RURAL INDUSTRIES RESEARCH
& DEVELOPMENT CORPORATION

Rambutan

Improving Yield and Quality

A report for the Rural Industries Research and Development Corporation

by Yan Diczbalis

November 2002

RIRDC Publication No 02/136
RIRDC Project No DAQ-251A (Rambutan)

ISBN 0642 58535 0
ISSN 1440-6845

Rambutan: Improving Yield and Quality
Publication No. 02/136
Project No. DAQ-251A (Rambutan)

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Published in November 2002
Printed on environmentally friendly paper by Canprint

Foreword

Rambutan (*Nephellium lappaceum* L.) and Longan (*Dimocarpus rambutan* Lour.) are popular exotic fruits native to Asia. Australia produces approximately 300 to 500 tonnes/annum of longan returning $2.0M, while rambutan production ranges from 500 to 1000 tonnes/annum valued at a maximum of $4.5M. The production of these crops in Australia is still in its infancy with rapid development in industry size, marketing and export opportunities occurring within the last decade.

Despite the rapid growth in these industries, there is still little research and documentation on production requirements. Both industries in association with RIRDC, DPI (Queensland Horticulture Institute) and the Northern Territory Department of Primary Industry (Horticulture Branch) have produced strategic plans for their development. The commissioning of this project is a result of the strategic planning exercise, with both industries rating further research on nutrient and irrigation requirements and management high on their agenda.

This publication (Part two – Rambutan) highlights the outcomes of an industry based leaf and soil nutrient and irrigation monitoring survey in rambutan orchards located in north Queensland (17 - 18^{o}S). The report discusses the concept of a nutrient budget and presents irrigation management guidelines to assist the rambutan industry in the management of fertiliser and water inputs.

This project was funded from RIRDC Core Funds (New Plant Products program) that are provided by the Federal Government.

This report, a new addition to RIRDC's diverse range of over 800 research publications, forms part of our *New Plant Products* R&D program, which aims to facilitate the development of new industries based on plants or plant products that have commercial potential for Australia.

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Simon Hearn
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Acknowledgements

The author would like to acknowledge the assistance of the rambutan industry and in particular the members who cooperated in the project. Without their contribution this project would not have been possible. Special thanks (in alphabetical order) to;

Brian and Jan Dodds
Fred and Marilyn Groom
Paul Koy
Barry and Kay Helmuth
Ken and Robin Lake
John and Denise McCormack
Keith Noble
Pedro and Marg O'Connor
Steve Ridolfi
Pius and Cynthia Sabag
Peter and Alison Salleras
Sue Smith
Mick and Jean Thompson
Les and Bev Williams
Joe, Ivy and Alan Zappala

Thanks, also goes to DPI staff that have assisted me with the project, in particular, Ian Bally and Dr. James Drinnan who started data collection prior to my joining the Department. Special thanks is extended to Gil Alvero for his dedication to his position as part time field officer in particular for his ability to assemble and maintain the weather stations used during the project. Colleagues in the Department of Natural Resources and Mines, Dr's. Phil Moody, V. Rasiah and John Armour, are thanked for their assistance with nutrient budgeting and nutrient loss concepts and fruit analysis.

My thanks to Pivot Fertilisers for supporting the development of the rambutan industry through their discounted analysis costs for project co-operators and in particular to Don Pollock, formally of Pivot Fertiliser who facilitated the transfer of analysis data from the laboratory to myself.

Many thanks to Pedro O'Connor and Alan Zappala for editorial comment on an early draft.

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Executive Summary

The rambutan (*Nephelium lappaceum* L.) is a tropical fruit and member of the Sapindaceae family closely related to the lychee and longan. The rambutan tree can grow to 10 m in height and up to 14 m in width.

The rambutan is native to west Malaysia and the island of Sumatra in Indonesia (Watson, 1984, Tindall 1994). The native environment of the rambutan is characterized by high rainfall (evenly distributed), high humidity, low evaporation rates and average minimum temperatures above 20^{o}C (Diczbalis et al. (1996).

Seedling rambutans were first introduced into Australia in the 1930's and commercial plantings commenced in the 1970's (Watson 1988). From the early 1970's to 1988 fifty-one cultivars were imported into Australia and underwent preliminary evaluation at Kamerunga on the outskirts of Cairns (Watson, 1988). The rambutan industry in Australia is now located in the NT and north Queensland (Lim and Diczbalis 1998). The industry initially spread along the coast north and south of Cairns (Cooktown 16^{o}S to Tully 18^{o}S). Trees were introduced to the Northern Territory in the early 1980's where a small but active industry is established in the rural areas near Darwin (12^{o}S). Current Australian plantings are reported to be in the vicinity of 40,000 trees and the annual production can range from 500 to 1000 tonnes is valued at a maximum of $4.5M (RTEGA 2002). The main commercial varieties in Australia include; R9, R134, R156(red), R162, R167, Binjai, Jitlee and Rongrien.

The Australian rambutan and longan industries, together with DPI, NT DPIF and RIRDC and other bodies have, over the last few years engaged in detailed assessments of industry research and development needs. Industry strategic plans have been developed for the rambutan industry (Anon 1997) and a commitment to support research has been made by the relevant organizations. The rambutan industry has identified nutrition and irrigation research as a priority issue.

The project aims were to;

- monitor changes in rambutan leaf and soil nutrient status over three seasons
- measure grower fertiliser inputs in relation to the above
- assess the effect of nutrient status on productivity
- monitor tree phenology in relation to climate and irrigation management
- quantify rambutan water/irrigation requirements.

This report details the findings of three years of study from July 1998 to May 2001. As a result of this project rambutan researchers, extension officers, growers and associated industry organizations are now able to access an improved understanding of the effect of nutrition on yield. Tentative leaf and soil standards were developed to use as a guide to fertiliser management.

The project was unable to identify any direct links between tree nutritional status, fertiliser inputs and yield. Its important to note that all commercial orchards surveyed had relatively high leaf nutrient status and no unfertilized trees were included in the study. This suggests that within the range of nutrient status observed other factors such as pruning practices and climate play a more important role in flowering and subsequent yield.

A guide to fertiliser requirements was developed using a nutrient budget approach where nutrient inputs are based on fruit production and removal and take into account additional nutrient loss via leaching, runoff and fixation.

As a result of the development of a nutrient budget, inputs can now be geared to production rather than based on an *ad-hoc* approach. This allows for potential savings on fertiliser inputs, however, more importantly the nutrient budget approach has the potential to reduce fertiliser loss and hence contamination of sub-soils and drainage systems.

Rambutan irrigation requirements during fruit filling were monitored at three sites. In north Queensland high rainfall, spread through out much of the year, negates the need for irrigation for much of the year. When low rainfall or dry conditions occur, observations suggest that evaporation rates based on work carried out in the Northern Territory be used. Hence irrigation requirements can be calculated using a simple evaporation based calculation;

Irrigation Requirements = canopy area (m^2) * Evaporation Rate (mm/week) * Crop Factor

Growers are advised to monitor the above irrigation input recommendations with readily available soil moisture sensing technology and where possible the addition of a water flow meter. These simple tools allow the orchard manager to fine tune irrigation inputs to their crop, season and soil type.

As an outcome of the project rambutan growers should be encouraged to monitor fertiliser inputs in conjunction with regular leaf and soil analysis and yield records. In this way fertiliser inputs can be geared more closely to nutrient outputs. The following key points should be included in a monitoring system;

- Develop fertiliser input worksheets that can be easily transferred to spread sheet software packages.
- Use of the tentative leaf and soil standards as a guide to current fertiliser management strategy.
- Develop a fertiliser management spreadsheet based on nutrient removal through fruit and other loss factors and encourage it use among industry members.
- Use the nutrient budget to develop a fertiliser program for the season, based on yield projections.
- Promote the use of fertigation to improve the application efficiency of fertiliser application.
- Monitor rambutan yields in conjunction with fertiliser management records to validate the nutrient budget approach over a minimum of 5 seasons, to reduce the effects of climate and other management issues (eg. pruning) on yield.

1. Introduction

1.1 Background

The rambutan (*Nephelium lappaceum L.*) is a tropical fruit and member of the Sapindaceae family closely related to the lychee and longan. Seedling rambutan trees can grow to 25 m in height and up to 14 m in diameter. Clonal stock are smaller with height usually less then 10 m. Trees are naturally well branched with pruning adding to branching complexity. The tree bark is smooth to rough, depending on origin, Leaves are described as alternate, paripinnate with 4 to 6 leaflets ovate to obovate in shape. New growth is light pink to green coloured and quickly develops into light green and then dark green as the leaves become fully formed and mature. Inflorescences are usually terminal, bearing small flowers that are either male (stamens well developed), or hermaphrodite. The hermaphrodite flowers can be either functioning female or male. The flowers are generally less than 6 mm in diameter and greenish in colour. The fruits are large (25 to 45 g in weight) and ovoid to globose in shape. Generally 5 to 20 fruits occur on a panicle. The outer skin (pericarp) is 2-4 mm thick and covered in long soft spines (spinterns). Fruits take 3 to 6 months to mature depending on cultivar and growing climate. In tropical regions 3 to 4 months is the usual duration from flowering to fruit maturity (van Welzen and Verheij, 1991; Yaacob and Subhadrabandhu, 1995; Nakasone and Paull, 1998).

The rambutan is considered to be a native of west Malysia and the island of Sumatra (Indonesia). van Welzen and Verheij, (1991) report that the origin is untraceable because escapees from cultivation blur the original distribution. They claim the species ranges from southern China down through the Indo-Chinese region and the Philippines. The crop is now grown in a number of locations outside its natural distribution including Central America, Sri Lanka, India, New Guinea, tropical Africa, Hawaii and northern Australia.

Seedling rambutans were first introduced into Australia in the 1930's and commercial plantings commenced in the 1970's (Watson 1988). From the early 1970's to 1988 fifty-one cultivars were imported into Australia and underwent preliminary evaluation at Kamerunga on the out skirts of Cairns (Watson, 1988). The rambutan industry in Australia is now located in the NT and north Queensland (Lim and Diczbalis 1998). The industry initially spread along the coast north and west of Cairns (Cooktown 16^{o}S to Tully 18^{o}S). Trees were introduced to the Northern Territory in the early 1980's where a small but active industry is established in the rural areas near Darwin (12^{o}S). Current plantings are reported to be in the vicinity of 40,000 trees and the annual production can range from 500 to 1000 tonnes is valued at a maximum of $4.5M (Industry Rep 2002). The main commercial varieties in Australia include; R9, R134, R156(red), R162, R167, Binjai, Jitlee and Rongrien.

The Australian rambutan and longan industries, together with DPI, NT DPIF and RIRDC and other bodies have, over the last few years engaged in detail assessments of industry research and development needs. Industry strategic plans have been developed by the rambutan industry (Anon 1997) and a commitment to support research has been made by the relevant organizations. The rambutan industry identified nutrition and irrigation research as a priority issue.

The project aims are to;

- monitor changes in rambutan leaf and soil nutrient status over three seasons
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This report details the findings of three years of study from July 1998 to May 2001.

1.2 Literature Review

1.2.1 Plant nutrition - introduction

Crop nutrition and management have a long history and much has been written on the quantification of plant nutrients and their relationships with soil nutrient status and to crop growth and yield. The bulk of literature revolves around nutrition management of annual grain and vegetable crops that have a relatively short lived and simple production pattern compared to fruit trees. The literature on fruit tree nutrition is sparse and more complex due to the perennial nature of trees and the many variables (tree age, climate, season, rootstock, fruiting type, pruning management, etc) involved in flowering and yield. This holds true for temperate, sub-tropical and tropical species.

This review does not attempt to give a comprehensive history of fruit tree nutrition but rather an update of currently accepted scientific information as it relates primarily to sub-tropical and tropical species. In general, there is a distinct lack of information available on the more exotic tropical species such as rambutan.

All living plants require a range of essential nutrients to allow them to function, grow and in the case of agricultural crops produce an economic yield, whether it is leaf, root, stem, grain, or fruit. The criteria for essentiality were set in the 1930's (Salisbury and Ross 1969) as;

a. the element must be essential for normal growth and reproduction, neither of which can occur in its absence,
b. the requirement for the element must be specific and cannot be replaced by some other element,
c. the element must act inside the plant and not simply cause some other element to be more readily available or antagonise a toxic effect of another element.

The essential nutrients are classified as either, macronutrients (those required in greatest concentrations and usually expressed as a percentage of plant dry matter) and micronutrients (those required in the least concentrations and commonly expressed in mg/kg of plant dry matter). Note; 1.0 % is equivalent to 10,000 mg/kg. Table 1, derived from Grundon *et. al*. 1997 and Bergmann 1992, lists the currently accepted essential macro and micro nutrients as well as basic information on their chief role in plant growth.

Table 1. Essential plant macro and micro nutrients, their chemical symbol (#) and their basic functions.

Nutrient	Level required	Function
Nitrogen (N)	Macro	- accounts for 1.0 – 5.0 % of the dry weight of plants - Controls growth and fruiting in plants - amino acid synthesis and protein formation - primary building block for all plant parts
Phosphorus (P)	Macro	- accounts for 0.1 – 0.5% of the dry weight of plants - involved in photosynthesis, respiration, root growth and flower and fruit development - energy storage and transfer - component of nucleic acid and phospholipids - stimulates seed development and root formation
Potassium (K)	Macro	- accounts for 1.0 – 6.0% of the dry weight of plants - regulates water relations of plants - involved in photosynthesis and respiration - promotes root growth
Nutrient	Level	Function

	required	
Sulphur (S)	Macro	- accounts for 0.1 – 0.5% of the dry weight of plants - involved in the synthesis of protein and function - electron transport in photosynthesis
Calcium (Ca)	Macro	- plant species differ greatly in their Ca needs. A Ca content of 0.5% dry weight is generally considered adequate - essential in cell wall and membrane construction - regulates nutrient uptake by roots and movement in plants - role in fruit ripening and quality
Magnesium (Mg)	Macro	- accounts for 0.1 – 0.5% of dry weight of plants - important component of chlorophyll (the green pigment in plants) - involved in CO2 assimilation - involved in carbohydrate partitioning - activator of enzymes for growth
Chlorine (Cl)	Micro	- high amount required relative to other micro-nutrients, hence concentration often expressed as a percentage. Accepted range highly variable (0.05 – 0.7%) of dry weight. - important enzyme component in the production of Vitamin A - role in photosynthesis, protein and carbohydrate metabolism - maintenance of plant turgor
Sodium (Na) #	Micro	- important role in photosynthetic pathway in C4 plants - can cause toxicity symptoms at relatively low levels
Copper (Cu)	Micro	- Compared to concentrations of iron, manganese and zinc, those of copper are very low and usually in the order of 5 to 15 mg/kg - stimulates lignification of cell walls - pollen formation and fertilisation - role in photosynthesis, protein and carbohydrate metabolism and respiration
Zinc (Zn)	Micro	- Zinc levels between 20 to 100 mg/kg are considered normal - involved in nitrogen metabolism - influences development of auxins (plant hormone) - membrane integrity
Manganese (Mn)	Micro	- Highly variable concentration in plants, often related to soil pH. Levels can range from 20 to 1500 mg/kg, however, sufficiency levels are in the range of 25 to 50 mg/kg. - enzyme activator - assimilates CO2 in photosynthesis - assists iron in chlorophyll formation - essential for uptake of P and K

Nutrient	Level required	Function
Iron (Fe)	Micro	- The iron content of plants is generally between 50 and 200 mg/kg, although values up to 800 mg/kg are not unusual - Required in the formation of chlorophyll - Activator in many biochemical processes (oxidation-reduction reactions)
Boron (B)	Micro	- range in plants 2.0 – 100.0 mg/kg - regulates metabolism of carbohydrates - involved in formation pollen tubes and feeder roots - aids in translocation of Ca, sugars and plant hormones
Nickel (Ni) *	Micro	- Component of urease enzyme used to metabolise urea.
Molybdenum (Mo)	Micro	- 0.5 - 1.0 mg/kg is generally sufficient - involved in nitrogen fixation and nitrate reduction

* - Sodium (Na) and Nickel (Ni) are not considered as essential elements in fruit trees, however they have important roles in tropical grasses. Other elements that are sometimes regarded as essential micronutrients or "beneficial elements" are Aluminium (Al), Cobalt (Co), Silicon (Si), Vanadium (V) and Fluorine (F) (Bergman, 1992).

