the FAO list of country production data, production of 14,921 tonnes would rank Australia at 38th, just behind Nepal [6]. The FAO ranks India, Dominican Republic, Brazil and Mexico as the world's greatest producers of Papaya [6].

Two main varieties of Papaya are grown: the red-fleshed variety known as Papaya accounts for approximately 65% of production volume; the yellow-fleshed (rounded) variety known as pawpaw accounts for approximately 35% of production volume.

Papaya grows all year round and because of this the industry has the capacity to provide consistent supply of fruit to consumers and year-round income to growers, although supply peaks in the winter months. Papaya grown in Queensland can be transported to all Australian states and territories except Western Australia because of quarantine restrictions.

The footprint of the Australian Papaya industry shown in Figure 2, is such that 85% of its production area flows into the Great Barrier Reef Marine Park from the Johnstone [2], Tully [3] and Murray [4] catchments and major components of the Barron catchment [5].

Figure 2. Major Papaya producing areas in Queensland [1 – p. 169].

Thorburn et. al. [98] reported that nitrate pollution of groundwaters in coastal Northeastern Australia is of particular concern because of its proximity to environmentally sensitive areas (e.g., the Great Barrier Reef) and the large number of people (in cities and rural areas) relying on groundwaters for drinking water. Their study found overall, groundwaters were relatively free from excessive nitrate contamination, with nitrate concentrations in only 3% of wells above the maximum permissible limit for drinking water (50 mg/l). However, a further 11% had elevated nitrate concentrations (≥20 mg/l). Their study concluded that it is likely that there is potential for reducing nitrate accessions to groundwater through improved nitrogen management.

The Queensland Reef Water Quality Report Card [99] for all of horticulture in Queensland's Wet Tropics Region rates nutrient management an "E" (very poor). See Figure 3 below.

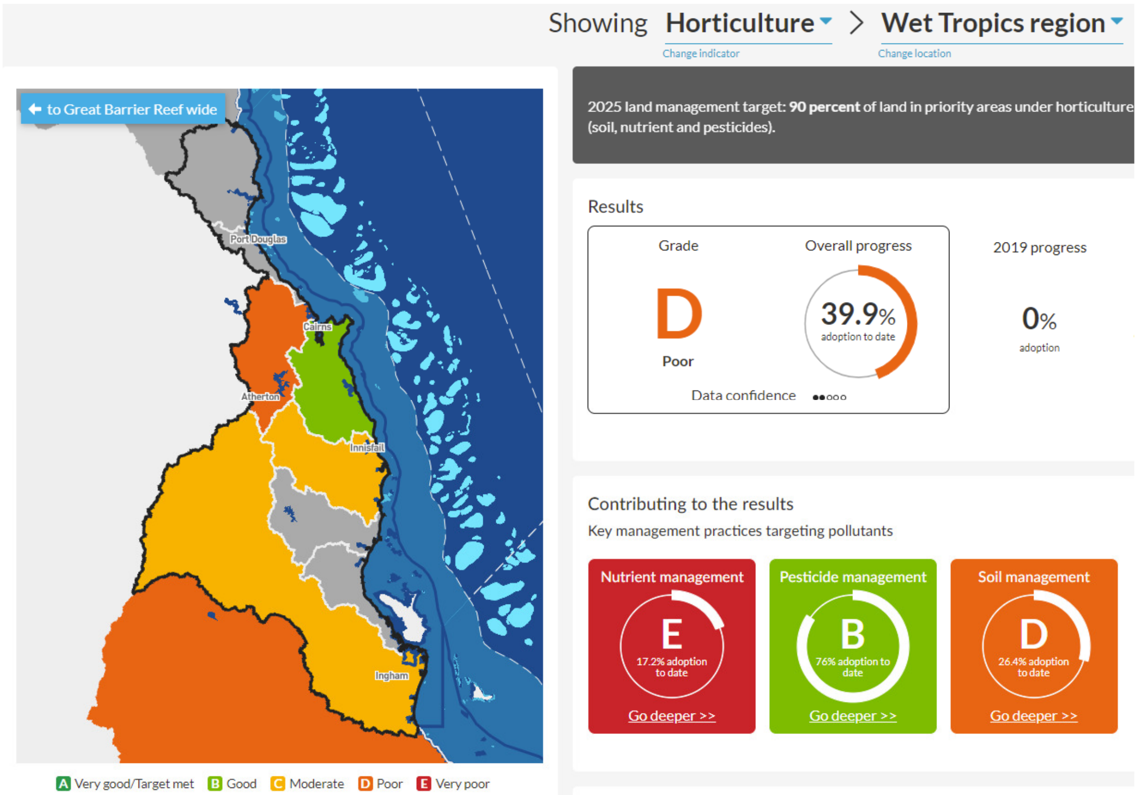


Figure 3. Reef Water Quality Report Card 2019 (current) for Horticulture in Queensland's Wet Tropics.

Community expectations of rural industries are that they show high levels of environmental stewardship to the use and protection of Australia's natural resources. The science-based management of farm nutrient use and any potential off-farm run-off is a community expectation to which the results from this project will contribute a better understanding.

In placing an economic overlay across the N and P nutrition of Papaya, is the recently completed QDAF Papaya gross margin analysis [8]. This tool shows that fertiliser costs represented 3.5% of total variable production costs with the N and P costs alone representing 2% of total variable production costs. A similar analysis of Papaya production economics in Southern Florida [9] indicated that total fertiliser costs represented 15.7% of total variable production costs. The higher proportion of fertiliser costs were due to the very low harvesting and packing costs incurred in the Florida situation. Additionally, the authors noted for their fertiliser calculations – "Because there were such wide variations among the rates applied by the growers we interviewed, we reported the average cost for our analysis.". This would indicate that there exists much variation in fertiliser programmes used by commercial Florida Papaya growers in considering their individual circumstances.

In both gross margin analyses, marketable yield was the main driver of achieving positive gross margins.

However, regardless of the relatively minor impact of fertiliser costs on the overall gross margin of Papaya production in Australia, best practice fertiliser management is becoming the expected norm from the public and government environmental agencies in order to minimise the impact of off-site nutrient movement on river systems and the Great Barrier Reef. This is evidenced by concerns expressed in the “From the Chair” column by Gerard Kath in the May 2020 edition of the Papaya Press [7].

The Crop

Papaya (*Carica papaya* L.) is a soft-wooded, perennial, herb-like, pachycaul tree in the family Caricaceae. It also has common names of Paw Paw and Papaw.

It is believed to have originated along the Caribbean coast of Mesoamerica and spread to many tropical and subtropical regions around the world, where its distribution is limited by chilling sensitivity. Domestication eventually led to substantial changes in vegetative growth and sexual forms that distinguish wild populations from cultivated genotypes. Because of its high yield, nutritional value, functional properties, and year-round fruit production, the importance of this crop around the world is undeniable [11].

Papaya trees can live as long as 25 years, but those in commercial fields are generally less than 3 years old due to reduced productivity by older trees and difficulty in harvesting fruit from tall trees. Papaya trees are generally single stemmed. The main stem, or trunk, is straight and tapers from a 20–30-cm base to a 5–7-cm width at the crown. The trunk is hollow between nodes and is covered with a thin bark that is smooth with prominent leaf scars. Under optimal conditions, Papaya trees are fast growing, producing two to four large palmate leaves per week at the apex and losing a like number toward the base to maintain a crown of 15–30 mature leaves, alternating spirally on the upper 2 m of the stem. Papaya leaves have stout petioles attached directly on the main stem [10].

Papaya is among the few plant species recognized as polygamous with three sexes—female, male, and hermaphrodite [10], [11].

The Papaya root is predominately a non-axial, fibrous system, composed of one or two 0.5–1.0 m long tap roots. Secondary roots emerge from the upper sections and branch profusely. These second order feeding roots remain shallow during the entire life of the plant and show considerable gravitropic plasticity. Many adventitious, lower-order categories of thick and fine roots are also observed in excavated specimens. Healthy roots are of a whitish cream colour. Root phenotypic plasticity is also high. Root size, number, distribution, and orientation adjust readily across the soil profile, to various soil conditions, and throughout the life of the plant [23].

Papaya has a tremendous yield potential due to its precocious bearing and indeterminate growth habit with simultaneous vegetative growth, flowering, and fruiting [12], [13]. After a brief juvenile phase, vegetative growth coincides with flower development - an inflorescence emerges continuously in the axil of each leaf, provided climatic and cultural factors are adequate [19]. Based upon published trial data from plant densities of approximately 1,600 plants per hectare, total fruit yields of 120 tonnes/ha [11] and 128 tonnes/ha [13] from a 2-year crop cycle are not uncommon in the literature. One trial reported up to 224 tonnes/ha in a year of Papaya production [17]. In Australia, marketable yield reduces this total yield figure by between 15-30% [13].

Papaya is therefore considered a nutritionally heavy feeder by all authors. It is an exhaustive crop requiring heavy and continuous supply of nutrients to sustain its high yield potential and also for its indeterminate growth habit with simultaneous leaf and fruit production [14], [15], [16], [18], [20], [21], [22], [24], [26], [48].

Papaya Nutrition

General

This present review focuses upon the management of nitrogen and phosphorus nutrition of Papaya. The findings presented here are based upon adequate supplies of other plant nutrients that researchers have found to be important in producing commercial yields of Papaya. Soil pH, cations such as potassium, calcium and magnesium and micronutrients such as boron, copper, iron, manganese, molybdenum, and zinc have all been noted in the research literature as having an influence on Papaya productivity [24], [25], [26], [56], [57], [58], [59].

The Queensland Department of Agriculture and Fisheries (QDAF) have published several research reports and commercial guides on their research and development (R&D) activities. These form the underlying basis of many Papaya crop management practices currently used commercially in Australia.

Of note is the "Papaya Agrilink Kit" [27]. This publication describes in detail the current interpretation by QDAF scientists of Australian and international research as it applies to managing commercial Papaya crop nutrition.

Other publications from QDAF that detail Papaya nutrition R&D outputs describe petiole sap nitrate correlations [28], investigated the effects of different rates of application of nitrogen and potassium fertilisers on the growth and yield of Papaya at South Johnstone [29] in North Queensland, Growing Papaws in Central Queensland [30], and Growing Papaws in South Queensland [31].

Nitrogen

General

Managing nitrogen fertility in Papaya is a difficult task. Mineral nitrogen is a very mobile and reactive element which undergoes many complex transformations and movements into and out of the soil. In high rainfall growing regions and with the large crop demand of nitrogen by Papaya, the dynamics of in-crop nitrogen management are complex and time critical. Nitrogen is added to the soil in many forms, most commonly as commercial fertilizers, crop residues and cover crops and manures. Nitrogen is also removed from the soil in the harvested portion of crops, by leaching and by gaseous losses to the atmosphere. In addition to these loss pathways, nitrogen undergoes many transformations while in the soil. The most important of these are the biochemical reactions of immobilization and mineralization. Nitrogen that is immobilized is unavailable to plants either because it is held in the tissues of microorganisms or because it has been changed into complex organic forms that resist breakdown. Mineralization is the opposite process where nitrogen in these complex organic forms or in plant residue are broken down into simple molecules that can be absorbed by plants.

By far the majority of the nitrogen in the soil is in the organic form. However, only 1-4 percent of this nitrogen may be mineralized to plant available forms annually. The rate at which these complex forms are broken down into the plant available forms is constantly changing, controlled by a series of interactions of crop residues, soil, microbes, and soil moisture and temperature. When plant residues which are low in nitrogen are incorporated into the soil, it may reduce the amount of nitrogen available to the plants by immobilization by microbes. In crops such as legumes where large amounts of relatively high nitrogen containing residues are incorporated into the soil, the result can be a rapid mineralization by microbes, increasing the inorganic nitrogen available. When high nitrogen containing residues are incorporated into the soil, succeeding crops can draw a substantial portion of the nitrogen they need, perhaps 50% or more, from the organic matter in the soil. From an economic standpoint, it is important to take this mineralized nitrogen into account to minimize fertilizer cost and reduce the chance of excess fertilizer being leached into the groundwater.