In modern horticulture, plant nutrition management is the result of interaction among growers, research and extension horticulturists, plant and soil analysis laboratories, fertiliser manufacturers and suppliers. The aim of all these players, although being profession specific, is to optimise the productivity of the crop in question. Plant analysis was developed to provide information on the nutrient status of plants to be used as a guide to nutrient management. Plant analysis data are used in various ways. The three most common are;

- diagnose nutrient problems (deficiencies or toxicities)
- predict nutrient problems likely to occur between sampling and harvest
- monitor crop nutrition status with a view to optimising production.

To act on any of the above the crop manager, researcher or extension officer requires information on plant analysis criteria pertinent to the crop in question. In tree fruit crops, this base level of information is generally gathered through a process of surveying commercial orchards, rather than by a research process as occurs in annual vegetable and grain crops where nutrients are added at varying levels and the differences in yield measured. This is, in a large part, due to the high cost of running traditional nutrition trials in tree crops and the fact that climate and other management variables can play a greater role in flowering and subsequent yield than nutrition management alone. The nutrient survey approach is based on the following;

determination of the ideal sampling time (when nutrient concentrations are most stable)
sampling a wide range of commercial orchards and documentation of yields
identification of leaf standards based on orchard yields and tree health

This process has been successfully used for kiwifruit (Cresswell, 1989), lychee (Menzel *et al*. 1992), mango (Catchpoole and Bally, 1996), grapes (Robinson and McCarthy, 1985), passionfruit (Menzel *et al*. (1993), persimmons (George *et al*. 2001) and form the basis of nutrition management in these crops. Caution is required in interpreting survey data to ensure that target (standard) leaf and soil nutrient data are not a result of bias toward luxury or sparse fertiliser inputs.

The survey technique is usually dependent on sampling plant tissue (generally leaf) of a known maturity. The interpretation of the data must take into consideration that there is no ideal leaf age for every nutrient. Essential nutrients have been characterised as either mobile, immobile or variably mobile, that is they vary in their ability, once deposited in leaf or other plant parts, to be remobilised and transported to other plant parts (Smith and Longeragan, 1997). Remobilisation generally occurs *via* the phloem (food conducting tissue) rather than the xylem (water conducting tissue). Nutrients that are considered as **phloem mobile** from leaves include; nitrogen, phosphorus and potassium. The phloem sap concentration of these elements is high and they are recycled rapidly through out the plant. Young leaves retain the cycling nutrients at the expense of older leaves. **Non phloem mobile** nutrients include; calcium, boron, manganese and iron. These elements do not move from where they were initially deposited to new growth regions where they may be deficient. Sufficiency levels in new growth can only be maintained by a continuous supply from root acquired or externally applied (foliar applications) sources. **Variably phloem mobile** nutrients include; sulphur, copper and zinc. These elements are not remobilised rapidly as they become deficient in new growth, but are able to rapidly remobilise once leaf senescence begins. Young immature leaves are generally the most sensitive for nutrients that are immobile or variably mobile while older leaves are the most sensitive for those, which are phloem mobile (Smith and Longeragan, 1997). In most cases, the decision as to what plant part to collect for nutrient analysis is based on several important considerations; the best correlation between plant appearance or performance with elemental content; ease of identification of the plant part and its collection and the stability of the element across similar sampled material (Jones, 1985). In many cases the youngest fully expanded (YFE) leaf has been used successfully for many nutrients in many plant species. In a number of tree crops (lychee, mango, passionfruit) the suggested sampling regime is based on sampling the youngest mature leaf at a time when vegetative flushing activity is low. This often coincides with late autumn/early winter months when the trees or vines are vegetatively dormant and early flowering is commencing. Lim *et al*. (1997), found that in rambutan the middle leaflet pair of the latest mature green flush (third or fourth leaf from the shoot terminal) sampled in May/June just prior to flowering resulted in the lowest coefficient of variability of nutrients.

1.2.2 – Rambutan nutrition

There are few references documenting rambutan leaf nutrient levels. Table 2 lists published material pertaining to rambutans grown in Malaysia, Thailand, North Queensland and the Northern Territory. Tindal (1994) reports extensively on fertiliser practices of the major rambutan growing countries. Tree recommendations from Malaysia, Thailand and Philippines are shown in Table 3.

Despite the availability of nutrient standards and fertiliser recommendations from a number of rambutan producing countries there is a paucity of work that relates fertiliser inputs, leaf nutrient levels and tree productivity. Prasittikhet *et al*. (1996) report on a long term fertiliser study conducted at Chantaburi Horticultural Research Centre from 1985 to 1994. In this trial tree growth and yield of control (unfertilised trees) were compared against trees receiving five fertiliser grades varying in concentrations of $N:P_2O_5:K_2O$ applied at the rate of 500 g per tree per year of age. All treatments including control trees received a yearly application of 10-20 kg of city waste (compost). At year 10, mean control trees yield of 33 kg/tree were considerably less than the mean yield of all fertilised trees (85 kg/tree). However, yield per canopy volume was similar 1.8 kg/m3 and 2.3 kg/m3 for control and fertilised trees respectively. Among the fertiliser treatments, $N:P_2O_5:K_2O$ ratios of 20:10:10, 10:10:20, 10:20:10 produced higher yields. The 20:20:10 and 10:10:20 ratios produced maximum fruit size and aril weight.

In recent work on the effects of fertigation versus traditional fertiliser application practices Lertrat (2000, in press) reports that plant growth, flowering, fruit development and fruit quality were not significantly different between fertiliser application methods. However, among fertigation treatments, fertigation at 272-230-372 gm/tree/year of $N-P_2O_5-K_2O$ per tree per year gave the highest yield (35.4 kg/tree) relative to 26 and 31.8 kg/tree for treatments 136-115-184 and 545-469-745 gm/tree/year respectively. The granular fertilised trees received 1000-1320-1640 gm/tree/year of N-P_2O_5-K_2O and the mean yield was 27.7 kg/tree.

Studies in Malaysia by Ng and Thamboo (1967) showed that 15 kg N, 2 kg P, 11.7 kg K, 5.9 kg Ca and 2.7 kg Mg per ha are removed for a crop (75trees/ha) of 7300 kg/ha. Fruit analysis showed that more than 50% of the total K, Ca and Mg is located in the pericarp (skin) while the aril (pulp) contained between 20-40% of the total N, P and K (Tindall 1994).

Table 2. Published rambutan nutrient standards compared with current NT rambutan standards

Comments	N %	P %	K %	Ca %a	Mg %	S %	Fe mg/kg	Mn mg/kg	Zn mg/kg	Cu mg/kg	B mg/kg	Reference
Malaysian data												Tindal (1994)
Leaves & twigs	1.14	0.25	0.66	-	-	-	-	-	-	-	-	
Leaves young trees	1.32	0.42	0.82	-	-	-	-	-	-	-	-	
Thai Fertiliser Trial report												Prasittikhet (1996)
$N:P_2O_5:K_2O$												
0:0:0	1.42	0.15	0.38	-	-	-	-	-	-	-	-	
10:10:10	1.44	0.17	0.39	-	-	-	-	-	-	-	-	
10:10:20	1.61	0.16	0.43	-	-	-	-	-	-	-	-	
10:20:10	1.54	0.19	0.40	-	-	-	-	-	-	-	-	
20:10:10	1.82	0.18	0.41	-	-	-	-	-	-	-	-	
20:20:10	1.82	0.18	0.40	-	-	-	-	-	-	-	-	
Mean	1.61	0.17	0.40									
Thai fertigation trial (2000), Year 2												Letrart (2000, unpublished)
Solid	1.27	0.65	0.92	-	-	-	-	-	-	-	-	
Fertigated	1.53	0.67	1.07	-	-	-	-	-	-	-	-	
NT rambutan standards	1.54-1.8	0.21-0.23	0.69-0.77	0.68-0.77	0.41-0.48	0.16-0.17	77-98	104-150	43-54	16-25	43-54	Lim *et al*. (1997)
NQ survey 1986	na	0.18	0.65	0.96	0.29	-	46.3	559	26.9	32.4	34	Mansfield (2000)
NQ Survey 93-94	1.52	0.15	0.60	0.58	0.21	-	25.8	296	16.0	9.5	90.6	

Table 3. Documented fertiliser practices for rambutan

Location	Young trees	Mature bearing trees	Reference/ comment
Malaysia Web Site	1 to 3 year old trees Compound fertiliser N:P:K:Mg (15:6.5:5:2.4) No rates supplied	Trees 4 years of age and onward Compound fertiliser N:P:K:Mg (12:5.2:14.1:1.2) + Trace elements No rates supplied	Annon., 2000) From Malaysian Ministry of Agriculture Web Site Agrolink.moa.my
Published	N:P:K (15:6.5:13.3) during the vegetative phase. Application rate begin at 0.5 kg/tree/year for two to three year old trees, split into two to three applications.	N:P:K:Ca (12:5.2:14.1:1.4) plus N:P:K (13:5.7:17.4). Application rates begin with 0.5 kg/tree/year for three year old trees, split into two or three applications. Rates are increasedby 0.5 kg/tree/year as the trees mature.	Pongsrihadulchai (1984) cited by Tindall (1994)
Thailand	Fertiliser requirements are considered low at this stage and applications should be tailored to tree appearance and vigour. Thai growers generally consider that dolomite and lime are detrimental to rambutan and are particularly harmful to actively growing trees, particularly during the first two years after planting.	*Prior to flowering* N:P:K (8:10.5:19.9) or (10:22.6:14) or (15:13.2:12.4), Foliar spray of MKP.(0:23:28). *At flowering* N:P:K:Ca (12:5.2:14.1:1.4) +micronutrients *Fruit set* N:P:K 1:0.4:0.8) + micronutrients + organic matter *9 wks after fruit-set* N:P:K:Ca (8:5.2:14.1) or (8:10.5:19.9) and (0:0:42) Post harvest N:P:K (15:6.5:12.4) + Urea + organic matter Application rate begins at 0.5 kg/tree at age three. From four years of age onwards rate of N:P:K application equal tree age	Muchjajib (1990) cited by Tindall (1994).
Philippines	In year 1. 200 g of Sulphate of Ammonia per tree per year split into two applications. Rate should be increased in following years.	At fruiting an additional 500 g of N:P:K (14 :6.1:11.6) should be applied per tree. Half at the beginning of the rain season and half after harvest. At the peak of fruiting an annual application of at least 2.0 kg/tree of a complete fertiliser will be required. In some instances additional N and P will be necessary.	Coronel (1983) cited by Tindall (1994).

Table 3. continued

Location	Young trees	Mature bearing trees	Reference/ comment
Hilo, Hawaii	For growing trees Fertiliser rate of 200g N, 25 g P, 100 g K per year of age. For the first four years the fertiliser should be applied in four equal applications every three months	For fruiting trees Fertiliser rate of 200g N, 25 g P, 130 g K per year of age. Maximum fertiliser rate is reached at 12 years of age and should remain constant there after. One fourth of yearly fertiliser should be applied four weeks after fruit set, half the amount immediately after harvest, and the remaining one fourth nine weeks after harvest. Additionally 0.4 kg of dolomite per tree per year of age, maximum at 10 years and constant after, is applied during slow growing months.	Zee (1995).
North Queensland	Young trees (1-4 years) require a steady year round fertiliser program. 50 g N, 15 g P, 30 g K per year of age up to four years. Applications are made in August, November, January and April. The first application is made 3 to four months after planting.	Fruiting trees (5 to 10 years) use 90 g N, 10 g P, and 60 g K per tree per year of age up to year 10. Fertiliser recommendations for 10 year old trees are based on using CK77S. Total application of 7.8 kg/tree with 5.2 kg added immediately after harvest and 2.6 kg added at panicle emergence. Dolomite (4.0 kg/tree) is added in August/September. Total N.P.K application rates/tree are; 1014 g N, 172 g P, 1037 g K, 660 g Ca, 400 g Mg and 1459 g S. Trees may need iron, zinc and possibly boron. These may be applied as foliar applications (1-2) per year or as straight or mixed trace elements to the soil.	Watson *et al.* (1988).
Northern Territory	For a non bearing tree an NPK = 10:4:8 grade fertiliser applied 5-6 times for year 1 and 2 commencing 3 months after planting. Year 1 0.5 kg/tree/year Year 2 1.0 kg/tree/year	Using a N:P:K: = 10:5:9 (chloride free) Suggested fertiliser schedule (note quantities should be adjusted according to leaf and soil nutrient analysis) Year 3 - 2.0 kg, Year 4 – 2.5 kg, Year 5 – 3.0 kg, Year 10 – 5.5kg/tree/year.	Lim *et al.* (1997)

1.2.3 Rambutan tree phenology

An understanding of tree phenology is vital to the interpretation of leaf nutrient status and its relationship to tree productivity particularly if links between yield and tree nutrient status are being made. The rambutan is a terminal flowering tree in which climate and environment play an important role in flowering subsequent fruit-set and hence yield.

In many tropical tree fruit crops the environmental triggers which control growth and fruiting cycles are not well understood (Chaikiattiyos, 1992). In some species a combination of triggers are required (temperature, drought, photoperiod, and irradiance) whereas in other species only a single environmental influence such as low temperature or soil moisture deficit is required. In rambutan, in its native environment panicle emergence has been observed to occur through out the year. In some regions two flowerings occur per year whereas in others only one distinct flowering and production period occurs (FAMA, 1988). Panicle emergence in rambutan usually occurs following a period of dry weather (Whitehead, 1959 cited by Tindall, 1994, Valmayor *et al*. 1970, Tatt, 1976). Low night temperatures have also been implicated in the initiation of flowering in rambutan (Manakasem, 1995). Nakasone and Paull (1998) have diagrammatically represented the rambutan fruiting cycle and the climatic and environmental clues that influence flowering (Figure 1). They suggest low soil water is the main trigger for flower induction while low temperatures (<22°C) following induction will result in no flowering.