The two forms of nitrogen that are taken up by plants are the ammonium and nitrate ions. The ammonium ion has a positive charge meaning that it is held by the soil particles and is resistant to leaching. Nitrate, on the other hand has a negative charge and moves freely in the soil solution and is readily lost by leaching. When soil organic matter is broken down, it is first transformed into ammonium and later it may be transformed into nitrate. When ammonium fertilizers are applied, the ammonium is also converted to nitrate by a process called nitrification. Since ammonium tends to be converted to nitrate in agricultural fields, soils usually contain higher levels of nitrate than ammonium [32].

Because of the complex nature of nitrogen in the soil, it is difficult to know how much fertilizer to apply, potentially resulting in under or over fertilization. The use of soil and plant tissue testing can be a valuable tool for determining the fertilizer needs and maximizing fertilizer efficiency. While plants take up nitrogen in both the ammonium and nitrate forms, nitrate is usually more abundant that ammonium, so nitrogen tests measure nitrate rather than ammonium. In principle, it is a good idea to measure both forms, but that becomes more time-consuming. However, measuring nitrate levels in organic fields or fields fertilized with large amounts of organic material or slow-release nitrogen may not work as well since the plants may take up more of their nitrogen in the ammonium form. Under conventional fertilizer practices, plants tissue contains high levels of nitrate which have been shown over many years to be a good indication of the nutrient status of the plant [33].

Crop Removal

Little, if any Papaya nutritional literature attempts to quantify in detail, the nutrient removal of the crop. Most references point to the USDA raw food data [36]. This source indicates that raw Papaya fruit contain 182mg potassium per 100g of raw fruit and 10mg phosphorus per 100g of raw fruit. No nitrogen or nitrate data is provided. If a fruit yield of 115t/ha is assumed across a 24 month crop cycle, then a nutrient removal by fruit can be calculated to be 207kg of potassium and 11.5kg phosphorus based on this data.

In researching Papaya processing issues, nitrogen content of fruit was calculated across four fruit parts as given in Figure 4 [36].

Stage of maturity	Fresh weight (g)	Percentage contribution by each portion			
		Seed	Endocarp	Mesocarp	Exocarp
Green	443	9	10	71	10
Mature green	616	11	12	67	10
Ripe	716	11	12	67	10

Figure 4. Fresh weights of fruits and the percentage of tissues in fruits at different stages of maturity

The author then provides (Figure 5), on an absolute basis, the amount of nitrate in the mesocarp of green, mature green, and ripe fruits at 538, 58, and 86 micromoles respectively.

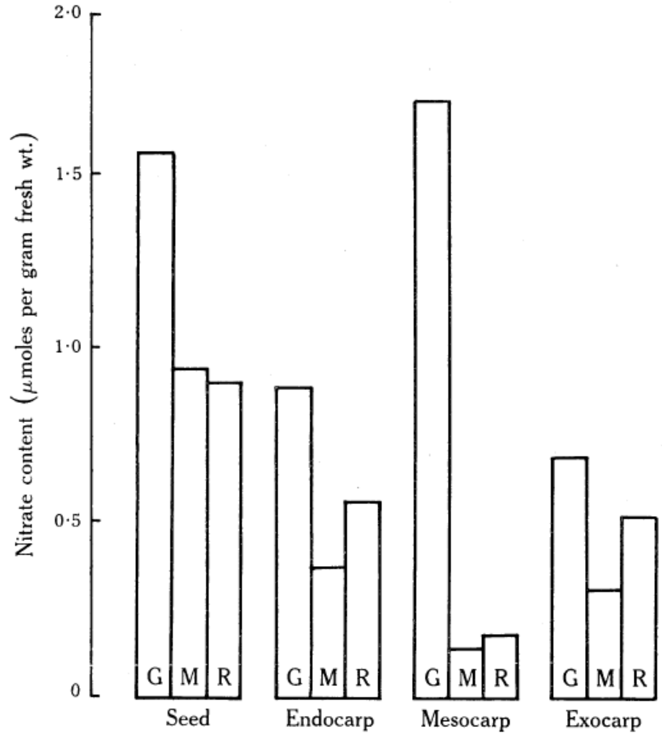


Figure 5. Nitrate content of four Papaya fruit parts of green (G), mature green (M) and ripe (R) fruit [36].

The final amount of nitrogen removed from the crop at harvest remained unaccounted for.

By far the most comprehensive analysis of Papaya nutrient removal is provided in the Papaya Agrilink Kit as shown in Figure 6 [38].

Tree age	3.5 months	5 months	6 months	7 months	8 months	15 months	21 months
Nitrogen							
Uptake	0.86	4.21	6.65	23.5	43.3	124.8	248
Removal	0	0	0	0	10.8	82.2	187
Total	0.86	4.21	6.65	23.5	54.1	207	435
Phosphorus							
Uptake	0.1	0.91	2.42	7.52	7	10.4	44.6
Removal	0	0	0	0	2.5	8	30.4
Total	0.1	0.91	2.42	7.52	9.5	18.4	75
Potassium							
Uptake	1.8	11.1	30.2	55.2	103.5	187	362
Removal	0	0	0	0	18	108	306
Total	1.8	11.1	30.2	55.2	121.5	296	668

Figure 6. Nutrient requirements (kg/ha) to satisfy harvest removal and plant uptake in papaw at various ages for papaws grown in north Queensland. Yield is based on 115t/ha [38].

This growing manual shows how to use this data and provides an improvement to the methodology by using plant girth to estimate crop growth rather than just plant age. This is presented in full below in Figure 7 (with Figure 12 of the growing manual embeded).

For example, over 21 months a total of 435 kg/ha of nitrogen (or 870 kg/ha of urea) is required for plant growth and that which is harvested and removed in the fruit. Between the age of seven and 15 months the plant would need (207 – 23.5) kg/ha = 183.5 kg/ha of nitrogen. To 'balance' the nitrogen application we need to know how much nitrogen is in the soil and apply fertiliser nitrogen as follows:

Fertiliser nitrogen to apply over 21 months
= 435 kg/ha – soil available nitrogen

Soil available nitrogen is complicated and difficult to measure but regular soil tests will help. For example, if 30 mg/kg of nitrogen is available in the soil, then for a rooting depth of 30 cm, over one hectare, the amount of nitrogen available is:

Volume of soil/ha x bulk density of soil x available nitrogen level
=(10000 sq m x 0.3 m) x 1300 kg/cu m x 30 mg/1000000 mg
= 117 kg

This soil is assumed to have a bulk density of 1.3 g/cu m (1300 kg/cu m). Bulk density of soil is the mass of dry soil per unit bulk volume. The bulk is determined before drying to constant weight at 105°C.

Thus, for 21 months we would apply (435 – 117) kg/ha = 318 kg/ha of nitrogen. This is about equivalent to 636 kg/ha of urea.

To determine the application rate per tree, divide amounts shown in Table 7 by the number of trees per hectare.

Nutrient requirements for other soils can then be estimated by using Table 7. You need to know:

- plant age
- crop yield
- soil available nitrate
- potassium, phosphorus, calcium and magnesium levels
- soil density, if possible.

If you do not know these figures, assume that 1 ha of soil 30 cm deep holds 3900 tonnes of soil. The nutrient balance approach must use known soil reserves otherwise simply replacing nutrients that are removed by harvesting will be inadequate.

The balance approach can be improved by considering plant girth, or diameter, in centimetres across the trunk 15 cm above ground level. Figure 7 shows uptake of nutrients for growth and that removed for harvest for papaw plants. From fruiting onwards (about eight months or 8 cm girth), papaw plants rapidly increase nutrient uptake.

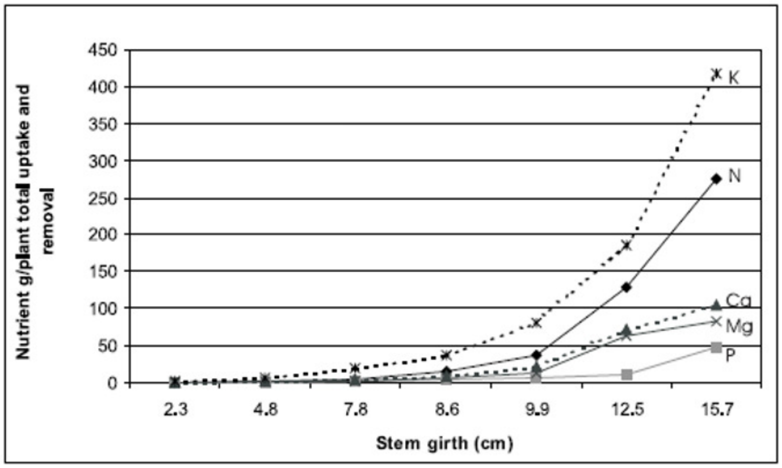


Figure 7. Nutrient balance approach to Papaya nutrition. Nutrient removal and uptake (g/plant) in relation to plant size as measured by stem girth [38].

Huett and Dirou [34], provide data for tropical crops passionfruit, mango and avocado and commend a nutrient balance as a sound approach to developing fertiliser recommendations that can be easily estimated from crop nutrient removal data.

Indian Institute of Horticultural Research provides data (Figure 8), but it is difficult to interpret as the report does not give any clear units for the values presented [35]. They report – "*Percentage distribution, during the development of Papaya, of the total nutrients in the crop at the end of the first year of growth, based on the rate of nutrient absorption estimated at IIHR and nutrient uptake by two year old whole plant of Papaya*."

Crop Stage	N	P	K	S	Ca	Mg	Fe	Mn	Zn	Cu	B
Vegetative Grand growth stage	1.6	2.9	3.5	2.8	3.8	3.1	4.6	4.0	6.3	5.1	6.0
Flowering and fructification	19.2	21.3	21.2	22.4	26.4	24.1	27.6	20.4	28.9	24.3	31.5
Fruit production (harvest)	37.1	33.5	33.3	33.0	41.2	37.3	34.6	38.3	37.5	33.8	39.7

Nutrient uptake by two year old whole plant of papaya

Figure 8. Papaya crop nutrient removal data [35].

In Hawaii, Awada and Suehisa [46] reported in descending order papaw fruit removal of K, N, Ca, Mg, P. They went on to report that quantities of N and K removed by fruits represented 38% and 56% respectively of the amounts applied as fertiliser. They found that significant amounts of nutrients were removed in fruits, as N 132g, P 18 g, K 177 g, Ca 42 g, and Mg 19 g per tree per year. Using a tree density of 1,600 trees per hectare, this equates to 211.2 kg N/ha and 28.8 kg/ha P/ha.

Whilst not comprehensive, sufficient insight into Papaya nutrient removal can be gained from these data sets.

Timing

The bulk of the literature suggests that split applications of nitrogen fertilizer be applied to account for its soil mobility (and potential loss from the root zone) and increasing crop requirement [16], [19], [20], [30], [31], [38], [39], [40], [41], [42], [43], [44], [45], [47].

Only one author [51], reported that “application timing generally had no effects on growth, yields or petiole N content”. The trial however involved four applications of nitrogen fertiliser per year at rather high rates with the only variable being the balance between pre-plant and post-plant splits.

Richards et.al. [29] reported from Queensland grower surveys that the timing of nutrient application (including nitrogen) followed the growth pattern of Papaya and seasonal influences of nutrient availability as shown in Figure 9 below.