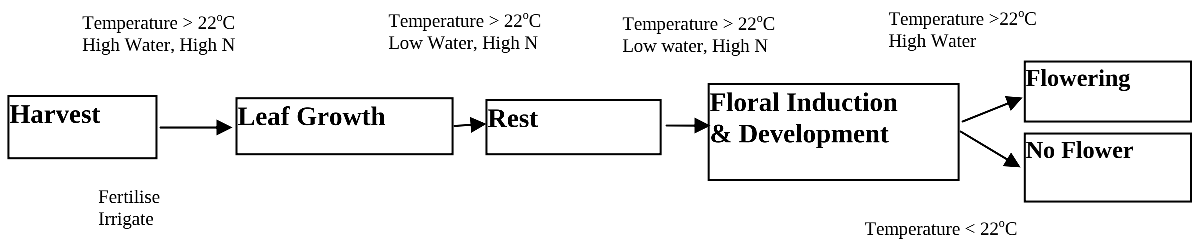


Figure 1. Fruiting cycle of rambutan (after Nakasone and Paull, 1998) as affected by temperature, nitrogen (N) fertilisation and soil water availability.

Watson (1988) states that rambutan flowering in the Cairns area commences in July/August and may continue on different trees or parts of the same tree until the following April. He states that flowering in north Queensland occurs in cold, dry, wet and hot periods and is not affected by cool weather or climate changes from wet to dry.

Diczbalis *et al.* (1997) suggest that in the Northern Territory growing environment flowering often follows the onset of the dry season when cool nights commence. They suggested that the trigger for flowering appears to follow the cessation of growth, whether caused by drought or low temperature. A number of authors have suggested that a lack of vegetative growth allows a build up of carbohydrates which improves flower initiation (Scholefield *et al*. 1985, Menzel *et al*. 1989).

1.2.4 Rambutan water requirements and irrigation management

Information on rambutan water requirements is scarce and is of a general nature (USDA 1979, Coronel 1983, Delabarre 1989, Tindal 1994) such that water requirements can not be quantified. Rambutan water requirements are generally not an issue in much of the plants native environment where rainfall is evenly distributed through out the year and the short dry season is necessary for flower induction. Nga (1980) reports that in Malaysia the rambutan requires a dry spell to induce flowering, a wet season during fruit development and a dry season toward maturity. A prolonged dry season during fruit development often causes poor fruit filling in some varieties, however no irrigation requirements are supplied. Watson *et al*. (1988) report that irrigation is essential through out the growing area with peak stress periods being in late spring and early summer when irrigation rates of 60-70 mm per week may be required. In winter rates of 25 – 30 mm per week are sufficient. They suggest that at least 70 to 80 % of the root system should be irrigated.

Diczbalis *et al*. (1996) report on environmental factors effecting growth and yield of rambutan in the wet/dry tropics of the NT. They report that;

- rambutan have a shallow root system with 80% of feeder roots occurring within the top 15 cm under the tree canopy
- relatively short periods (7 – 14 days) of nil irrigation and rainfall will lead to severe leaf wilting and death
- stomatal closure does not occur with increasing leaf to air vapour pressure deficit until relatively high VPD’s (5.0 kPa) which increases water loss during the dry season
- mild water stress can be used to synchronise flowering
- crop factors (water use/evaporation) range from 0.65 preflowering to 1.2 during fruit development.

Hence the amount of irrigation during fruit filling should, at a minimum, replace that lost be evaporation.

1.2.4 Summary

Any interpretation of the effectiveness of fertiliser management will need to take into account other factors that control productivity. Gollmick *et al.* (1970) cited by Bergmann (1992) states: “…*the probability of achieving correct fertiliser recommendations will be best at low nutrient levels in plants. The closer the nutrient content of plants comes near to the optimum, as it will be with the increasing application of fertiliser, the more uncertain will be the forecast of any fertiliser effect, because in such cases the yield will be determined and limited by other factors, especially by climate and weather conditions*”.

2. Objectives

The objectives of this project were to;

- monitor changes in rambutan leaf and soil nutrient status over three seasons
- measure grower fertiliser inputs in relation to the above
- assess the effect of nutrient status on productivity
- monitor tree phenology in relation to climate, nutrition and irrigation management
- quantify rambutan water/irrigation requirements.

This report details the findings of three years of study from July 1998 to May 2000

3. Methodology

3.1 Site Description

Fourteen rambutan growers collaborated in the project. The orchards were located on the wet tropical coast of far north Queensland from Bellenden Ker in the north (xxxS) to Murray Upper 18°04.004'S, 145°51.796'E) in the south.

3.2 Leaf and soil sampling

Rambutan orchards were leaf sampled twelve times over three seasons (Oct 1998 to April 2001) and soil sampled six times over the same period. An additional two leaf samples and one soil sample pre dating the onset of the trial were added to the data set. Sampling occurred at key phenological stages; panicle emergence/early flowering, fruit set, fruit filling, harvest, post harvest mature flush.

Nutrition sampling occurred predominately on one rambutan cultivar R134 (13 sites) however other cultivars were also monitored and included Jitlee (3 sites), R167 (3 sites), Rongrien (2 sites), R156R(2 sites), Binjai (1 site) and R9 (1 site). Results for all cultivars were pooled for analysis.

2.2.1 Leaf and soil collecting and analysis procedures

At the start of the project ten trees within a block of uniform aged trees at each of the collaborator sites were identified as the "nutritional trial trees". All leaf and soil nutrient sampling related to the project was confined to these trees.

At each of the soil sampling periods, two samples per tree, within the drip-line were taken with a 50 mm auger to a depth of 20 cm. The samples from each of the ten trees were bulked and thoroughly mixed, by hand, prior to taking a sub-sample for analysis. The sub-sample was placed in a "Pivot" soil analysis bag, labelled and dispatched within 24 hours to Pivot Laboratories in Werribee, Victoria for analysis. The samples were air dried, ground to <2 mm and analysed for pH (1:5 water and 1:5 $CaCl_2$), electrical conductivity (1:5 water), Colwell extractable P, nitrate N, organic carbon, K (NH4Ac), labile S (KCl), extractable B ($CaCl_2$), DTPA extractable Cu, Zn, Mn, Fe, exchangeable Na, Al, K, Ca and Mg. All methods were those described in Australian Laboratory Handbook of Soil and Water Chemical Methods (Rayment and Higginson, 1992).

At each leaf sampling period, the middle leaflet pair of the latest mature green leaf or during flowering and fruit set (the leaflet pair of the leaf under the panicle) was chosen for sampling. Eight to 10 leaflet pairs were sampled per tree and samples from the ten monitoring trees were combined, packed in a "Pivot" leaf sampling bag, labelled and dispatched within 24 hours of sampling to Pivot Laboratories in Werribee, Victoria for analysis. The samples were washed, dried, oven dried at 65°C and ground to < 1 mm. Nutrient analysis for N (nitrogen), P (phosphorus), K (potassium), Ca (calcium), Mg (magnesium), Na (sodium), Cl (chlorine), S (sulphur), Mn (manganese), Fe (iron), Cu (copper), Zn (zinc), B (boron) and Al (aluminium) using inductively coupled plasma technology (ICP) spectrometry. Procedures carried out meet NATA standards.

Soil and leaf analysis results were generally available within two weeks of sampling and were mailed directly by Pivot laboratories to the respective grower. An electronic form of the data was emailed to the principal researcher generally within one month of sampling. Soil and leaf analysis results were compiled and presented by grower by sampling occasion, mean of all growers by sampling date ± standard error (se), mean grower over all sampling periods ± se and over all mean ± se. Mean leaf concentrations (all growers, all varieties, all regions) with associated 95% confidence intervals are presented as initial standards. These are compared to mean leaf concentrations with associated 95%

confidence intervals for the sampling date which showed the least coefficient of variation among all sites sampled. Standards of this type are naturally tentative and it is normal for them to be refined with use (Cresswell, 1989).

In respect of grower privacy, individual orchard leaf and soil nutrient results are presented under a grower code. The code was issued at the start of the project. The code is only known by the grower and the principal researcher.

3.3 Climate and irrigation monitoring

3.3.1 Weather station details

Three solar powered, weather stations were commissioned in the rambutan project in early August 1999. Each station was equipped with the following;

- Campbell CR10 data-logger
- Air temperature sensor (CS500)
- Relative humidity sensor(CS500)
- Tipping Bucket Rain Gauge (Monitor Sensors , 0.5 mm/tip)
- Soil Temperature sensor @ 20 cm (CS107)
- Water Mark soil tension sensor (CS253). At two of the stations one sensor was placed at 30 cm depth whereas at the third station three Water Mark sensors were placed at 20, 40 and 80 cm.

The units were programmed to sense climatic and soil moisture variables every 15 seconds. Temperature, RH, soil temperature, rainfall, matric potential and SWSR were recorded hourly. At midnight daily maximum and minimum temperature, RH, soil temperature and max, min and average matrix potential, total rainfall and SWSR were recorded. The stations were downloaded fortnightly to monthly, depending on the season and phenology observations. The daily summary data was imported into an Excel® spreadsheet file and data tabulated and graphed.

The three units were placed on rambutan orchards and the locations were chosen to capture the extreme differences in climate across a relatively small geographic area. Soil types are described by Murtha (1986).

Rambutan Unit 1. Cooroolands Road, Upper Daradgee (17°31.302’S, 145°56.711’E). The *cv*. R134 was monitored at this site. Soil was a reddish brown clay loam (Krasnozem).

Rambutan Unit 2. Mena Creek road, (17°40.700’S, 145°55.504’E). The *cv*. R134 and Rongrien were monitored at this site. Soil was a reddish brown clay loam at the surface changing to dark red light clay at 100 cm (Red Earth)

Rambutan Unit 3. Murray Upper, south west of Tully (18°04.004’S, 145°51.796’E). This station represents the cooler and dryer rambuatn-growing environment. The *cv*. R134 was monitored at this site. The soil was a dark grey sandy loam at the surface and degrading to course sand at 100 cm depth (Yellow Earth).

In late 2000, pyranometers (for the measurement of total shortwave solar radiation inputs) were installed at all weather station sites. These sensors were installed to provide information on energy inputs, with particular reference to the period from flowering to harvest.

3.3.2 *Irrigation monitoring*

Grower water inputs were monitored *via* the installation of Amiad® water meters at a location which allowed the output from 10 under-tree sprinklers (10 trees) to be measured. Readings were made at the same frequency in which the weather stations were downloaded (fortnightly to monthly, depending on season and phenology). Daily water inputs (L/tree/day) were calculated and graphed. This data in conjunction with Water Mark sensor, rainfall data and tree canopy area are used to calculate irrigation requirements which includes tree water use + evaporation + deep drainage.

3.4 Phenology monitoring

Detailed phenology monitoring (occurrence of leaf flushing, flowering and fruit development) occurred on the three farms where climate recording took place. At each visit (fortnightly to monthly) trees were rated for percentage new flush (red to pale pink leaflet colour), maturing flush (light green to mid green leaflet colour) and mature flush (dark glossy green leaflet colour). From the commencement of panicle emergence the tree ratings included the percentage of terminals displaying panicles. Panicle development, flower opening and fruit development were also recorded. Commencement, peak and final harvest dates were also noted.

At the remaining sites, notes were made of phenology at leaf sampling occasions.

3.5 Compilation of fertiliser inputs and yield data

During the projects inception the rambutan growers, *via* their industry organisation, agreed to contribute to the project the following;

- Availability of orchard sites for monitoring
- Direct payment of leaf and soil analysis costs
- Recording of fertiliser inputs
- Recording of yield data (kg/tree)

Fertiliser input data sheets were made available to all growers. Six of fourteen growers provided full fertiliser input and yield records. Individual input data, ie. fertiliser type used, remains anonymous. Fertiliser inputs were converted to grams of element (N, P, K etc) added to trees. This data was used as a reference point for inputs (high, medium, low) when comparing leaf and soil nutrient levels between sites.

3.6 Fruit analysis

Fruit from ten farms were sampled in the 2001 season so that an analysis of fruit nutrients could be undertaken. Five samples of fruit were from the cultivar R134 and the remaining five were made up of one sample each of Jitlee, Rongrien, R9, R156 and R167. The samples included fruit, panicle wood and approximately 20 to 30 cm of wood and leaf behind the panicle. On arrival in the laboratory, the total fresh weight was measured and the panicle divided into two parts; a). fruit as per industry packing standards and b). the remaining panicle wood, stem and leaf material. The fresh weight of these two parts was recorded. The material was then dried at 40^{o} to 50^{o}C for approximately three weeks until such time as it was determined that the material was oven dried. The dried material was weighed and then ground to < 1mm. The ground material was packed in polyethylene bags and dispatched to the Department of Natural Resources, Analysis Laboratory in Mareeba. Fruit and remaining panicle wood, stem and leaf material were analysed for N, P, K, Ca, Mg, Na and S (%) and Cl, Mn, Fe, Cu, Zn, B and Al (mg/kg). The mean, maximum, minimum and standard error (se) data for each element are presented.

3.7 Nutrient budget calculations

In a bid to maximise the practical aspects of this study a nutrient budget was carried out for each orchard sampled, where a full record of fertiliser inputs and yield data was available. The budget calculations used were relatively simple but allow growers to compare their nutrient "*inputs*" over the three seasons monitored with nutrient "*exports*" through fruit and panicle harvesting. The practical applications of the nutrient budget approach to fertiliser management are then discussed.

4. Results

4.1 Climate

Weather station data and phenology recording allow a picture to develop of the climatic factors that effect flowering and fruit set. Climate data is only shown for two sites, Upper Daradgee and Murray Upper. Frequent station breakdowns at the Mena Creek site meant that the quality of the data was not reliable enough to present. Climate monitoring commenced on the 5 August 99 and continued until the 28 February 2002. This allowed three seasons to be recorded.

Daily maximum and minimum temperature, minimum soil temperature and minimum RH are shown in Figures 2 and 3 for Station 1 and Station 3 respectively. Daily maximum temperatures varied with season, 28- 35^oC during summer and 20-25^oC during winter. The period of low maximum temperatures was relatively short and generally occurred from mid to late May through to late August. Large variations in maximum temperatures could occur during any season, most likely due to periods of cloud cover and rainfall. A summary of air and soil temperature, minimum RH and total rainfall during the monitoring period are shown in Table 4.

Table 4. A summary of air and soil temperature, minimum RH and total rainfall during the monitoring period (5 August 1999 to 28 February 2002).