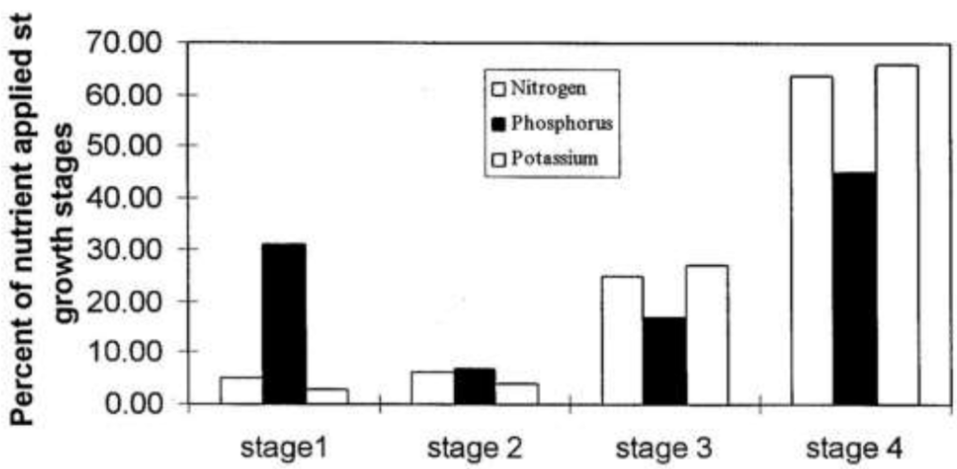


Figure 9. Application of N (on left), P (in centre) and K(on right) fertilisers in relation to Papaya development and fruiting stages.

The whole cycle is for a two year period from planting to last harvest. Stages of development: 1 = pre-plant, 2 = vegetative growth, 3 = flowering/pre-harvest, 4 = flowering/harvest.

Placement

Little if any research findings specifically on the placement of nitrogen fertilisers was uncovered. However, most authors reported fertigation as their application technique for split nitrogen applications which given the Papaya root system plasticity, would indicate that soluble nitrogen fertiliser was being applied into the wetted root zone of the crop .

Where fertigation was not used, application to the soil under each tree canopy was reported. This is assuming that the bulk of the Papaya roots were in that region which seems a very reasonable assumption [49].

Plant nutrient management knowledge on other crops would suggest that placement within the active root zone of Papaya would be the optimum location to place nitrogenous fertiliser.

Rate Response

Many authors have reported an almost linear response of Papaya yield to increasing nitrogen input. A comparison of results from a range of authors is provided by Vawdrey and Justo [28] and presented in Appendix 1. The author in their own trials reported increasing fruit weight per plant with increasing nitrogen rate per hectare continuously up to their maximum nitrogen rate trialled being 620kg N/ha/24 months. The results are presented in Figure 10

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 ($P = 0.05$).

Figure 10. The effect of nitrogen rate on agronomic attributes during Stage 2 (flowering to harvest) [28].

Several authors [53], [54] observed that the increase in the number of fruits produced, due to increased fertilisation with nitrogen, was accompanied by a reduction in fruit weight and size. This was not observed in the results by Vawdrey and Justo [28] under north Queensland trial conditions.

Richards et.al. [29] reported amounts of nitrogen uptake and harvested removal over 21 months for five rates of N studied (Figure 11) and found a peak of 507 kg/ha at the N4 rate and 265 kg/ha at the N1 rate. For mature plants the harvested N proportion of Total N uptake and removal is on average about half and illustrates the effects of intensive and sustained high production levels. They noted the importance of potassium on yield, ahead of nitrogen in terms of both uptake and cropping requirements.

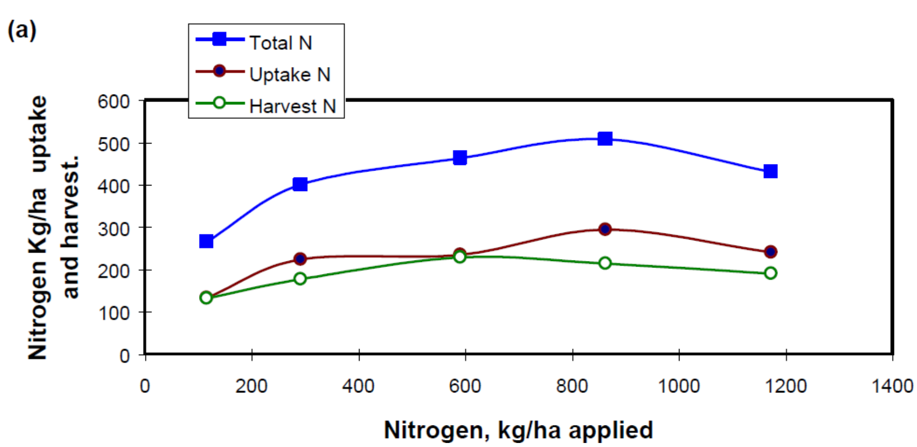


Figure 11. Uptake and fruit removal (kg/ha) in response to applied nitrogen [29].

Richards [29] went on to report "the importance of stems and fruits of Papaya as storage organs for all the macronutrients is apparent from this study, as is the high requirements for K by Papaya plants particularly in roots and fruits. The high rate of fruit production by Papaya crops (135t/ha/year) means that subsequent removal of this harvested fruit draws large quantities of nutrients from the plant/soil system. This removal at maturity, equates to 46% of total uptake and removal for K down to 23% for Ca, with other nutrients in between. There is no doubt thus that the nutrient requirements of Papaya under tropical, irrigated management are high, and Papaya growers in north Queensland believe this also; survey results have shown that mean application rates are 692 kg/ha N, 414 kg/ha P, and 940 kg/ha K per 2 year cycle. The sustainability however of such high average industry application rates does need to be considered, in the light of results from this study and the Papaya nutrition trial which indicated that rates of applied N above 300 kg/ha and applied K above 574 kg/ha does not increase yields".

This indicates possible super-optimal levels of nitrogen fertiliser are being applied to Papaya in Queensland leading to a reduction in the nitrogen use efficiency by the crop.

Fertigation

Due to the higher efficiency of fertigation when compared to traditional broadcast application [52], experimental studies with other crops indicate that, when drip irrigation and fertigation are used, productivity can increase in proportion with the increase in nutrient dosages. For the same dosage, the uses of fertigation can even double productivity. Papaya trees appear to be no different with data of Papaya fruit harvesting in commercial areas pointing to an increase of more than 25% in productivity [52].

Yamanishi and Zuffo [47] translate a paper by Villas Boas et al. [60] indicating this can be explained by the higher efficiency in the take-up of nutrients that occurs with drip irrigation, which are above 80% for N and K and around 70% for P. As a comparison, Yamanishi and Zuffo [47] translate a paper by Lopes and Guilherme [61] who estimate the percentage of efficiency using conventional solid fertilisers is 60% for N and K and only 20 to 30% for P.

Fertigated Papaya tree culture has various advantages when compared to traditional culture, such as labour and energy savings; reduction in soil compaction; efficiency and economy of fertilizers; uniformity of fertilizer application (assuming uniform irrigation application); control of the depth of nutrient application; adequate supply of micronutrients; enhancement of the use of irrigation equipment and uniformity of crops.

The Queensland Agrilink Kit [27] notes for fertigation that, "With fertigation less fertiliser can be applied more often to maintain growth and fruit set. Fertigation is an efficient method of fertiliser application. Labour input is reduced and fertilisers are distributed more uniformly around the plant roots. Nutrients are more rapidly available for plant uptake than by spreading solid fertilisers".

Vawdrey and Justo [28] in reviewing the nitrogen use efficiency of fertigation, noted that the available information at the time did not confirm outright the nutrient use efficiency benefits in Papaya from fertigation. They noted that while both Jeyakuma [55] and Sadarunnisa [52] found improved nitrogen use efficiency with fertigation over conventional application techniques (broadcast), their results were conflicting. In contrast, Vawdrey and Justo [28] report the fertigated rates of two growers in north Queensland that produce economic yields are below non-fertigated rates, suggesting that improved nitrogen use efficiency is possible in Papaya with fertigation.

Soil/Plant Nitrogen Status Measurement

The use of plant analysis as a diagnostic tool has a history dating back to studies of plant ash content in the early 1800s [62]. It's use to commercially manage crop nutrition has developed significantly with many methods now available to commercial Papaya growers in Australia.

Soil testing for crop nutrients is now a standard practice in Australia for making pre-plant fertiliser decisions [63]. It is based upon the premise of the yield response curve given in Figure 12.

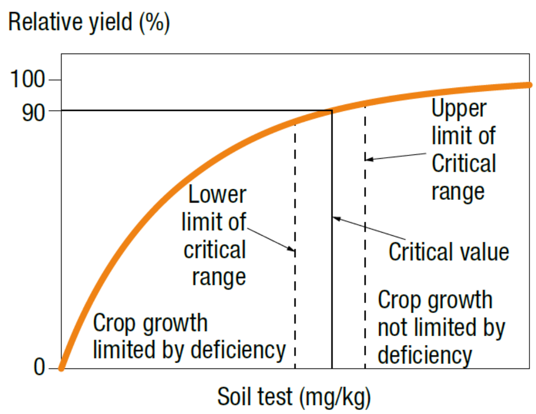


Figure 12. Generalised soil test response calculation curve [63].

The Queensland Agrilink Kit [38], provides the following guide (Figure 13).

Nutrient	Extraction method	Optimum range
PH	1:5 soil:water	5.5 – 6.5
Organic carbon	Walkley – Black	>2%
Nitrate nitrogen	1:5 aqueous extract	>40 mg/kg
Sulphate sulphur	Phosphate extraction	>20 mg/kg
Phosphorus	Sodium bicarbonate extraction(Colwell method)	>30 mg/kg
Potassium	Exchangeable	>0.6 meq/100 g
Calcium	Exchangeable	>3.0 meq/100 g
Magnesium	Exchangeable	>1.0 meq/100 g
Sodium	Exchangeable	<10% exchangeable cations
Chloride	1:5 aqueous extract	<250 mg/kg
Conductivity	1:5 aqueous extract	<0.2 mS/cm
Copper	DTPA extractable	0.3 – 10 mg/kg
Zinc	DTPA extractable	2 – 10 mg/kg
Manganese	DTPA extractable	4 – 45 mg/kg
Iron	DTPA extractable	>2.0 mg/kg
Boron	Hot calcium chloride	1.0 – 2.0 mg/kg

Figure 13. Recommended soil nutrient levels for papaw [38].

For managing crop nutrition during the cropping cycle, some form of crop nutrient analysis is necessary [38].

Traditionally, this has involved sampling a standard plant part and sending the samples away to a laboratory for dry weight analysis. [38]. Many authors have provided data on what nutrient content standards may be useful in interpreting the results in making a fertiliser decision for Papaya [28], [29], [62], [64], [65] [66], [67], [68], [69], [70], [71], [72]].

The Queensland Agrilink Kit [38] presents a comparison of Richards [29] and Reuter and Robinson [62] recommendations for Australian Papaya in Figure 14 below.

Nutrient	Adequate levels Richards[29]	Optimum levels Reuter & Robinson [62]
Nitrogen	1.05%	1.3 – 2.5%
Sulphur		0.3 – 0.8%
Phosphorus	0.27%	0.2 – 0.4%
Potassium	3.5%	3.0 – 6.0%
Calcium	1.15%	1.0 – 2.5%
Magnesium	0.8%	0.5 – 1.5%
Sodium		<0.2%
Chloride		<4.0%
Copper mg/kg		4 – 10 mg/kg
Zinc mg/kg		10 – 30 mg/kg
Manganese mg/kg		35 – 150 mg/kg
Iron mg/kg		20 – 80 mg/kg
Boron mg/kg		20 – 50 mg/kg
Nitrate nitrogen mg/kg	1680	
Sap nitrate nitrogen (RQFlex)	35 mg/L	
Sap potassium (RQFlex)	2400 mg/L	
Sap phosphorus (RQFlex)	118 mg/L	

Note: These values refer to petioles sampled from the youngest fully expanded leaves subtending the most recently opened flowers. RQFlex refers to quick test sap analysis using MERCK Reflectoquant.

Figure 14. Optimum nutrient concentrations for papaw petioles and sap [38].

There now exists additional technologies with which to gain a rapid assessment of the nitrogen status of a Papaya crop [33].

Technologies such as Merck's Reflectoquant meter and test strips [73], and the SPAD 502 chlorophyll meter [74] are two commonly reported instruments [28], [29], [70], [75], [76] [77], [78], [79].

Ali et.al. [33], provides an in depth analysis of the use of the SPAD 502 on chlorophyll determination in plants. He notes there are mainly two limitations which restrict the use of the SPAD meter for indirect N measurement in plant the tissue. The stress-induced sampling errors that influence chlorophyll contents in the plants, and the varietal / species based difference that may lead to variable results from different varieties using the same SPAD meter calibration. The latter problem could be avoided by calibrating the SPAD meter for specific crop variety being grown. He goes onto note that this method is not helpful for detecting luxury N uptake as plants will achieve maximum chlorophyll content regardless of the level of over-fertilization. Porro [100] and Shapiro [101] both report that the majority of leaf nitrogen is contained in chlorophyll molecules. Shapiro [101] reports a two day response lag between soil nitrogen application and chlorphyll increase as measured by a SPAD meter. Additionally, he provides a mthodology for the establishment of adequately fertilised nitrogen reference plots for proper calibration of the nitrogen/chlorophyll relationship.

Choi et.al. [79] reported that SPAD readings were found useful in estimating 'Fuyu' persimmon leaf nitrogen status at a specific time and in quickly judging the need for nitrogen application at that time. Seasonal changes of leaf SPAD readings from five well-managed orchards were presented as a reference guide for practical use (see Figure 15).

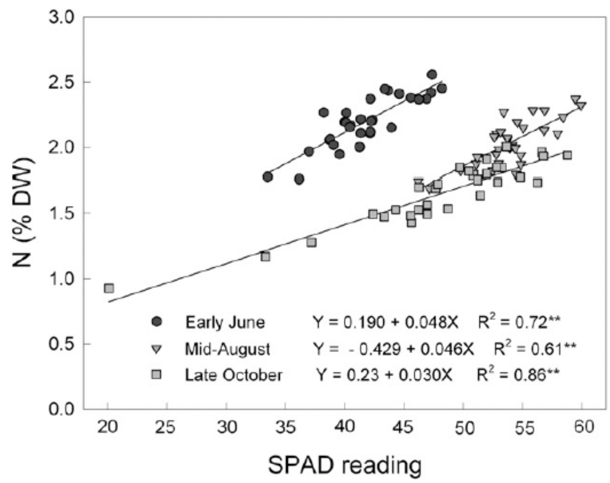


Figure 15. Relationship between the SPAD readings and N concentrations of leaves of 'Fuyu' persimmon [79].

Vawdrey and Lusto [28] reported no significant correlations between petiole nitrate measured with the Merck Reflectoquant Rqflex 10 test strips and nitrogen fertiliser rates (Figure 16). The data did show an increase in petiole nitrate levels (though not significant) up to a rate of 344kg/ha nitrogen. They concluded that further work needs to be done to improve the method of sap extraction and nitrate testing to establish the reliability of the instrument for assessing nitrogen in the Papaya tissue.

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

Figure 16. Petiole nitrate concentration of nitrogen treatments as evaluated by the Reflectoquant RQflex 10 [28].

Unfortunately, the authors did not provide units for their data presented in figure 16 thus rendering comparison to other authors data virtually impossible.

Richards [29], reported the relationship of petiole sap nitrate measured with Reflectoquant RQflex 10 against petiole nitrate nitrogen measured on a dry weight basis in the laboratory (see Figure 17).

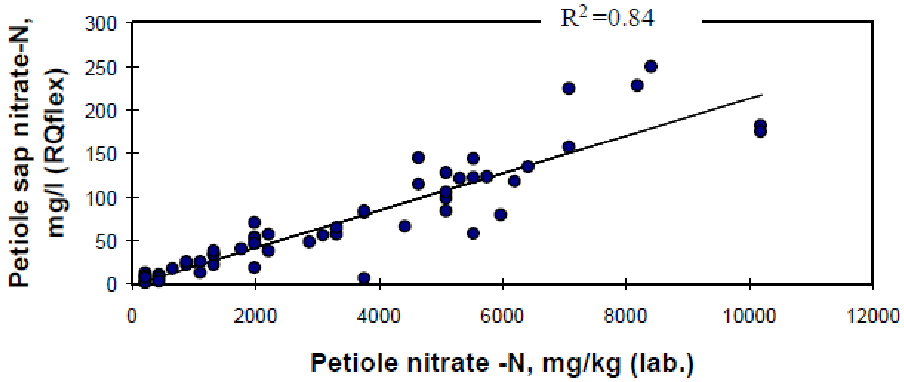


Figure 17. Changes in petiole sap nitrate N (RQFlex) with petiole sap nitrate (laboratory) [29].

Richards [29] also reported the relationship of petiole sap nitrate measured with Reflectoquant RQflex 10 against Papaya yield (see Figure 18).

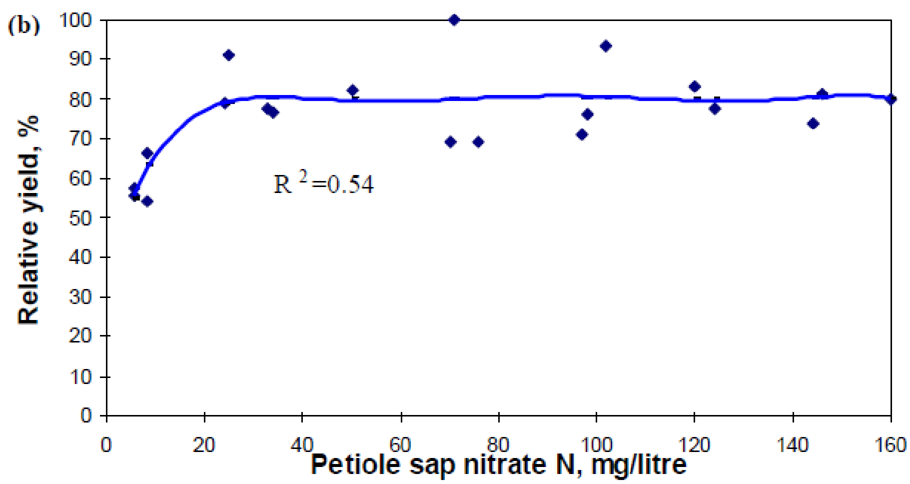


Figure 18. Mean relative yield with petiole sap nitrate N (RQFlex) taken from petiole subtending most recently opened flowers [29].

Nitrogen Knowledge Gaps

A knowledge gap exists in defining an industry standard measure and objective methodology/protocol to manage the optimisation of nitrogen use efficiency of commercial Papaya production systems within Australia.

A knowledge gap exists in defining a broadly applicable technique for the application of non-destructive and rapid assessment technology to determine the nitrogen status of Papaya crops in a way that allows a commercial nitrogen fertiliser decision to be made. The exploration of a non-destructive technique to determine the nitrogen status by direct digital measurement of one or several attributes of the papaya crop would provide real-time decision making data. This could replace the need for destructive sampling that then requires either the sample to be tested at a farm laboratory or a commercial laboratory with additional time frames and laboratory procedures to be incurred.

Phosphorus

General

Plants obtain their phosphorus from the soil solution in the form of $H2PO4^-$ and $HPO42^-$, although plant uptake of $HPO42^-$ appears to be slower than uptake of $H2PO4^-$. The ratio of these two forms is dictated by the pH, with $H2PO4^-$ dominant in acid solutions (pH < 7), and $HPO42^-$ dominant in alkaline solutions. It is important to note that these ions are negatively charged (anions), so the plant will need a different mechanism to take up phosphorus, than the one used for cations uptake. In addition to inorganic phosphate ions, in most soils a substantial proportion of the soil solution phosphorus is present as soluble organic-phosphorus compounds. However, it is unclear whether these forms contribute significantly to plant nutrition [80].

At any instant, the amount of phosphorus in soil solution is only a small fraction of an ecosystem or crops annual requirement. Bulgarelli et.al. [103] suggest that less than 5% of the soil phosphorus is readily available to plants. Thus an important aspect of a soils phosphorus status is its ability to replenish the soil solution following plant phosphorus uptake. This short term replenishment is generally the result of the desorption of specifically adsorbed phosphorus, though dissolution of phosphorus minerals may be a contributor in young soils and in soils that have been highly fertilised. When soluble phosphorus fertiliser is added to the soil the phosphorus concentration is increased, then drops quickly due mainly to a variety of reactions with inorganic soil components and to biological uptake [80].

The tissue phosphorus concentration required for good growth of Papaya is reported as 0.2 – 0.4 %; this is comparable to the demand for sulfur, and about one tenth the demand for nitrogen and potassium [30], [31].

Phosphorus is important for the development of an active root system, and in flower initiation and fruit set. When applied as superphosphate, it is relatively insoluble and moves very slowly through the soil profile. Low pH and high soil iron levels, particularly in leached red soils can reduce phosphorus availability [31].

Crop Removal

Figure 6 and Figure 7 presented earlier in the nitrogen section also report phosphorus crop removal. General consensus from the literature is that 30 – 50 kg/ha per crop cycle of phosphorus is removed.

Jiminez [23] noted that in high-density Papaya plantings, 10kg/ha phosphorus may be extracted but this maybe higher, depending on yield. He went onto to observe, “the development of healthy rhizosphere and mycorrhizal associations should sustain locally tight biogeochemical cycles and guide the formulation of fertilizers and amendments to deal with multiple soil stresses in tropical environments”.

Placement and Timing

As a general guide for phosphorus, the Queensland Agrilink Kit [27] recommends spreading superphosphate along plant rows before mounding as a pre-plant operation and an NPK mixed fertiliser application incorporated into the mound just prior to planting. Ongoing split applications of a NPK mixed fertiliser is suggested if fertigation is not being used.

Richards [29] notes "preplant incorporation of P fertilisers also renders it less subject to erosive loss and potential adverse environmental impacts offsite. It should be possible to supply most of the Papaya crop's lime and P requirements preplant". This is at odds with the recommendation in the Queensland Agrilink Kit [38] for on-going applications.

Bell et.al. [104] [105] goes into some detail in reviewing phosphorus placement and timing of application in broad acre grain crops in Queensland. The authors note that supplying adequate phosphorus for early growth stages (pre-plant "starter" phosphorus) is essential for early vigour and to set yield potential in grain crops, while phosphorus in deeper soil layers helps to meet the demand to grow the crop. They note additionally, that the residual benefits of deep phosphorus bands will persist for a number of years. This may give insights into Papaya phosphorus nutrition as grain crops can remove up to 10kg/ha/crop of phosphorus – not that dissimilar to Papaya over a 24 month cropping cycle. The timing and placement of phosphorus fertiliser to increase phosphorus use efficiency of Papaya seems to not have been fully explored in the Australian context.

Awada and Long [67] reported there was a twofold increase in growth rate of the trunk circumference between trees not supplied any phosphorus and those supplied with phosphorus during the vegetative growth phase of Papaya. They went onto to report that fruiting response of Papaya to phosphorus fertilisation was substantial, with a significant feature being the tremendous increase in fruit-set in trees supplied with high amounts of phosphorus at the early stage of growth.