Location	Variable	Max. Temperature (^oC)	Min Temperature (^oC)	Min RH (%)	Min Soil Temperature (^oC)	Rainfall (mm)
Station 1	Mean	30.6	20.1	55.3	23.5	
	Max	41.1	25.7	97.7	27.1	270
Upper	Min	19.4	8.7	13.1	18.0	
Daradgee	Total	na	na	na	na	12168
Station 3	Mean	31.5	18.5	49.3	23.0	
	Max	43.0	25.9	95.1	28.1	220
Murray	Min	21.0	3.8	10.9	14.1	
Upper	Total	na	na	na	na	7458

The mean temperature over the monitoring period was 25.4 ^oC for Station 1 and 25.0 ^oC for Station 3. The Murray Upper site had higher maximum temperatures but lower minimum temperatures.

This is reflected by the mean minimum soil temperature that was virtually identical for both sites, 23 ^oC and 23.5 ^oC for Stations 3 and 1 respectively. Another factor that may influence phenology, in particular flowering, is soil temperatures. The relationship between root temperature and phenology in general is not well understood. In Figures 2 and 3 minimum soil temperatures at 15 cm depth under the tree canopy are shown. Observations suggest this is where the bulk of the trees feeder roots are active (Diczbalis *et al*. 1997, Mansfield 2000). As expected the fluctuations in soil temperature are not as great as that experienced by air temperatures as there is a damping effect. However, sudden decreases and increases in soil temperature appear to be closely linked to rapid movements in the minimum temperature.

Mean minimum relative humidity was less for Murray Upper, 49.3% versus 55.3 % for Upper Daradgee. This is not unexpected given the large difference in total rainfall, between the two sites. Approximately 40% less rain was recorded at Murray Upper (6,938 mm) than was recorded at Upper Daradgee (11,280 mm) over the duration of monitoring. Minimum relative humidity (RH) levels varied greatly from day to day and with the season. Minimum RH levels were generally higher during the summer months, particularly during rain periods. Lowest levels were recorded during the winter (dry months) with readings falling as low as 5.0% (Figure 5). Low or high RH levels can interfere with crop production.

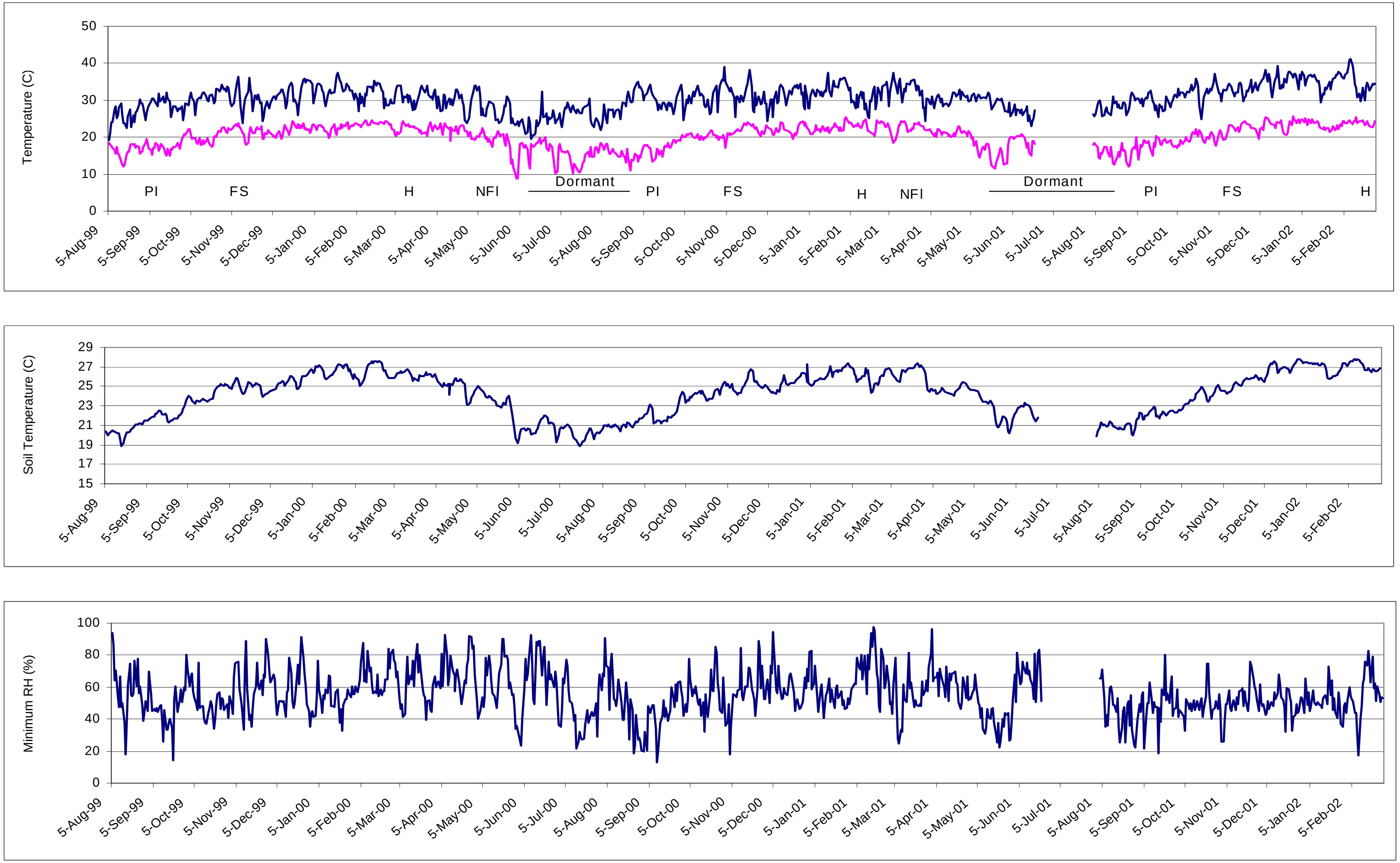


Figure 2. Daily temperature (max and min), soil temperature, minimum RH and phenology for Rambutan Site 1 (Upper Daradgee). PI = Panicle Emergence, FS = Fruit Set, H = Harvest, NFI = New Flush (major), Dormant = period during which no new flush activity occurred.

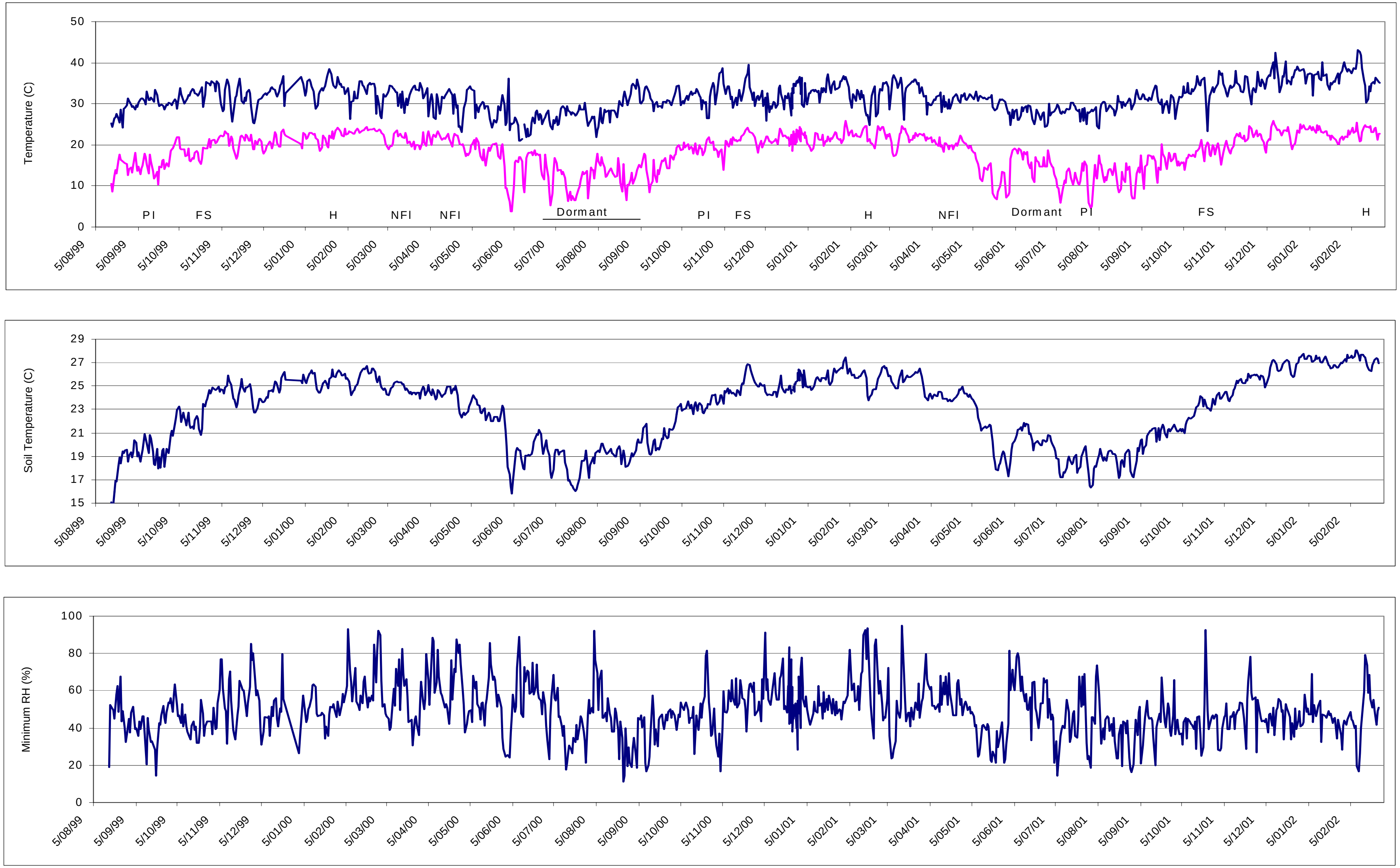


Figure 3. Daily temperature (max and min), soil temperature, minimum RH and phenology for Rambutan Site 3 (Murray Upper). PI = Panicle Emergence, FS = Fruit Set, H = Harvest, NFI = New Flush (major), Dormant = period during which no new flush activity occurred.

Dry conditions during flowering may be implicated in poor fruit set, whereas moist conditions during fruit filling may be associated with an increase in fungal contamination.

SWSR is a measure of the suns energy inputs. Plant photosynthesis, assimilation rates and tree productivity are directly dependent on solar energy inputs. Daily total Shortwave Solar Radiation (SWSR, MJ/m2/day) which was measured from 7 December 2000 was similar for both sites (Figure 4). Daily totals were slightly lower for the Upper Daradgee site, this corresponds with the higher rainfall and hence cloud measured at the site.

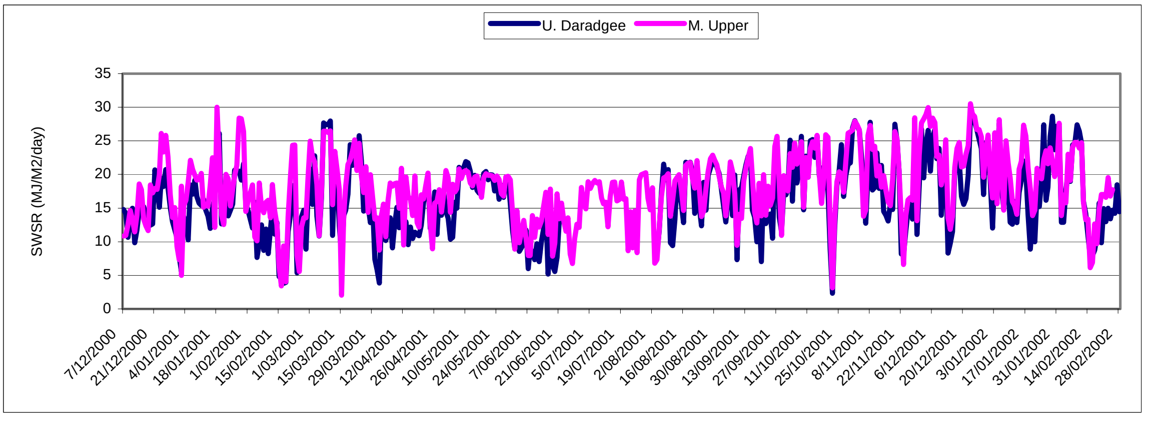


Figure 4. Daily SWSR (MJ/m^2/day) for the Upper Daradgee and Murray Upper climate monitoring sites. Note; measurements commenced on 7 December 2000, 16 months after climate monitoring commenced.

4.1.4: Daily rainfall

Daily rainfall patterns were seasonal with November to April being the wet season months (Table 5). Peak falls occurred from December through to February. The pattern at the two sites was similar. Yearly rainfall totals were highest for 2000, with the Upper Daradgee receiving 6018 mm relative to a yearly total of 3797 mm at the Murray Upper site where the measured yearly totals were the least over the period monitored. The month of February was the wettest for all sites in 2000.

Table 5. Rainfall summary from Aug 1999 to Dec 2001, for Upper Daradgee (U.D.)and Murray Upper (M.U.). * indicates missing data; - indicates not recorded.

	1999	1999	2000	2000	2001	2001	2002	2002
	U.D.	M.U.	U.D.	M.U.	U.D.	M.U.	U.D.	M.U.
Jan	-	-	333.0	236.0	362.0	159.5	310.0	218.5
Feb	-	-	1606.0	1346.0	1238.5	710.0	518.5	424.5
Mar	-	-	734.0	396.0	445.5	324.0	-	-
Apr	-	-	1188.5	524.0	495.0	217.0	-	-
May	-	-	250.5	53.0	42.0	0.0	-	-
Jun	-	-	197.5	59.5	255.0	89.0	-	-
Jul	-	-	39.0	12.0	*	15.5	-	-
Aug	153.0	23.0	203.0	68.5	31.0	12.0	-	-
Sep	174.0	19.5	22.5	12.0	61.5	57.0	-	-
Oct	77.0	34.5	196.5	141.5	253.5	116.5	-	-
Nov	592.0	563.0	728.0	529.5	192.0	182.0	-	-
Dec	739.0	375.0	519.5	418.5	210.5	120.5	-	-
TOTAL	1735.0*	1015.0*	6018.0*	3796.5.0	3586.5*	2003.0	828.5*	643.0

4.2 Tree phenology

In the 1998/99 season flowering was poor to non-existent across rambutan growing areas and was generally considered an "off year". Flowering occurred in the 1999/2000 and 2000/2001 seasons (Table 6).

Table 6. Phenological patterns over three seasons (1999 to 2002) for *cv*. R134 grown at three sites. N.B. Tree phenology stages advance over the calendar years related to the season indicated, starting from panicle emergence.