Awada and Long [67] further noted from their trials that Papaya trees receiving the early phosphorus applications had greater fruit yield than those receiving the late phosphorus, probably because of the greater number of fruits produced in the former. They noted their results on Papaya yield agreed with vegetable research that had reported that in tomato plants a greater yield resulted when phosphorus was applied at planting time than when it was applied to established plants.

Vos and Arancon [59] in their research recommended "applying phosphorus fertilisers, such as triple super phosphate in the plant hole prior to planting to develop a strong root system in the first year after planting. Phosphate fertilisers that are broadcast on the soil surface after the first year may never reach the root system, while incurring unnecessary costs for Papaya farmers and potentially causing environmental problems through phosphorus runoff".

Rate Response

Allan et.al. [57] reported from their trials that total Papaya fruit mass was significantly "*quadratic*" (linear increase initally followed by a reduction in the rate of increase of total fruit mass – but always increasing) for increasing nitrogen and phosphorus rates. They also noted that the response to phosphorus was significantly affected by different levels of nitrogen and potassium.

Awada and Long [67] for the volcanic soils of Hawaii, noted in their conclusions for phosphorus management of Papaya that "*102 lb. during the vegetative stage and 100 lb. from flowering through bearing, with modifications appears appropriate. Because there is a possibility that the percentage of marketable fruits can be raised further by applying less P at the vegetative stage than the amount used in this study, and because there was evidence that the trees needed more P to maintain yield toward the end of the fruit harvest, P at 1 7 lb/acre was subtracted from the 102 lb. scheduled for application before flowering, and this amount (17 lb.) was added to the 100 lb/acre for application during the last 5 months of fruit harvest. Hence , the following fertilization is recommended: P at 85 lb/acre from the vegetative to the bearing stage and at 9.7 lb/acre at 6-week intervals during the bearing stage*".

The Queensland Agrilink Kit [38} recommends 100kg/ha of phosphorus be applied in the pre-harvest stage followed by an additional 180 kg/ha of phosphorus during the harvest stage of the crop cycle. Given that crop removal accounts for between 30-50kg/ha of phosphorus, the nutrient use efficiency of this recommendation seems poor. However, given that some Papaya in Queensland is grown on red krasnozem soils which would tie up in the soil a significant proportion of applied phosphorus [30], [31], such a recommendation could be justified to overcome such soil chemistry constraints. It becomes critical however, to ensure that this fertilised soil is not eroded from the production area thus removing into the environment substantial quantities of phosphorus.

Mycorrhizal Fungi and Rhizosphere Bacteria

Papaya plants are dependent on mycorrhizas for their nutrition and benefit greatly from soil mulching and appropriate drainage that facilitate biotic interactions in the rhizosphere and water and nutrient uptake, especially phosphorus and nitrogen [23].

It is estimated that less than 5 % of the soil P is readily available to plants [103]. In this regard, a role for bacteria, mainly of the Bacillus, Pseudomonas and Penicillium genera, as well as arbuscular mycorrhizal fungi in nutrient acquisition is further demonstrated in their ability to solubilise phosphorus. Phosphate solubilising microbes perform their role by exuding organic acids such as citrate, acetate, succinate and gluconate, as well as by the enzymatic activities of phosphatases and phytases [103]. Thus, within the limits allowed by the complexity of soil chemistry and/or resident soil microbial interactions, microbial formulations, or preparations of organic acids that they produce, could be used as soil amendments specifically in soils with low phosphorus availability [102]. Such formulations could contribute in the recycling of phosphorus fixed in soil from fertiliser treatments, thus reducing the entry of new phosphorus into the fertiliser system. Moreover, as phosphorus has been shown to increase the proliferation of root hairs, the effect on root density in turn could contribute in the better mining and uptake of other nutrients. In this regard, arbuscular mycorrhizal fungi, as part of the root system, are more extensive in nature and could explore spaces not reached by roots to exploit phosphorus for plant use [102].

Four to five genera and 11 species of arbuscular mycorrhizal fungi have been reported associated with Papaya roots: *Glomus* , *Acaulospora* , and *Gigaspora* , among others (Walsh and Ragupathy [86]; Khade et al. [87]). Vega-Frutis and Guevara [88] reported mycorrhizal interactions of male and female Papaya plants may differ: females seem more responsive to changes in soil fertility and readily adjust mycorrhizal colonization accordingly.

Arbuscular mycorrhizal fungi colonisation of Papaya root has been reported by Cruz et al. [81], Ragupathy and Mahadevan [82], and Reddy et.al. [83]. Reddy et.al. [83] found an increase in the growth of Papaya seedlings in nursery conditions was obtained by introducing arbuscular mycorrhizal fungi. In glasshouse seedling trials, Trindade et al. [84] noted a linear response in growth of non- arbuscular mycorrhizal fungi inoculated plants to applied phosphorus (0–240 mg P/dm3), while arbuscular mycorrhizal fungi -inoculated plants displayed a quadratic response (with a large response at low soil phosphorus levels). Working with 1.5-year-old Papaya plants, Mamatha et al. [85] reported an increased fruit yield in the arbuscular mycorrhizal fungi inoculated plants. Plants provided with 50% of the recommended phosphorus fertilisation essentially failed to provide a crop when plants were not inoculated. When inoculated, plants produced fruit biomass equivalent to plants receiving 100% recommended phosphorus. Co-inoculation of plants with *Bacillus coagulans* as a helper bacterium, improved the extent of arbuscular mycorrhizal fungi infection of Papaya roots, but there was no synergistic effect on fruit yield of co-inoculation.

In their Central Queensland studies, Walsh and Ragupathy [86] found the enhanced frequency of arbuscular mycorrhizal fungi colonisation of plant roots under mulching treatments, compared to the bare ground treatments, is consistent with a role for arbuscular mycorrhizal fungi in the observed increase in growth and fruit yield of Papayas in mulched treatments (Elder et. al. [89], Elder et.al. [90]). They noted that mycorrhizal colonisation may affect the mineral nutrition of the host plant by enhancing plant growth through nutrient acquisition by the fungus or indirectly modifying transpiration and the composition of rhizosphere microflora.

Gianinazzi [91] in his review noted that external mycorrhizal hyphae can deliver up to 80% of plant phosphorus, 25% of plant nitrogen, 10% of plant potassium, 25% of plant Zinc and 60% of plant Copper.

Additionally, several authors [92], [93], [94], [95], [96], [97] have reported increased Papaya yields with the addition of biological soil amendments/supplements along with reduced manufactured fertiliser inputs.

Measuring Crop Status

Soil testing before planting is recommended in all texts. Figure 13 in the nitrogen section notes that greater than 30g/kg of phosphorus extracted from the soil sample using the Colwell method is the optimum range for phosphorus.

Figure 14 in the nitrogen section provides two leaf phosphorus ranges that are published to guide growers in maintaining adequate phosphorus nutrition in Papaya. Interestingly, Richards' {29] optimum phosphorus level is approximately in the middle of the optimum phosphorus range provide by Reuter and Robinson [62] which possibly suggests that a large flat "optimum" plateau of leaf phosphorus levels exists in the yield response of Papaya to plant phosphorus levels as measured in plant tissue.

The need for a rapid test to measure the phosphorus status of a Papaya crop is not deemed as important as a nitrogen and/or potassium rapid test given the significantly lower amounts of phosphorus used by the crop and the large, less mobile, soil reserves generally developed in cropping land after several seasons of cropping. This may imply that a pre-plant soil test for phosphorus is generally sufficient to generate a phosphorus management plan for a standard Papaya crop cycle.

Phosphorus Knowledge Gaps

The role and quantification of biological soil health practices (including mycorrhiza, phosphate solubilising microbes and organic mulches) and their management for increasing the phosphorus use efficiency of Papaya and minimising off-site movement of phosphorus remains a gap in the literature.

The timing and placement of phosphorus fertiliser to increase phosphorus use efficiency of Papaya seems to not have been fully explored in the Australian context. Review of the Australian grains R&D on phosphorus use efficiency management via timing and placement management of phosphorus fertiliser may well yield insights into phosphorus management in Papaya.

Conclusions

This literature search has provided scientific evidence that Papaya is an intensive high yielding, high nutrient requirement crop. Yields of over 150t/ha from a 24 month crop cycle are not uncommon and can be easily attained with intensive crop management.

As fertiliser inputs form only a small expense item in the Papaya gross margin, the provision of luxury amounts of nitrogen and phosphorus during the crop cycle are a “safe” option for many producers. However the risk of low crop nutrient efficiencies and the risk of off-site movement of nitrogen and phosphorus are increased under this management protocol.

The review has found that an industry standard protocol for rapidly measuring the nitrogen status of a Papaya crop and making a commercial nitrogen fertiliser decision that optimises crop yield and nitrogen use efficiency is yet to be fully developed. Technologies such as fertigation, soil testing leaf testing, petiole sap nitrate testing and chlorophyll measurement have been trialled but a broadly applicable industry standard protocol has yet to be developed. This is in comparison to other industries that in part face the Great Barrier Reef such as sugarcane that have standardised on the “Six Easy Steps” protocol [106] for nitrogen management.

The review also found that Papaya plants are dependent on mycorrhizas for their phosphorus nutrition and benefit greatly from soil mulching and appropriate drainage that facilitate biotic interactions in the rhizosphere. Further exploration of the commercial application of arbuscular mycorrhizal fungi colonisation of Papaya root and the introduction and management of phosphate solubilising microbes seems warranted. Additionally, the timing and placement of phosphorus fertiliser to increase phosphorus use efficiency of Papaya seems to not have been fully explored in the Australian context.

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Appendix 1 – Information for nitrogen rates derived from the literature and north Qld papaya industry [28].

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.

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.

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PP20002 - Nutrient requirements for papaya production

High Level Nutrient Budget for Nitrogen and Phosphorus

Dianne Fullelove & Associates P/L – April 2021

Report as part of Milestone 190 of project PP20002.

Table of Contents

Hort Innovation Strategic levy investment | PAPAYA FUND

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

Background – Nutrient Budgets

Nutrient budgeting is a technique used to quantify or predict nutrient deficits or surpluses, either at a whole-farm or field scale, in an attempt to improve nutrient use efficiency and reduce nutrient losses from agriculture. A broad range of nutrient budgeting approaches are used internationally, and depending on their purpose, they vary from the simple to the very complex. Nutrient budgeting has been widely used to assist on-farm nutrient management decisions, in research to identify major nutrient pools, transformations and losses, to enable farmers to access cost-sharing support from governments, and in some countries as a major regulatory tool (4).

The implementation of farm/block nutrient budgets using element balances as tools to meet environmental targets for nutrient management in agriculture assumes that there is a relation, direct or indirect, between nutrient surpluses and their environmental impact. Intuitively, it may seem correct to assume that a reduction in nutrient inputs will result in a corresponding reduction in losses, and therefore also impact on the wider environment. There are, however, both theoretical reasons and practical examples to suggest that the relation is not so simple. At best, nutrient balances and surpluses provide an integrated measure of the total nutrient loss potential. At any time, a nutrient surplus may either be temporarily stored within the system (e.g. in the soil) or dissipated directly to the wider environment. Conversely, a decrease in nutrient surplus may not translate directly into decreased losses. A nutrient surplus is at best an indicator of total nutrient losses to the wider environment if integrated over a relatively long period (5).

Farm-gate nutrient budgets do not normally attempt to directly quantify environmental losses such as Phosphorus and Nitrogen runoff, Phosphorus and Nitrogen leaching, denitrification or Nitrogen volatilisation, as these are difficult to measure and are highly variable in space and time (4). Although the primary purpose of using nutrient budgeting is to reduce nutrient surplus and potential for loss to the environment, evidence of a direct link between nutrient budgeting and reduced nutrient surplus at the farm scale and reduced environmental losses at the catchment scale is scarce (6).

Shober et.al. (3) presents diagrammatic representations of the Nitrogen and Phosphorus cycles in their fact sheet on nutrient budgeting.

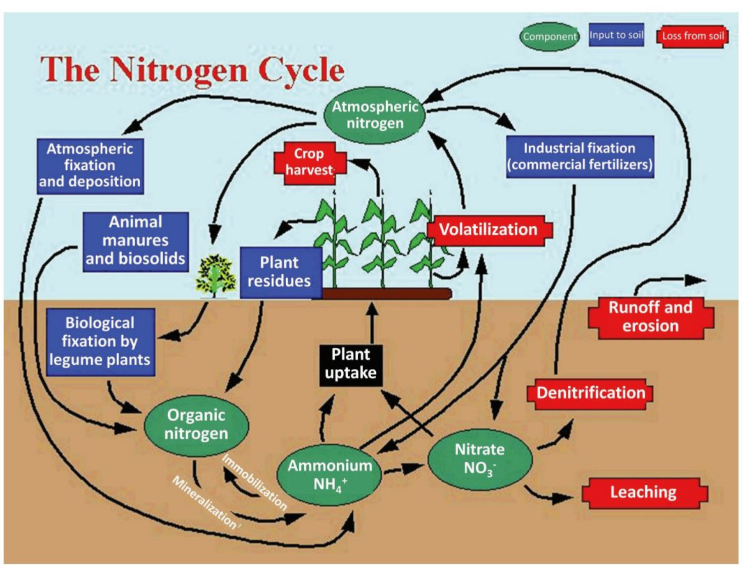

Figure 1 – The Nitrogen Cycle (3).

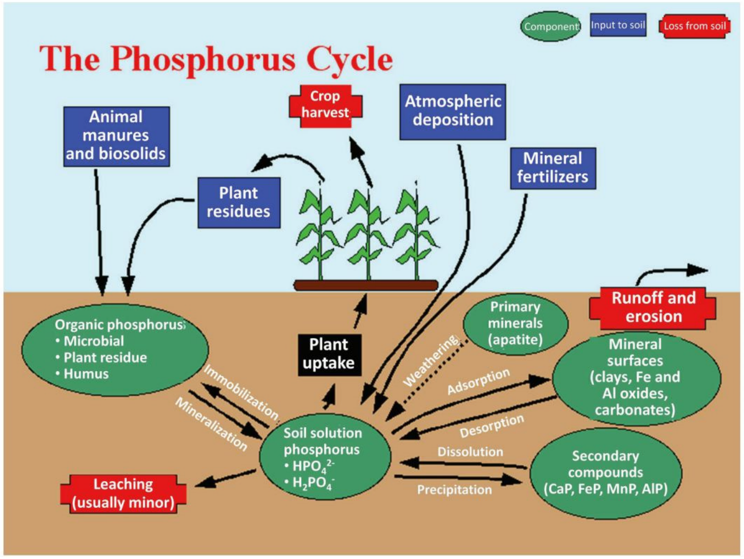

Figure 2 – The Phosphorus Cycle (3).

This high-level study does not attempt to account for each nutrient flow in the above diagrams, but at a paddock level, simply attempts to account for a soil nutrient starting state, crop inputs and removals, a nutrient ending state leaving an unaccounted-for amount.

Papaya Nitrogen

Several Queensland studies have previously endeavoured to quantify Nitrogen use and losses of a 21-month papaya crop grown in North Queensland.

Richards et.al. (11) described papaya Nitrogen data as per Figure 3 and Table 1 below.

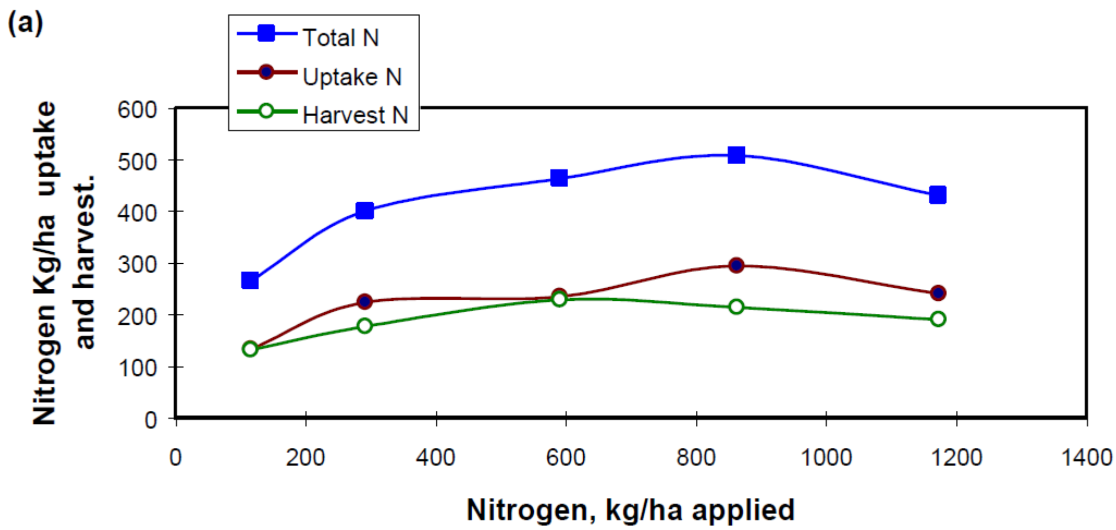

Figure 3 – Uptake and fruit removal (kg/ha) in response to applied Nitrogen. (11)

Table 1 - Nitrogen balance sheet for Nth Qld papaya (11)

	N1	N2	N3	N4	N5
Total soil N %	0.17	0.13	0.15	0.145	0.145
Est.Soil reserves avail N at Dec 1995, g	25.7	19.6	22.7	22	22
N applied g/plant	70	177	358	523	711
N reserves + applied	96	197	381	545	733
Plant uptake and harvest loss, g	177	266	308	338	287
N reserves +applied -uptake -harvest, g	-82	-69	73	207	446
Soil nitrate N Mar 97 mg/kg	4.5	40	55	122	159
Soil avail NH_4 N Mar 97 mg/kg	2.7	3.9	7	59	127
Total Soil avail N reserves Mar 97	5.5	32	47	137	216
N unaccounted for g/plant	86.8	101	-25.7	-70	-230
N unaccounted for kg/ha	144	167	-42.6	-116	-382

The Nitrogen content of harvested papaya fruit is not commonly reported in literature, however Richards et.al. (11) provides a figure on a dry weight basis and several indirect sources provide data sufficient to estimate a figure (7), (8), (9), (10).

High level nutrient budget scenarios for papaya are presented below using values for a range of variables in line with Queensland research (11), (12). Nitrogen content in rainfall was assessed as per levels reported in (1) and (2) but due to the insignificant addition of Nitrogen to the cropping system from this source, this amount was not included in the given scenarios.

Nitrogen Budget

Scenario #1

Data similar to Project FR405

Assumptions							
	Soil bulk density	1260	kg/cu.m				
	Soil root volume per plant	0.6	cu.m		756	soil - kg/plant	
	Plant density	1660	plants/ha		1254960	soil - kg/ha	
	Calculated soil weight per plant						
	Calculated soil weight per hectare						
	Fruit moisture content	92	%				
	Green mature fruit N content (dw)	1.97	%				
	Green mature fruit N content (fw)	0.158	%				
	Fruit yield (removed from field)	120	t/ha		72.3	kg/tree	
Starting State				per plant		per hectare	
	Soil Nitrate Nitrogen	12	mg/kg	0.009	kg	15	kg
Crop Additions							
	Nitrogen from fertiliser	360	g/plant	0.36	kg	598	kg
	Nitrogen mineralised from soil	23	g/plant	0.023	kg	38	kg
Crop Removal							
	Nitrogen in fruit	-189	kg/ha	-0.114	kg	-189	kg
Ending State							
	Nitrogen in crop residue	-248	kg/ha			-248	kg
	Soil Nitrate Nitrogen	-40	mg/kg	-0.030	kg	-50	kg
Unaccounted for				0.099	kg	164	kg

Scenario #2

Fruit moisture content changed to USDA standard for papaya.

Assumptions							
	Soil bulk density	1260	kg/cu.m				
	Soil root volume per plant	0.6	cu.m		756	soil - kg/plant	
	Plant density	1660	plants/ha		1254960	soil - kg/ha	
	Calculated soil weight per plant						
	Calculated soil weight per hectare						
	Fruit moisture content	88	%				
	Green mature fruit N content (dw)	1.97	%				
	Green mature fruit N content (fw)	0.236	%				
	Fruit yield (removed from field)	120	t/ha		72.3	kg/tree	
Starting State				per plant		per hectare	
	Soil Nitrate Nitrogen	12	mg/kg	0.009	kg	15	kg
Crop Additions							
	Nitrogen from fertiliser	360	g/plant	0.36	kg	598	kg
	Nitrogen mineralised from soil	23	g/plant	0.023	kg	38	kg
Crop Removal							
	Nitrogen in fruit	-284	kg/ha	-0.171	kg	-284	kg
Ending State							
	Nitrogen in crop residue	-248	kg/ha			-248	kg
	Soil Nitrate Nitrogen	-40	mg/kg	-0.030	kg	-50	kg
Unaccounted for				0.042	kg	69	kg

Scenario #3

Yield (fruit removal) reduced to 100t/ha.

Assumptions							
	Soil bulk density	1260	kg/cu.m				
	Soil root volume per plant	0.6	cu.m		756	soil - kg/plant	
	Plant density	1660	plants/ha		1254960	soil - kg/ha	
	Calculated soil weight per plant						
	Calculated soil weight per hectare						
	Fruit moisture content	92	%				
	Green mature fruit N content (dw)	1.97	%				
	Green mature fruit N content (fw)	0.158	%				
	Fruit yield (removed from field)	100	t/ha		60.2	kg/tree	
Starting State				per plant		per hectare	
	Soil Nitrate Nitrogen	12	mg/kg	0.009	kg	15	kg
Crop Additions							
	Nitrogen from fertiliser	360	g/plant	0.36	kg	598	kg
	Nitrogen mineralised from soil	23	g/plant	0.023	kg	38	kg
Crop Removal							
	Nitrogen in fruit	-158	kg/ha	-0.095	kg	-158	kg
Ending State							
	Nitrogen in crop residue	-248	kg/ha			-248	kg
	Soil Nitrate Nitrogen	-40	mg/kg	-0.030	kg	-50	kg
Unaccounted for				0.117	kg	195	kg

Scenario #4

Yield (fruit removal) increased to 135t/ha.

Assumptions								
	Soil bulk density		1260	kg/cu.m				
	Soil root volume per plant		0.6	cu.m		756	soil - kg/plant	
	Plant density		1660	plants/ha		1254960	soil - kg/ha	
	Calculated soil weight per plant							
	Calculated soil weight per hectare							
	Fruit moisture content		92	%				
	Green mature fruit N content (dw)		1.97	%				
	Green mature fruit N content (fw)		0.158	%				
	Fruit yield (removed from field)		135	t/ha		81.3	kg/tree	
Starting State					per plant		per hectare	
	Soil Nitrate Nitrogen		12	mg/kg	0.009	kg	15	kg
Crop Additions								
	Nitrogen from fertiliser		360	g/plant	0.36	kg	598	kg
	Nitrogen mineralised from soil		23	g/plant	0.023	kg	38	kg
Crop Removal								
	Nitrogen in fruit		-213	kg/ha	-0.128	kg	-213	kg
Ending State								
	Nitrogen in crop residue		-248	kg/ha			-248	kg
	Soil Nitrate Nitrogen		-40	mg/kg	-0.030	kg	-50	kg
Unaccounted for					0.084	kg	140	kg

Papaya Phosphorus

North Queensland research has shown there is poor correlation between phosphorus fertiliser use and papaya yields. The krasnozem soils have a high ability to bind phosphorus, limiting availability to plants (12).