	Tree Phenology Stages					
Season	Farm	Panicle emergence	Fruit set	Harvest	New flush	Dormant Period
1999/2000	Mena Creek	7 Sep 99	21 Oct 99	29 Feb 00	No new flush, harvested late & pruned in May	na
	Upper Daradgee	7 Sep 99	8 Nov 99	24 Mar 00	12 May 00	21 Jun 00 – 3 Aug 00
	Murray Upper	7 Sep 99	21 Oct 99	26 Jan 00	6 Mar 00, 24 Mar 00, 20 May 00	21 Jun 00 – 5 Sep 00
2000/2001	Mena Creek	5 Sep 00	no set	no harvest	15 Feb 01	26 Mar 01 – 23 Aug 01
	Upper Daradgee	5 Sep 00	9 Nov 00	28 Feb 01	26 Mar 01	24 May 01 – 23 Aug 01
	Murray Upper	16 Oct 00	9 Nov 00	21 Feb 01 – 26 Mar 01	15 Apr 01	24 May 01 – 15 Jul 01
2001/2002	Mena Creek	14 Sep 01	14 Nov 01	1 Mar 02	not monitored	not monitored
	Upper Daradgee	14 Sep 01	14 Nov 01	1 Mar 02	not monitored	not monitored
	Murray Upper	26 Jul 01	25 Oct 01	20 Feb 02	not monitored	not monitored

The *cv.* R134 behaved similarly, in terms of flowering, fruit development and harvest dates. For cv. R134 there was generally sufficient time following harvest for two flushes to occur following the onset of cooler weather when the trees became dormant. The last flush occurred in early to mid April, but was not necessarily uniform across all trees monitored. Where pruning occurred late (May) a new flush was not observed until the following spring (Sep-Oct).

4.3 Tree yield

Growers provided yield data, in most cases, based on their total orchard performance (Table 7). Although not a direct reflection of what occurred on the trees that were monitored for leaf nutrient levels, this data allowed an examination of variability in tree yield over season and across growers.

Yield (kg/tree) varied from 0 to 200 kg/tree while tree density varied from 69 to 208 trees/ha with the mean orchard density being 149 tree/ha. Yield on a per hectare basis ranged from 0 t/ha to 14.56 t/ha. There was no trend in yield performance across the three seasons monitored. Yields were poor to non-existent in the 98/99 season, most likely due to a failure in flowering. In the remaining two seasons high yields either preceded or followed low yields. In a number of cases poor production occurred in all monitored seasons.

Table 7. Yield data for commercial rambutan orchards monitored over three seasons.

	1998-1999		1999-2000		2000-2001		
Grower Code	Yield kg/tree	Yield t/ha	Yield kg/tree	Yield t/ha	Yield kg/tree	Yield t/ha	Tree Density (t/ha)
D	0	0	60	9.96	40	6.64	166
E	0	0	1	0.14	6	0.83	139
I	0	0	20	4.16	70	14.56	208
K	0	0	200	13.80	60	4.14	69
L	0	0	60	6.66	27	3.00	111
N	5.9	0.83	3.6	0.50	1.4	0.20	140
O	0	0	60	12.48	20	4.16	208

4.4 Irrigation monitoring

Irrigation inputs and soil moisture tension were monitored in detail at three sites (Table 8). Tree variety, age and size varied between sites; hence the results are not definitive of water use and requirement but a record of grower management. In no cases were trees observed to be under stress and irrigation inputs were generally highest during the flowering and fruit set period, which coincided with low rainfall months from July to September (Table 4).

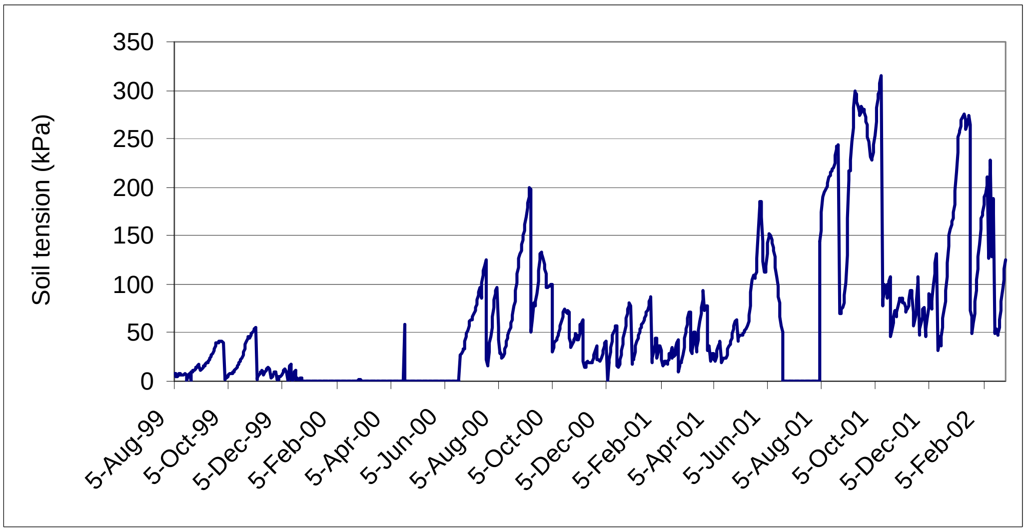
Table 8. Irrigation inputs during the driest months (1 July to 30 September) over three seasons (1999-2001).

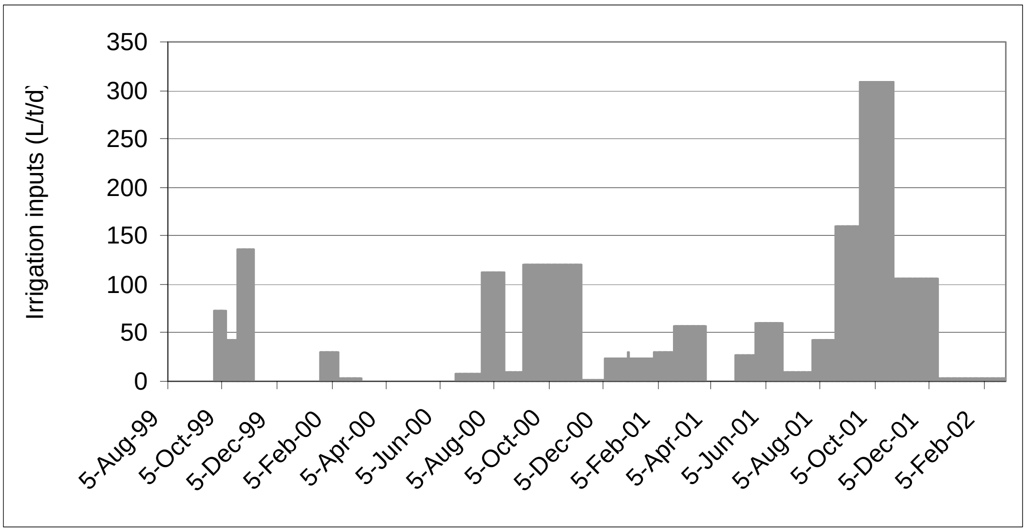
Grower Code	Av. Irrigation input (L/tree/day)	Av. Canopy area (m^2)	Litres per m^2 of Canopy ($L/m^2/day$)	Av. Daily rainfall during period (mm/day)
I	82	30.0	2.7	3.4
N	18	30.0	0.6	4.4
O	140	20.0	7.0	1.0

Average irrigation inputs during the driest months varied from 18 to 140 L/tree/day over the three seasons in which monitoring occurred. Litres per unit canopy area varied from 0.6 L/m2 at the wettest site to 7.0 $L/m^2/day$ for the driest site.

Data sets for the three monitoring sites are shown and include; soil tension (kPa), rainfall and irrigation inputs expressed as L/tree/day, which represented the mean input between recording periods (Fig. 5, 6 and 7).

Irrigation inputs vary between sites, dependent on tree size, rainfall, season, soil type and management. The highest irrigation inputs (>350 l/t/day) occurred for short periods of time at site I to reduce soil tension. The lowest irrigation inputs coincided with the wet season while the highest inputs coincided with fruit set and fruit filling. Soil tensions increase during periods when rainfall is less than 30 mm/week and irrigation inputs are less than 50 L/tree/day (or 350 L/week). Irrigation frequency varied between sites depending on soil type and season. Generally irrigation occurred up to three times per week during fruit filling when hot/dry conditions were experienced. One of the three orchards monitored, actively used soil moisture monitoring equipment to determine irrigation schedules. Most growers use a combination of techniques to determine irrigation frequency. These techniques rely on a range of factors including; perception of weather conditions, stage of growth, short term use of tensiometers and observation of tree health.





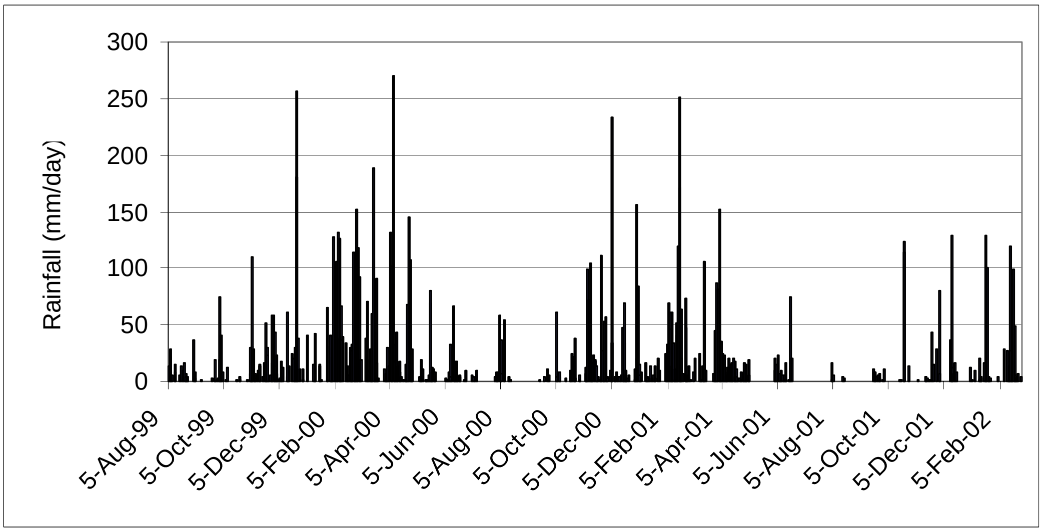


Fig. 5. Soil tension (30 cm), irrigation inputs and daily rainfall for *cv*. R134 grown in the Upper Daradgee area.

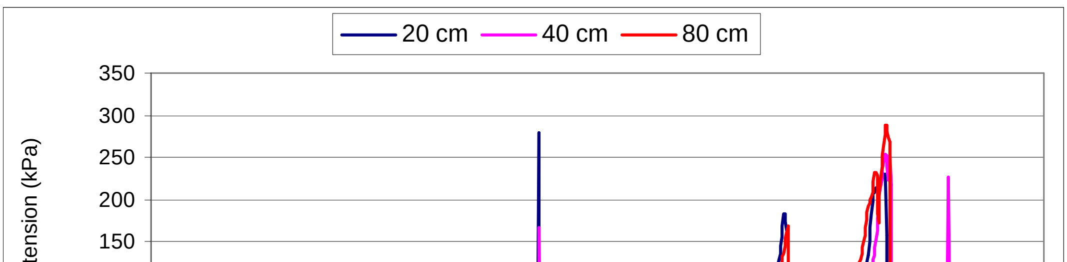


Figure 6. Soil tension at 20, 40 and 80 cm (kPa), irrigation inputs (L/tree/day) and daily rainfall(mm) for *cv*. R134 grown in the Mena Creek area.

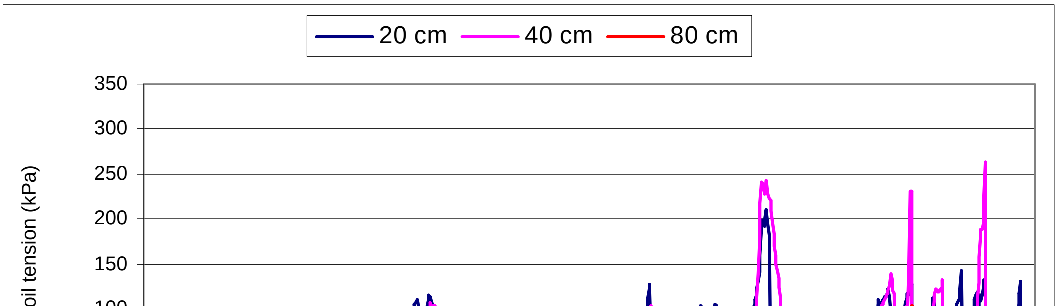


Figure 7. Soil tension at 20, 40 and 80 cm (kPa), irrigation inputs (L/tree/day) and daily rainfall(mm) for *cv*. R134 grown in the Murray Upper area.

4.5 Leaf nutrient monitoring

4.5.1 Mean leaf nutrient levels

Mean leaf nutrient levels, across all varieties and sampling locations over the 43 month sampling period revealed that rambutan nutrient composition varied with season and year. The seasonal cycle of leaf nutrients varied with the nutrient. Seasonal trends for the macro-nutrients (N, P, K, Mg, Ca and S) are shown in Figure 8.

Leaf N, P and K: Concentrations of these nutrients changed greatly throughout the year with significant differences occurring between sampling months. Leaf N, P and K followed similar trends, with small exceptions. Common peaks occurred in Dec 98, with a peak in N and P occurring in Oct 99. Leaf P levels than peaked in Jul 00 and Apr 01.

Leaf Mg, S, and Ca: Concentrations of these elements also changed throughout the monitoring period. Leaf Mg and Ca both peaked from October 1999 to March 1999, while Leaf S concentrations were declining at this time.

Leaf micronutrients: The concentrations of leaf micronutrients Fe, Zn, Mn, Cu and B all had different seasonal patterns through out the monitoring period. The standard errors at sampling intervals were the least for Fe and B. The concentration of elements Cu and Zn fluctuated greatly between sampling intervals and the standard error at individual sampling intervals was large in some cases. Concentration of leaf Mn varied greatly over the first three sampling intervals and than stabilised at 550 mg/kg over the remainder of the monitoring period (Figure 9).

The overall mean leaf nutrient concentrations and means at distinct phenological stages (post-harvest, post summer flush, early flowering emergence and fruit filling) their coefficient of variation (CV) and confidence limits (95%) are shown in Table 9. The variability in concentration was least for the macro-nutrients with CV ranging from 13.5% for N at early panicle emergence to 47.1% for Ca at the fruit set sampling. Variability was much greater for the micro nutrients were CV's ranged from 25% for B at the post harvest mature flush sample to 174% for Cu at the early panicle emergence sampling. This variability is within the range experienced in other nutrient research projects (Menzel et al. 1993, George *et al*. 1995). The post harvest mature flush and fruit filling sampling were the phenological stage at which five of thirteen elements showed the least variation (CV).

Nutrient concentrations of Cl and Na, elements which, although essential are only required in small amounts were within the acceptable range, 0.02-0.03 mg/kg and 0.04-0.05 mg/kg for Na and Cl respectively (Bergmann 1992).