Richards et.al. (11) presented data showing the total phosphorus uptake and removal of a 21-month North Queensland papaya crop cycle in Figure 4 below.

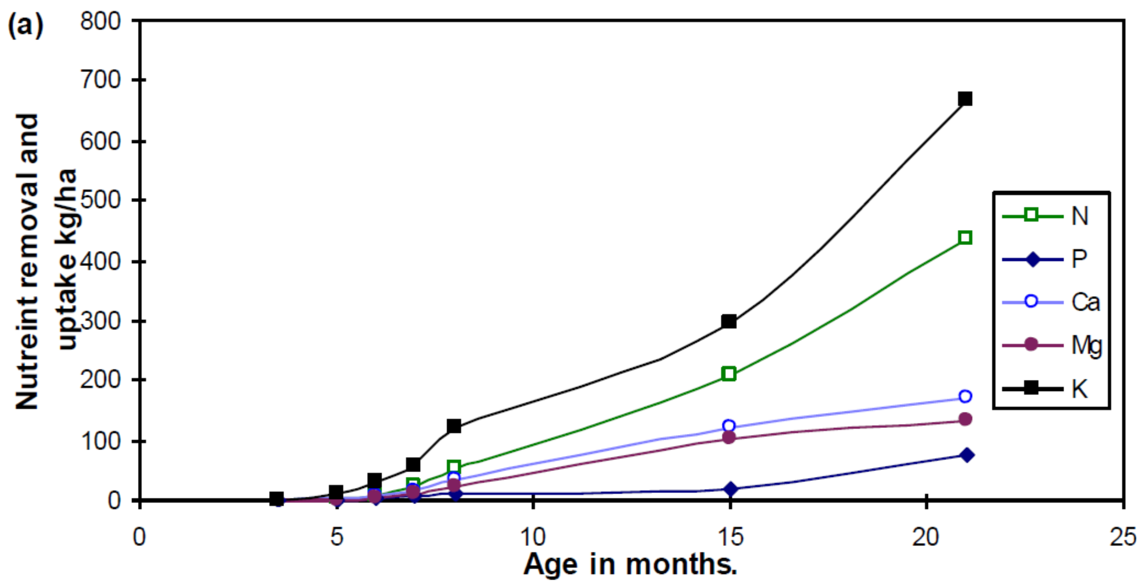

Figure 4 – Nutrient removal and uptake of a 21-month papaya crop cycle in North Queensland.

Richards et.al. (11) concluded, for phosphorus nutrition of papaya, that scope existed for investigating ways of enhancing Phosphorus uptake through practices such as timing of soil pH adjustment, frequency and method of application and the form of Phosphorus fertiliser used on the crop.

High level nutrient budget scenarios for papaya are presented below using values for a range of variables in line with major Queensland reports (11), (12).

Phosphorus Budget

Scenario #1

Data similar to Project FR405

Papaya - Draft Nutrient Budget Worksheet for Phosphorus							
Assumptions							
	Soil bulk density	1260	kg/cu.m				
	Soil root volume per plant	0.6	cu.m			756	soil - kg/plant
	Plant density	1660	plants/ha			1254960	soil - kg/ha
	Calculated soil weight per plant						
	Calculated soil weight per hectare						
	Fruit moisture content	92	%				
	Green mature fruit P content (fw)	25	mg/100g			0.25	g P / kg fruit
	Fruit yield (removed from field)	120	t/ha			72.3	kg/tree
Starting State				per plant		per hectare	
	Soil Phosphorus (Colwell)	50	mg/kg	0.038	kg	63	kg
Crop Additions							
	Phosphorus from fertiliser	250	g/plant	0.25	kg	415	kg
	Phosphorus from soil reserves	63	g/plant	0.062748	kg	104	kg
Crop Removal							
	Phosphorus in fruit	-30	kg/ha	-0.018	kg	-30	kg
Ending State							
	Phosphorus in crop residue	-45	kg/ha			-45	kg
	Soil Phosphorus	-50	mg/kg	-0.038	kg	-63	kg
Unaccounted for				0.268	kg	444	kg

Scenario #2

USDA fruit content data

Assumptions									
	Soil bulk density			1260	kg/cu.m				
	Soil root volume per plant			0.6	cu.m		756	soil - kg/plant	
	Plant density			1660	plants/ha		1254960	soil - kg/ha	
	Calculated soil weight per plant								
	Calculated soil weight per hectare								
	Fruit moisture content			88	%				
	Green mature fruit P content (fw)			10	mg/100g		0.1	g P / kg fruit	
	Fruit yield (removed from field)			120	t/ha		72.3	kg/tree	
Starting State						per plant		per hectare	
	Soil Phosphorus (Colwell)			50	mg/kg	0.038	kg	63	kg
Crop Additions									
	Phosphorus from fertiliser			250	g/plant	0.25	kg	415	kg
	Phosphorus from soil reserves			63	g/plant	0.062748	kg	104	kg
Crop Removal									
	Phosphorus in fruit			-12	kg/ha	-0.007	kg	-12	kg
Ending State									
	Phosphorus in crop residue			-68	kg/ha			-68	kg
	Soil Phosphorus			-50	mg/kg	-0.038	kg	-63	kg
Unaccounted for						0.265	kg	439	kg

Conclusions

The scenarios presented above indicate that papaya has a very high requirement for nitrogen over a 21-month production cycle and that at the end of the crop, significant amounts remain in the field crop residue (roots, stem, leaves, petioles, unharvested fruit) and a portion cannot be accounted for at this level of Nitrogen budgeting.

For Phosphorus, luxury levels appear to be applied which may explain the lack of response to applied Phosphorus, however the luxury levels seem to be standard practice in an attempt to overcome the high Phosphorus binding (limiting availability for plant use) nature of the soils. Like Nitrogen, there appears to be significant differences between fertiliser input of Phosphorus and harvested crop removal.

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Hort Innovation Papaya R&D Levy Project – PP20002

April 2021

Nutrient Requirements for Papaya Production

Project Background

Current information on the nitrogen (N) and phosphorus (P) requirements of papaya in Australia is based upon RD&E information more than a decade old. The opportunity exists to review the current scientific literature on the nutrient requirements of papaya in commercial production to either validate current practices or identify knowledge gaps in the Australian production system that indicate the need for RD&E to bring Australian papaya crop nutrition management closer to world's best practice.

The results and outputs of this project will:

- provide the papaya industry with a better understanding of the current global scientific evidence base for the nutrient requirements of papaya in commercial production through a systematic literature review
- prioritise any knowledge gaps for the nutrient requirements of papaya in commercial production for potential R&D investment.

Industry

The Australian papaya industry is a small tropical fruit industry. Papaya is produced in tropical Australia, particularly Queensland (85%) dominated by Mareeba and Tully, with remaining commercial production occurring in Western Australia (8%) and the Northern Territory (7%). There are over 130 growers in Australia, but production is dominated by several large producers. In 2018/19, 14,921 tonnes of papaya were produced with a production value of $27.5 million.

The volume of papaya production has remained steady over the last 6 years, while value has increased by $7.5 million (38%) since 2012/13. 99% of the volume of papaya production is supplied to the domestic market, with negligible volumes of processing and exported product. Insignificant volumes of product are imported to the fresh market.

The footprint of the Australian papaya industry is such that 85% of its production area flows into the Great Barrier Reef Marine Park. Community expectations of rural industries are that they show high levels of environmental stewardship to the use and protection of Australia's natural resources. This project will contribute to the science-based management of farm nutrient use and any potential off-farm impact.

Literature Review Summary

Papaya (*Carica papaya* L.) is a soft-wooded, perennial, herb-like, pachycaul tree in the family Caricaceae. It also has common names of Paw Paw and Papaw.

Papaya has a tremendous yield potential due to its precocious bearing and indeterminate growth habit with simultaneous vegetative growth, flowering, and fruiting. After a brief juvenile phase, vegetative growth coincides with flower development - an inflorescence emerges continuously in the axil of each leaf, provided climatic and cultural factors are adequate. Based upon published trial data from plant densities of approximately 1,600 plants per hectare, total fruit yields of 128 tonnes/ha from a 2-year crop cycle are not uncommon.

One trial reported up to 224 tonnes/ha in a year of papaya production. In Australia, marketable yield reduces this total yield figure by between 15-30%.

Papaya is therefore considered a nutritionally heavy feeder by all authors. It is an exhaustive crop requiring heavy and continuous supply of nutrients to sustain its high yield potential and its indeterminate growth habit with simultaneous leaf and fruit production.

The Queensland Department of Agriculture and Fisheries (QDAF) have published several research reports and commercial guides on their research and development (R&D) activities. These form the underlying basis of many papaya crop management practices currently used commercially in Australia.

Of note is the "Papaya Agrilink Kit". This publication describes in detail the current interpretation by QDAF scientists of Australian and international research as it applies to managing commercial papaya crop nutrition. Nitrogen and phosphorus uptake into the crop and removal through fruit harvest is presented in the "Papaya Agrilink Kit" and shown below in Table 1.

Nitrogen

The bulk of the literature suggests that split applications of nitrogen fertilizer be applied to account for its soil mobility (and potential loss from the root zone) and increasing crop requirement.

Little, if any research findings specifically on the placement of nitrogen fertilisers was uncovered. However, most authors reported fertigation as their application technique for split nitrogen applications which given the papaya root system plasticity, would indicate that soluble nitrogen fertiliser was being applied into the wetted root zone of the crop.

Many authors have reported an almost linear response of papaya yield to increasing nitrogen input. In one North Queensland trial report the author reported increasing fruit weight per plant with increasing nitrogen rate per hectare continuously up to their maximum nitrogen rate trialled being 620kg N/ha/24 months.

Another North Queensland researcher reported amounts of nitrogen uptake and harvested removal over 21 months for five rates of N studied and found a fruit removal peak at approximately 600kg/ha/21 months for nitrogen.

Tree age	3.5 months	5 months	6 months	7 months	8 months	15 months	21 months
Nitrogen							
Uptake	0.86	4.21	6.65	23.5	43.3	124.8	248
Removal	0	0	0	0	10.8	82.2	187
Total	0.86	4.21	6.65	23.5	54.1	207	435
Phosphorus							
Uptake	0.1	0.91	2.42	7.52	7	10.4	44.6
Removal	0	0	0	0	2.5	8	30.4
Total	0.1	0.91	2.42	7.52	9.5	18.4	75

Table 1. Nutrient requirements (kg/ha) to satisfy harvest removal and plant uptake in papaw at various ages for papaws grown in north Queensland. Yield is based on 115t/ha

Nutrient Requirements for Papaya Production

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Hort Innovation Papaya R&D Levy Project – PP20002

For mature plants, the harvested N proportion of total N uptake and removal is on average about half and illustrates the effects of intensive and sustained high production levels. See Figure 1.

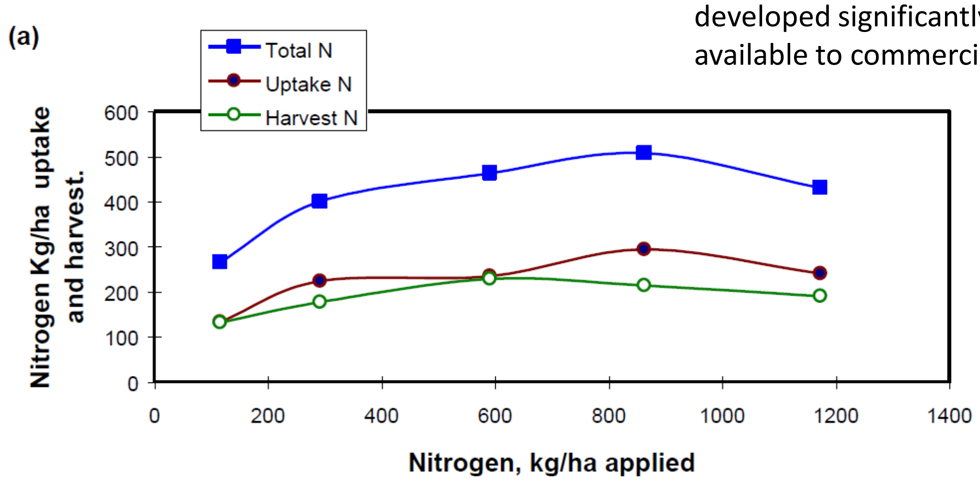

Figure 1. Uptake and fruit removal (kg/ha) in response to applied nitrogen

The use of plant and soil analysis as a diagnostic tool has a history dating back to studies of plant ash content in the early 1800s. It's use to commercially manage crop nutrition has developed significantly with many services now available to commercial Papaya growers.

The "Papaya Agrilink Kit" presents soil and leaf analysis test levels and their interpretation in making soil management and fertilizer decisions.

There now exists additional technologies with which to gain a rapid assessment of the nitrogen status of papaya.

There is no doubt that the nutrient requirements of papaya under tropical, irrigated management are high. Grower survey results from North Queensland have shown that mean application rates are 692 kg/ha N and 414 kg/ha P per two-year cycle. However, the sustainability of such high average industry application rates does need to be considered in the light of results from these previous studies which indicated that rates of applied N above 300 kg/ha only marginally increase yields.

Due to the higher efficiency of nitrogen fertigation when compared to traditional broadcast application, productivity can increase. With a productivity increase of 25% when fertigation is used, papaya trees appear to respond the same as many other crops to this application method.

Technologies such as Merck's Reflectoquant meter and test strips, the SPAD 502 chlorophyll meter, and Near Infrared Spectroscopy (NIR S) are three commonly reported instruments used to rapidly gauge the nitrate status of plant tissue.

A knowledge gap exists in defining an industry standard measure and methodology/protocol to manage the optimisation of nitrogen use efficiency of papaya production systems within Australia.

A knowledge gap exists in defining a broadly applicable technique for the application of non-destructive and rapid assessment technology to determine the nitrogen status of papaya crops in a way that allows a nitrogen fertiliser decision process to be undertaken in near real time.

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Phosphorus

Phosphorus is important for the development of an active root system, and in flower initiation and fruit set. When applied as superphosphate, it is relatively insoluble and moves very slowly through the soil profile. Low pH and high soil iron levels, particularly in leached red soils can reduce phosphorus availability.

Consensus from the literature is that 30 – 50 kg/ha per crop cycle of phosphorus is removed.

As a general guide for phosphorus, the "Papaya Agrilink Kit" recommends spreading superphosphate along plant rows before mounding as a pre-plant operation and an NPK mixed fertiliser application incorporated into the mound just prior to planting.

The "Papaya Agrilink Kit" recommends 100kg/ha of phosphorus be applied in the pre-harvest stage followed by an additional 180 kg/ha of phosphorus during the harvest stage of the crop cycle. With crop removal accounting for between 30-50kg/ha of phosphorus, the nutrient use efficiency of this recommendation seems poor. However, given that some papaya in Australia are grown on red soils that tie up a significant proportion of applied phosphorus, such a recommendation could be justified to overcome such soil chemistry constraints. It becomes critical however to ensure that this fertilised soil is not eroded from the production area releasing into the environment substantial quantities of phosphorus.

Papaya plants are dependent on mycorrhizas for their nutrition and benefit greatly from soil mulching and appropriate drainage that facilitate biotic interactions in the rhizosphere and phosphorus uptake.

Soil testing before planting is recommended in all reports. The literature notes that greater than 30g/kg of phosphorus extracted from the soil sample using the Colwell method is the optimum range for papaya for soil phosphorus.

The need for a rapid test to measure the phosphorus status of a papaya crop is not deemed as important as a nitrogen rapid test given the significantly lower amounts of phosphorus used by the crop and the large, less mobile, soil reserves generally developed in cropping land. This may imply that a pre-plant soil test for phosphorus is generally sufficient to generate a phosphorus management plan for the crop.

A knowledge gap exists for the role and quantification of biological soil health practices (including mycorrhiza, phosphate solubilising microbes and organic mulches) and their management for increasing the phosphorus use efficiency of papaya.

The timing and placement of fertiliser to increase papaya phosphorus use efficiency has not been fully explored in the Australian context. Review of the Australian grains R&D on phosphorus use efficiency management via timing and placement management of phosphorus fertiliser may well yield insights into phosphorus management in papaya.

Hort Innovation Strategic levy investment | PAPAYA FUND

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

Project M&E Plan

Nutrient requirements for papaya production (PP20002)

Dianne Fullelove & Associates Pty Ltd

January 2020

Contents

1 Program logic

Relevant SIP outcome(s)	**SIP outcome 2.4 - Continue to research and refine agronomic practices to improve productivity, quality and environmental outcomes**		
End-of-project outcomes	The Papaya industry is fully informed of the scientific evidence for the nutrient requirements of commercial papaya production in the Australian context. R&D opportunities for nutrient management in commercial papaya production are identified.		
Intermediate outcomes	Current commercial papaya nutrition practices across Australia documented, with specific focus on N and P management.	Scientific literature review of contemporary research on papaya crop nutrition with specific focus on N and P management for crop and environmental responses. R&D gaps within contemporary papaya projects identified.	
Outputs	Document describing current commercial papaya nutrition practices and RD&E projects within Australia specifically focussing upon N and P.	Scientific literature review of contemporary research on papaya crop nutrition with specific focus on N and P management.	Document describing issues and opportunities that may indicate to Hort Innovation areas for further R&D investment.
Activities	What you do; i.e. work performed including experiments, field trials, extension events, training, technology development, etc	What you do; i.e. work performed including experiments, field trials, extension events, training, technology development, etc	What you do; i.e. work performed including experiments, field trials, extension events, training, technology development, etc

Foundational outputs	Current papaya nutritional practices documented. Current papaya nutiritional projects identified. Literature review of contemporary scientific information on payaya nutrition. Gap analysis and opportunity identification for future R&D investment in papaya nutrition.				
Foundational activities	Project administration	Baseline data collection	Establishing partnerships	Project planning	Funding

Figure 1 Logic model for PP20002

2 Project M&E scope

2.1 Audience

For assistance, refer to Section 1: Project M&E Guide – part 2.1.

➢ *Complete the M&E audience and their information needs for your project in Table 1.*

Table 1: M&E audience and their information needs

Audience	Information need
Primary	
Project team	Project progress status – timelines and budget.
Hort Innovation	Project plans. Project progress updates. Levels of levy payer engagement in the project.
Papaya Industry	A succinct project outputs summary for papaya growers.
Secondary	
Project stakeholders and growers	General update on project progress.

2.2 Key evaluation questions

Table 2: Project key evaluation questions

Key evaluation questions	Relevant?	Project-specific questions
Effectiveness		
1. To what extent has the project achieved its expected outcomes?	Yes	To what extent has the project improved knowledge and awareness of contemporary papaya nutrition practices and their environmental impacts?
Relevance		
2. How relevant was the project to the needs of intended beneficiaries?	Yes	To what extent has the project met the needs of Hort Innovation and industry levy payers?
Process appropriateness		
3. How well have intended beneficiaries been engaged in the project?	Yes	Have regular project updates been provided through linkage with the industry communication project?
4. To what extent were engagement processes appropriate to the target audience/s of the project?	Yes	Did the project engage with industry levy payers through their preferred communication channel?
Efficiency		
5. What efforts did the project make to improve efficiency?	No	

2.3 M&E budget

The M&E activities are budgeted within project management and administration including the development of the program logic framework, the monitoring and evaluation plan and the project risk register.

Budget is $2,500 and delivered via normal project activities and record keeping by the project team.

3 Performance expectations, data collection and analysis

Table 3: Project monitoring plan

Logic level	What to monitor	Performance expectation (KPIs) and/or monitoring questions	Data collection – method (e.g. survey) and source (e.g. growers)	Timing of, and responsibility for, data collection
Foundational activities	Start up meeting with Hort Innovation and industry stakeholders.	Performed as part of MS 102	Record keeping (Project Leader)	As start up meeting occurs (Project Leader)
Activities and outputs	Current papaya nutrition practices documented Current papaya nutrition projects documented Literature review completed	Document published Document published Review published	Record keeping (Project Officer)	Ongoing (Project Officer)
Intermediate outcomes	Changes in awareness of project stakeholders on contemporary papaya nutrition issues and related R&D opportunities.	Number of communication products delivered.	Record keeping (Project Officer)	Ongoing (Project Officer)
End-of-project outcomes	R&D opportunities for nutrient management in commercial papaya production are considered by Hort Innovation and SIAP.	R&D investment informed by project outputs.	Post-project review of papaya R&D investments made by Hort Innovation	Papaya levy investment cycle (SIAP)

4 Evaluation

Note: A well-designed monitoring plan usually provides the information you need to demonstrate project effectiveness. Any data collected at the point of evaluation usually complements the monitoring data to either answer the effectiveness KEQ more fully and/or answer other evaluation questions identified in Table 2.

Table 4: Additional evaluation data requirements

KEQ	Data collection requirement	Source and method
	'NA'	

5 Reporting and continuous improvement

Table 5: Project progress reporting

Report type	To whom	Timing
Milestone Reports	Hort Innovation	As per contract
Final Reports	Hort Innovation	At end of project
Articles	Industry magazine	Near end of project
Written fact sheet	Industry	Near end of project
Financial reports	Project Partners	At end of project

Table 6: Project continuous improvement activities

Continuous improvement process	Details	Timing
Team meetings	Meeting of project team members to discuss project progress and adjust accordingly to deliver on-time and on-budget.	Monthly
Project Reference Group meetings	Meetings between project team members, Hort Innovation and industry representatives to gain feedback on project activities and refine methodology	Start up meeting and others as required.

Risk matrix table – PP20002

Risk	Inherent risk rating	Mitigation strategy	Residual risk
Project not supported by industry	Moderate	Industry will be engaged in the process and outcomes of the project.	Minor
Poor project coordination	Low	Experienced staff are available to manage the project and have delivered this type of program previously and in other industries.	Minor
Content and delivery mechanism poorly designed, not relevant	Low	Research supports that vale of mentoring/ coaching in gaining trust and delivering outcomes in rural extension. SMEs co-opt into the program through an Expression of Interest. SMEs contribute funds for in-country visit.	Minor
Project personnel do not have appropriate qualifications, knowledge and experience	High	As outlined in proposal, project personnel are experienced in agronomy, research and reviews with rural industries.	Low
Information and conclusions drawn in final recommendations misussed or misinterpreted	High	Fully contextualise all recommendations made in the final report. Ensure that all recommendations are in line with the objectives of the project and not outside the scope of the project. Standard Hort Innovation disclaimer statement included in final report.	Minor
Project activities are disrupted due to external circumstances eg Covid-19	Moderate	Travel is not essential to this project Meetings can be conducted online.	Low

		CONSEQUENCE RATINGS				
		Low	**Minor**	**Moderate**	**High**	**Very High**
LIKELIHOOD RATINGS	**Almost Certain**	MINOR	HIGH	HIGH	VERY HIGH	VERY HIGH
	Likely	MINOR	MODERATE	HIGH	HIGH	VERY HIGH
	Possible	LOW	MINOR	MODERATE	HIGH	VERY HIGH
	Unlikely	LOW	MINOR	MODERATE	MODERATE	HIGH
	Rare	LOW	LOW	MINOR	MODERATE	HIGH