Table 9. Mean rambutan leaf nutrient concentrations (with 95% confidence intervals in parenthesis) and coefficient of variation (CV%) for orchards sampled from 1997 – 2001 from 23 sites on fourteen orchards with a history of good production, management and the absence of nutrient deficiency or toxicity symptoms.

Nutrient	Overall	Harvest	Post harvest mature flush	Early panicle emergence	Fruit set	Fruit filling
N (%)	2.00 (1.96-2.05) 18.8%	1.94 (1.87-2.00) 16.0%	**1.85 (1.77-1.93) 13.5%**	2.01 (1.92-2.11) 19.2%	2.36 (2.26-2.45) 14.1%	1.88 (1.77-1.99) 20.2%
P (%)	0.21 (0.20-0.22) 30.0%	0.20 (0.19-0.21) 25.0%	**0.20 (0.19-0.22) 23.9%**	0.21 (0.19-0.22) 26.0%	0.23 (0.20-0.25) 39.3%	0.20 (0.18-0.22) 33.2%
K (%)	0.62 (0.60-0.64) 27.4 %	0.59 (0.56-0.61) 22.3%	0.56 (0.52-0.60) 21.0%	0.66 (0.62-0.71) 29.2%	0.68 (0.62-0.75) 32.7%	**0.57 (0.54-0.60) 19.7%**
Ca (%)	1.14 (1.09-1.19) 37.2%	0.99 (0.91-1.07) 35.5%	**1.12 (1.01-1.23) 28.8%**	1.20 (1.10-1.29) 32.7%	1.11 (0.96-1.26) 47.1%	1.37 (1.24-1.50) 32.0%
Mg (%)	0.33 (0.32-0.34) 23.9%	**0.33 (0.31-0.34) 17.7%**	0.33 (0.30-0.36) 23.9%	0.32 (0.30-0.34) 27.4%	0.32 (0.29-0.35) 28.1%	0.34 (0.32-0.36) 24.1%
S (%)	0.20 (0.20-0.21) 18.4%	**0.18 (0.18-0.19) 13.7%**	0.20 (0.19-0.21) 16.6%	0.21 (0.21-0.22) 17.8%	0.22 (0.20-0.23) 23.2%	0.20 (0.19-0.21) 15.9%
Mn (mg/kg)	448 (405-491) 82%	383 (307-459) 91%	398 (305-492) 72%	485 (387-583) 83%	395 (309-480) 76%	**610 (486-735) 69%**
Fe (mg/kg)	78 (73-82) 51%	58 (52-64) 45%	69 (57-81) 52%	102 (90-114) 48%	87 (77-98) 43%	**74 (66-83) 38%**
Cu (mg/kg)	49 (39-58) 166%	51 (33- 70) 164%	**66 (37-96) 135%**	54 (31-77) 174%	31 (16-47) 171%	42 (21-63) 170%
Zn (mg/kg)	27 (23-31) 126%	**20 (18-22) 51%**	22 (17-27) 70%	26 (20-32) 96%	33 (22-45) 119%	38 (19-56) 166%
B (mg/kg)	45 (43-47) 40%	38 (36-40) 28%	**37 (34-40) 25%**	51 (45-56) 42%	50 (44-56) 41%	51 (45-57) 39%
Na (%)	0.04 (0.03-0.04) 66%	0.02 (0.01-0.02) 53%	0.05 (0.05-0.06) 51%	0.03 (0.02-0.04) 71%	0.04 (0.03-0.05) 68%	**0.04 (0.04-0.04) 33%**
Cl (%)	0.09 (0.07-0.10) 101%	0.05 (0.04-0.06) 63%	0.11 (0.09-0.12) 49%	0.05 (0.04-0.06) 56%	0.13 (0.05-0.20) 162%	**0.09 (0.08-0.10) 43%**

Data in bold: Represents the leaf nutrient with the least CV between sampling periods

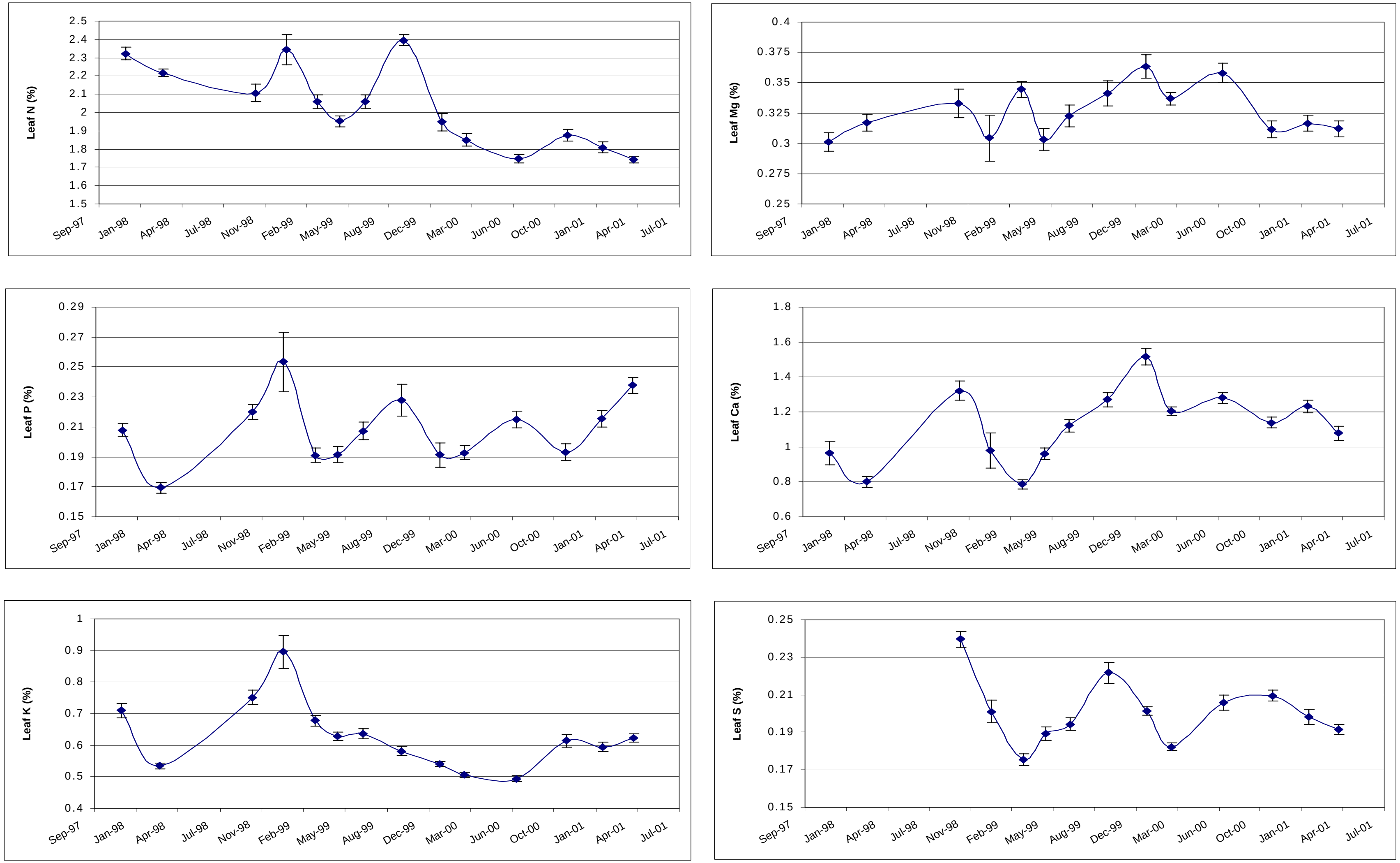


Figure 8. Mean seasonal macronutrient concentrations over 43 months, for all varieties, all locations. Bars denote standard error at each sampling occasion.

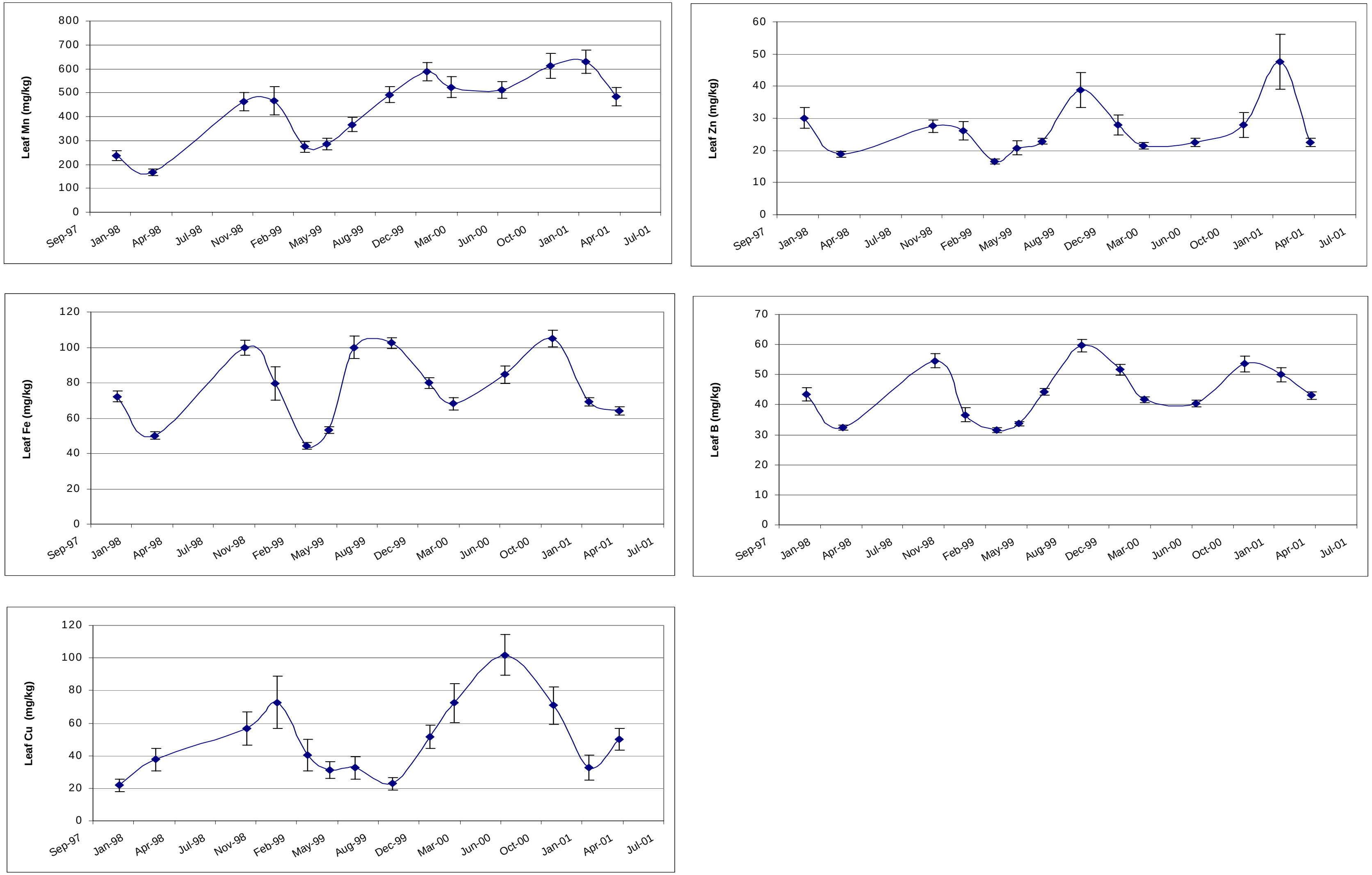


Figure 9. Mean seasonal micronutrient concentrations over 43 months, for all varieties, all locations. Bars denote standard error at each sampling occasion.

4.5.2 Comparison of mean nutrient levels between growers

From a commercial perspective, growers are interested in seeing how their orchards compare with their competitors. Values from the DPI South Johnstone Research Station- orchard are included to allow comparison against an orchard, which has not been fertilised for a number of years.

Mean macronutrient levels by grower code are shown in Figure 10. For elements such as N, Mg and S mean nutrient concentrations are relatively similar among growers, whereas for P, Ca and K there are relatively large differences between growers. For Ca and K the levels are often reversed, where a grower has a high mean level of Ca there is a tendency to have a lower mean leaf K concentration. These differences may be due to interactions with soil type and the ratio of soil cations (K, Ca and Mg). Among orchards, leaf N was the lowest in the unfertilised reference orchard, however, for all other macro-nutrients the unfertilised reference orchard did not possess the lowest leaf nutrient concentrations.

For micronutrients the variability in mean leaf concentrations between growers is much larger, particularly for Mn, Cu and Zn (Figure 11). For leaf Mn high levels in a few orchards are associated with low pH. Manganese is more readily available at low soil pH's. The high concentrations of Cu and Zn in a few orchards are directly due to the high foliar inputs either as a elemental spray or the use of Copper based fungicides. This variability reinforces the need to interpret leaf micronutrient concentrations with caution, because management practices other than nutrient application can markedly affect the concentration of micronutrients in leaves. It also suggests that growers need to wash their leaf samples in deionised water prior to dispatch to the laboratory or notify the laboratory of any recent foliar nutrient or pesticide applications.

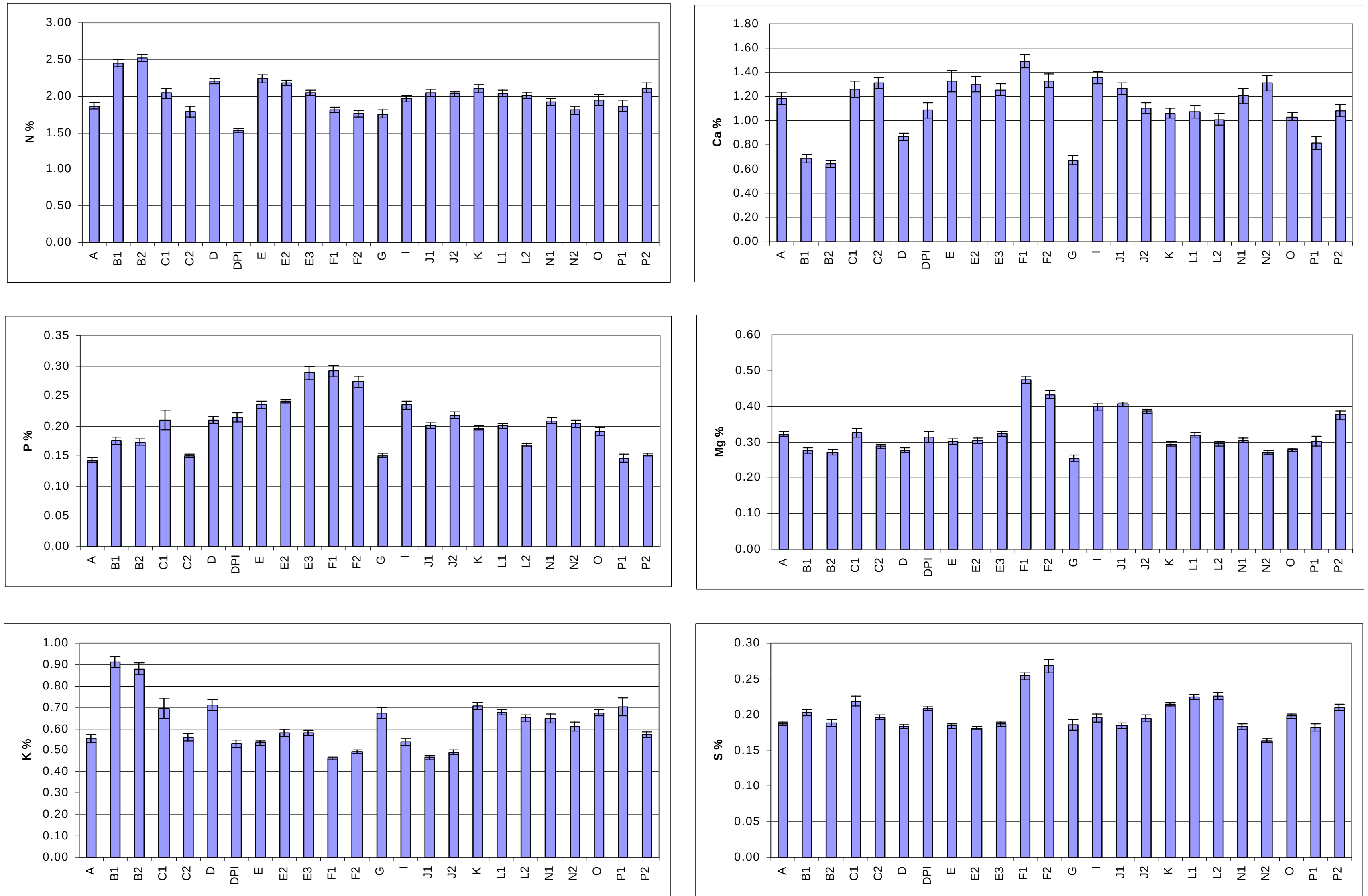


Figure 10. Mean leaf macronutrient concentrations by grower. Vertical bars represent the standard errors.

Figure 11. Mean leaf micronutrient levels by grower. Vertical bars represent the standard errors.

4.6 Soil chemical characteristics and nutrient monitoring

4.6.1 Soil pH, EC and Organic Matter

Average Soil pH, EC and Organic Matter are shown in Table 10 and variations over time in Figure 12. Soil pH varied over time from 5.4 to 6.1. The first sample was significantly higher than the remaining. The range measured was well within optimum soil specifications. Likewise soil EC also varied over time, (0.04 – 0.08 dS/m) with seasonal differences apparent, however, the range remained within optimum soil levels. Organic matter percentage measured ranged from 2.92 – 3.51 % and also varied with season. These levels are within the range expected on horticultural soils.

4.6.2 Mean soil chemical and nutrient values

Soil nutrient levels (0-20 cm), their range and the variation are shown in Table 10. Mean soil chemical characteristic and nutrient concentrations were generally within the optimum range for tropical fruit and vine crops. The median values (value at which lies at the middle of the data set) and the range (minimum to maximum recorded levels) are presented so that interpretations can be made on the whole data set rather than the mean and standard error data alone. Tropical and subtropical tree crops will grow successfully under a range of soil chemical and nutrient values, hence soil nutrient and chemical qualities although important are not necessarily exacting. The survey sites were based on a range of soil types from sandy loams to clay loams. The low mean cation exchange capacity (CEC) and low organic mater % is a reflection of the sandy nature of the bulk of sites included in the survey.

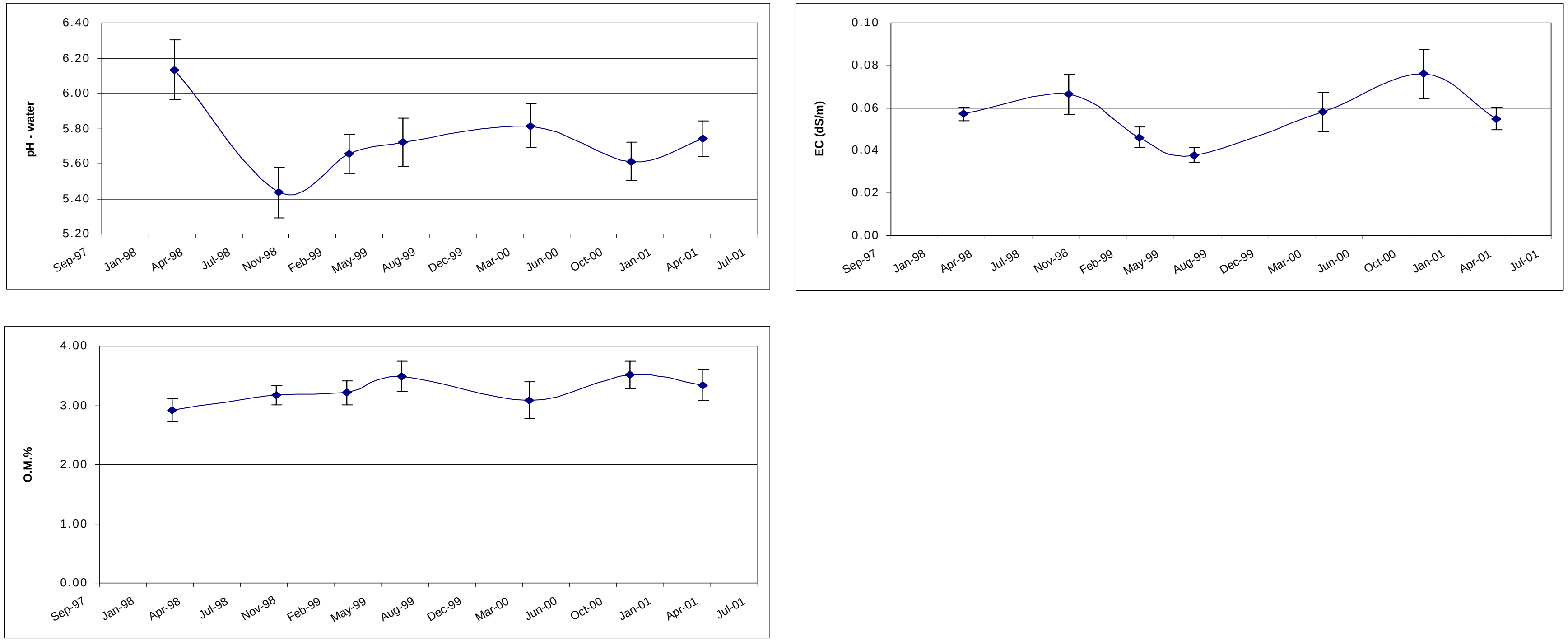


Figure 12. Average soil pH, EC and Organic Matter (0-20 cm) in rambutan orchards monitored from January 1998 to April 2001. Vertical bars represent standard errors at each sampling period.

Table 10. Mean soil nutrient levels/ chemical characteristic and ranges encountered in rambutan orchards.

Nutrient/Chemical characteristic	Mean ± se	Median (range)	Generalised optimum values#
pH (1:5 water)	5.73 ± 0.05	5.7 (4.3-7.1)	5.5-6.5
pH (1:5 $CaCl_2$)	5.00 ± 0.05	4.9 (3.9-6.5)	
EC (1:5 aqueous)	0.06 ± 0.01	0.05 (0.02-0.16)	<0.4
Organic Matter (%)	3.22 ± 0.11	3.3 (1.4-6.7)	3.4-6.9
Nitrate nitrogen (mg/kg)	7.04 ± 0.72	5.3 (1.0-76.00)	10-60
Phosphorus (Colwell) (mg/kg)	158.5 ± 11.9	85.0 (22.0-670.0)	20-120
Sulphur (KCl) (mg/kg)	17.8 ± 2.2	8.2 (2.0-220.0)	
Potassium (exchangeable) (meq/100g)	0.24 ± 0.02	0.19 (0.04-1.31)	>0.4
Calcium (exchangeable) (meq/100g)	3.10 ± 0.19	2.55 (0.27-12.75)	>5.0
Magnesium (exchangeable) (meq/100g)	0.89 ± 0.07	0.57 (0.25-5.08)	>1.6
Sodium (exchangeable) (meq/100g)	0.06 ± 0.00	0.06 (0.00-0.34)	<0.5
Aluminium (exchangeable) (meq/100g)	0.40 ± 0.05	0.15 (0.01-3.22)	<0.5
Chloride (1:5 aqueous) (mg/kg)	13.0 ± 0.5	12.0 (3.7-52.0)	<300
Manganese (DTPA) (mg/kg)	16.7 ± 1.7	9.3 (0.8-95.0)	4-45
Iron (DTPA) (mg/kg)	117.9 ± 6.2	108 (16-420.0)	Meaningless test (McFarlane 1999)
Copper (DTPA) (mg/kg)	5.0 ± 0.5	3.47 (0.16-39.0)	0.3-10.0
Zinc (DTPA) (mg/kg)	6.8 ± 0.7	3.7 (0.25-41.00)	2.0-10.0
Boron (calcium chloride) (mg/kg)	0.61 ± 0.03	0.50 (0.11-2.93)	1.0-2.0
Cation balance			
Ca:Mg ratio	4.40 ± 0.28	3.28 (0.41-17.64)	3.0-5.1
Calcium (%)	61.7 ± 1.7	67.4 (52.0-77.0)	65-80
Magnesium (%)	18.4 ± 0.6	16.8 (5.1-41.1)	10-15
Potassium (%)	5.4 ± 0.2	5.0 (0.8-16.3)	1-5
Sodium (%)	1.6 ± 0.9	1.4 (0.0-7.1)	< 1.0
Aluminium (%)	12.9 ± 1.5	3.3 (0.1-73.0)	< 1.0
C.E.C.	4.7 ± 0.2	3.8 (1.7-19.4)	> 7.0

- range of publications; (Menzel *et al*. 1992, Menzel *et al*. 1993, George *et al*. 2001)

4.6.3 Seasonal variations in soil nutrient concentrations

Soil nutrient concentrations varied through out the sampling period (Figure 13 and 14). Differences between mean values which occurred over sampling time were generally not significant as values were within the standard error. Seasonal variations are to be expected and may reflect rainfall patterns (particularly for mobile elements), fertiliser application practices and plant uptake due to heavy fruit loads or periods of vigorous vegetative growth.

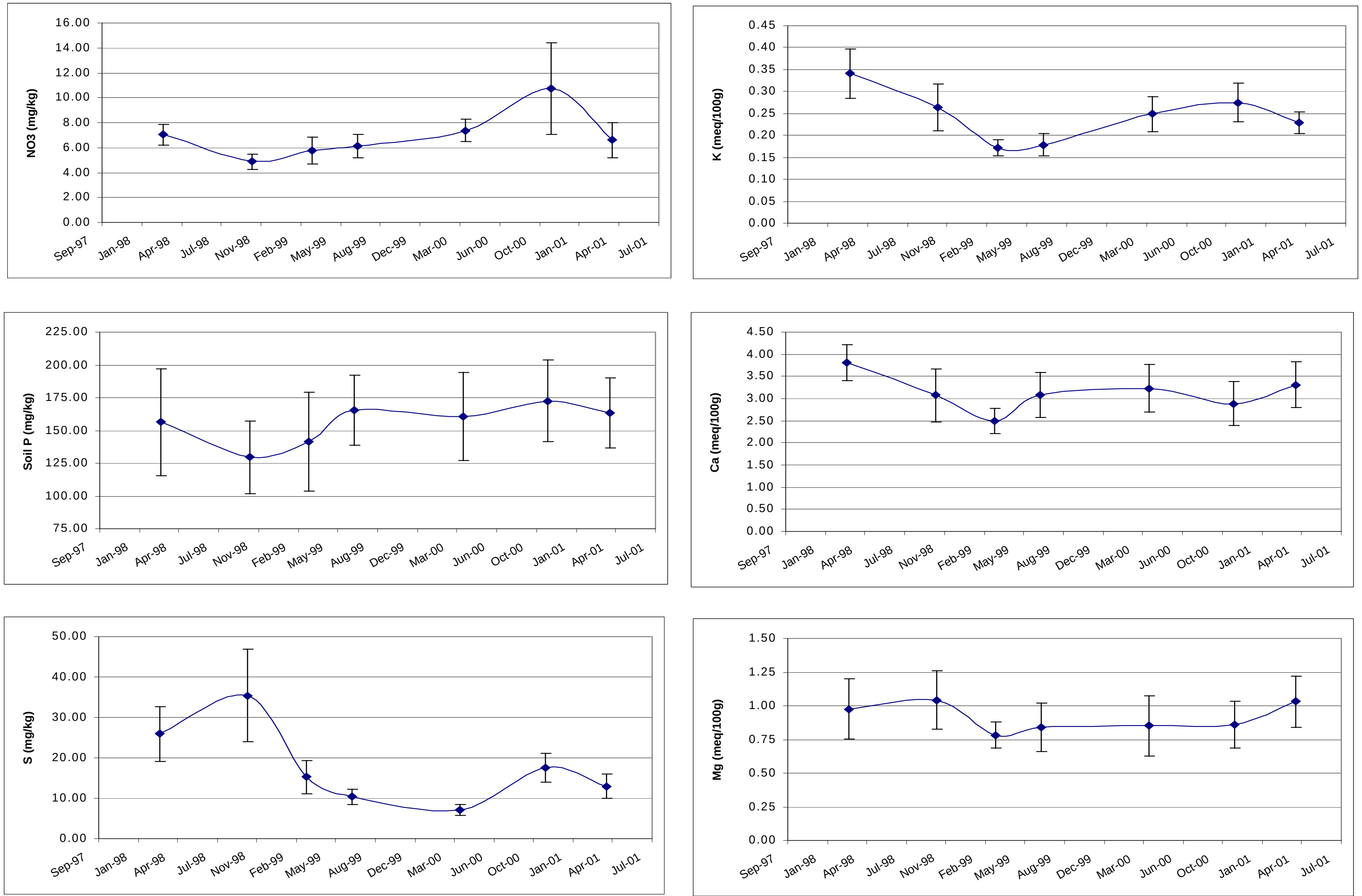


Figure 13. Seasonal variation in mean soil macronutrient concentrations (NO_3-, P, S, K, Ca, and Mg) in fourteen commercial rambutan orchards. Bars represent standard errors at each sampling.

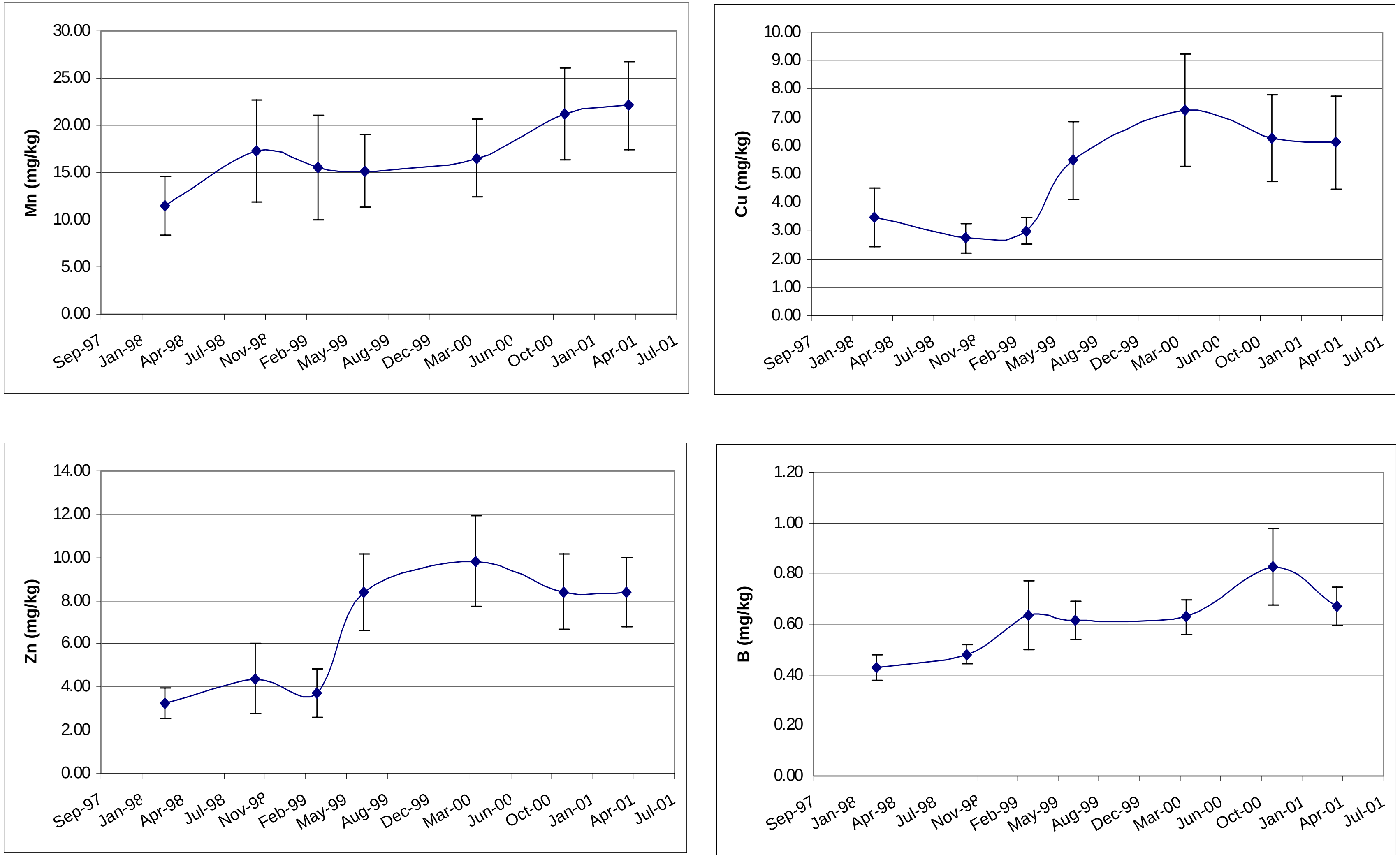


Figure 14. Seasonal variation in mean soil micronutrient concentrations (Mn, Cu, Zn and B) in fourteen commercial rambutan orchards. Bars represent standard errors at each sampling. Iron levels are not shown due to the unreliability of the test and its interpretation.

4.7 Fertiliser inputs

Details on fertiliser inputs were calculated over the monitoring period for orchards where growers provided full fertiliser input information. Fertiliser inputs were converted to grams of element at each application and the total elemental input was then calculated (Table 11).

Seasonal inputs were calculated by summing all inputs from early post harvest to the following harvest. Fertiliser inputs varied considerably among orchards and season. For macro elements such as N, P and K minimum inputs were 0, 0, 3 g/tree respectively where as maximum inputs were 2127, 3256, 4321 g/tree respectively. Similarly for Ca, Mg and S inputs varied from 0 to 11,187 g/tree for Ca, 0 to 3,548 g/tree for Mg and 0 to 2,497 g/tree for S.

Micro nutrient inputs were also variable; however the range in inputs was smaller (0-1,160 g/tree/season). Maximum orchard/seasonal inputs for Zn, B, Cu, Mn, Mo and Fe were approximately 59, 62, 51, 217, 5 and 1160 g/tree respectively.

The above analysis of fertiliser inputs suggests that management of fertiliser inputs is a somewhat haphazard affair.

Table 11. Rambutan orchard fertiliser (foliar, granular, fertigated) inputs (g/tree) over three seasons. Maximum inputs of elements for each season are highlighted in bold. Median fertiliser inputs are shown in ***bold italics***.

Season	Grower	N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Mo	Fe
98/99	D	**1533**	265	714	250	60	201	3.47	2.43	0.22	0.00	0.13	7.50
98/99	E	0	0	3	0	0	0	0.13	0.33	0.00	0.00	0.00	0.00
98/99	I	697	752	727	580	26	627	5.26	**13.11**	0.01	**16.25**	0.01	3.02
98/99	K	391	**852**	**1713**	**6560**	**2404**	**953**	**58.64**	0.60	**46.87**	16.16	0.11	**420.60**
98/99	L	240	104	282	100	24	80	0.20	0.40	0.01	0.00	0.01	3.00
98/99	N	393	319	650	332	18	231	0.50	5.13	1.50	15.00	0.00	0.02
98/99	O	389	363	467	702	39	138	0.96	0.70	0.77	0.00	**1.19**	4.50
98/99	***Median***	***391***	***319***	***650***	***332***	***26***	***201***	***1***	***1***	***0***	***0***	***0***	***3***
98/99	Min	0	0	3	0	0	0	0	0	0	0	0	0
98/99	Max	1533	852	1713	6560	2404	953	59	13	47	16	1	421
99/00	D	**1533**	265	714	1530	420	201	3.47	2.43	0.22	0.00	0.13	7.50
99/00	E	63	27	79	25	6	20	0.32	0.30	0.00	0.00	0.00	0.78
99/00	I	737	640	964	**2915**	280	989	9.78	2.02	3.55	11.94	0.96	**504.00**
99/00	K	1486	306	**1801**	172	97	916	**22.00**	24.60	**50.60**	**217.00**	**3.90**	0.05
99/00	L	1185	**779**	1563	2873	**775**	**1070**	3.71	**45.21**	0.91	21.58	2.67	285.66
99/00	N	369	363	900	0	8	405	0.00	7.18	1.50	32.50	0.00	0.02
99/00	O	816	531	1001	890	84	269	1.27	1.22	0.79	0.03	0.03	9.18
99/00	***Median***	***816***	***363***	***964***	***890***	***97***	***405***	***3***	***2***	***1***	***12***	***0***	***7***
99/00	Min	63	27	79	0	6	20	0	0	0	0	0	0
99/00	Max	1533	779	1801	2915	775	1070	22	45	51	217	4	504
00/01	D	1533	265	714	890	240	201	3.47	2.43	0.22	0.00	0.13	7.50
00/01	E	132	63	179	51	16	41	0.41	0.34	0.09	0.26	0.01	2.06
00/01	I	744	646	984	2920	280	988	16.33	8.30	3.70	12.41	0.96	501.00
00/01	K	**2127**	**3256**	**4321**	**11187**	**3548**	**2497**	**16.76**	**61.61**	4.11	**167.42**	**4.95**	**1160.09**
00/01	L	701	341	1108	5035	395	677	3.55	27.91	0.86	13.39	0.06	235.14
00/01	N	290	8	550	2005	0	231	0.00	15.38	**4.50**	50.00	1.95	0.01
00/01	O	73	432	73	738	5	33	1.32	0.21	0.76	0.00	0.00	0.06
00/01	***Median***	***701***	***341***	***714***	***2005***	***240***	***231***	***3***	***8***	***1***	***12***	***0***	***7***
00/01	Min	73	8	73	51	0	33	0	0	0	0	0	0
00/01	Max	2127	3256	4321	11187	3548	2497	17	62	5	167	5	1160

4.8 Fruit nutrient content

Fruit panicles from ten orchards, including five cultivars (R134, Rongrien, Jitlee, R9, R156) were analysed for nutrient concentrations in the 2000/2001 season. Panicles were harvested at maturity, approximately a fortnight after commercial harvest had commenced. As described in the materials and methods, fruit as per commercial packaging was analysed separately from the remaining heavy panicle stem and stem plus leaf behind the panicle (Table 12).

Table 12. Nutrient concentration (dry weight basis) of fruit (skin, aril, seed) and panicle wood (stem plus leaf). Data is presented as mean ± se and maximum and minimum values.

Cultivar	Tissue	% N	% P	% K	% Ca	% Mg	% S	mg/kg Zn	mg/kg B	mg/kg Cu	mg/kg Mn	mg/kg Fe
Rongrien	fruit	0.87	0.13	0.78	0.37	0.13	0.09	19.6	14.7	31.7	260.0	40.0
R134	fruit	1.18	0.17	0.80	0.31	0.12	0.11	20.9	17.7	20.6	23.0	100.0
R134	fruit	1.07	0.16	0.69	0.29	0.12	0.08	24.7	13.4	9.4	95.0	69.0
R167	fruit	1.11	0.19	0.95	0.30	0.17	0.10	23.4	19.4	15.2	58.0	38.0
R134	fruit	0.93	0.17	1.38	0.14	0.10	0.10	16.4	14.2	11.5	28.0	37.0
R134	fruit	1.03	0.16	0.92	0.27	0.16	0.09	19.2	14.0	11.6	53.0	38.0
R156	fruit	0.85	0.12	0.94	0.12	0.11	0.08	17.1	10.7	12.5	64.0	38.0
R9	fruit	0.78	0.11	0.71	0.21	0.12	0.08	13.6	12.4	7.3	130.0	36.0
R134	fruit	1.03	0.14	0.65	0.43	0.18	0.09	15.4	15.5	12.2	94.0	33.0
Jitlee	fruit	0.98	0.16	0.95	0.26	0.13	0.09	15.4	10.7	13.7	71.0	48.0
Mean		***0.98****	***0.15***	***0.88***	***0.27***	***0.13***	***0.09***	***18.6***	***14.3***	***14.6***	***87.6***	***47.7***
SE		***0.04***	***0.01***	***0.07***	***0.03***	***0.01***	***0.00***	***1.2***	***0.9***	***2.2***	***21.7***	***6.7***
Max		***1.18***	***0.19***	***1.38***	***0.43***	***0.18***	***0.11***	***24.7***	***19.4***	***31.7***	***260.0***	***100.0***
Min		***0.78***	***0.11***	***0.65***	***0.12***	***0.10***	***0.08***	***13.6***	***10.7***	***7.3***	***23.0***	***33.0***
Rongrien	leaf+stem	0.79	0.16	0.76	1.67	0.23	0.17	18.2	26.2	169.6	780.0	62.0
R134	leaf+stem	1.14	0.24	0.68	1.77	0.24	0.18	31.5	36.9	249.0	120.0	74.0
R134	leaf+stem	1.16	0.18	0.56	1.47	0.25	0.14	24.4	19.5	6.5	500.0	85.0
R167	leaf+stem	0.95	0.21	0.54	0.99	0.30	0.13	21.1	20.2	6.2	330.0	65.0
R134	leaf+stem	0.80	0.15	1.01	0.81	0.13	0.14	13.4	20.1	13.0	270.0	130.0
R134	leaf+stem	0.88	0.15	0.53	1.10	0.34	0.13	21.4	18.9	6.0	340.0	94.0
R156	leaf+stem	0.75	0.08	0.59	0.91	0.24	0.13	30.2	14.5	85.7	440.0	64.0
R9	leaf+stem	0.90	0.11	0.77	0.93	0.20	0.15	8.6	19.4	21.4	550.0	59.0
R134	leaf+stem	0.86	0.13	0.29	1.11	0.26	0.10	10.3	13.1	5.3	340.0	62.0
Jitlee	leaf+stem	0.73	0.21	0.77	0.87	0.16	0.15	10.4	13.0	7.7	350.0	48.0
Mean		***0.90***	***0.16***	***0.65***	***1.16***	***0.24***	***0.14***	***19.0***	***20.2***	***57.0***	***402.0***	***74.3***
SE		***0.05***	***0.02***	***0.06***	***0.11***	***0.02***	***0.01***	***2.6***	***2.2***	***27.2***	***56.6***	***7.5***
Max		***1.16***	***0.24***	***1.01***	***1.77***	***0.34***	***0.18***	***31.5***	***36.9***	***249.0***	***780.0***	***130.0***
Min		***0.73***	***0.08***	***0.29***	***0.81***	***0.13***	***0.10***	***8.6***	***13.0***	***5.3***	***120.0***	***48.0***
Mean	***panicle***	***0.94***	***0.16***	***0.76***	***0.72***	***0.18***	***0.12***	***18.8***	***17.2***	***35.8***	***244.8***	***61.0***
SE	***panicle***	***0.03***	***0.01***	***0.05***	***0.12***	***0.02***	***0.01***	***1.4***	***1.4***	***14.1***	***46.6***	***5.7***

* Underlined mean values indicate if element is at higher concentrations in fruit or associated panicle stem and leaf.

Fruit contained higher concentrations of N and K than the remaining panicle stem plus leaf. Levels of macronutrients S, Ca and Mg and all micronutrient levels were at a higher concentration in the panicle stem and attached leaf than in the fruit. Fruit nutrient concentrations are generally less than those in leaf samples, except for potassium, which is at a higher level in fruit (0.88 %) than in leaf at any stage of sampling (0.62 %).

4.9 Nutrient Budget

The tree productivity, fruit nutrient analysis and fertiliser input survey carried out as part of this project has allowed crop nutrient removal to be calculated. Mean fruit analysis concentrations (dry weight basis) were used to calculate nutrient removal based on an average fresh to dry weight ratio of 4.87 for fresh fruit (Table 13). Nutrient budget in its simplest form is the difference between nutrient inputs and crop removal, in this case expressed as the difference.

Table 13. Mean rambutan fruit nutrient concentrations (dry weight basis) used for nutrient removal calculations.

Fruit Analysis	% N	% P	% K	% Ca	% Mg	% S	mg/kg Zn	mg/kg B	mg/kg Cu	mg/kg Mn	mg/kg Fe
Average	0.98	0.15	0.88	0.27	0.13	0.09	18.6	14.3	14.6	87.6	47.7

Nutrients budgets were calculated for participating growers who provided full details on their nutrient inputs and crop yields (Tables 14 – 20).

Table 14. Nutrient budget (g/tree) for Grower E based on fertiliser input and tree yields provided.

Inputs												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99		0.2	0.1	3.1	0.1	0.0	0.1	0.1	0.3	0.0	0.0	0.0
99/00		62.9	27.0	79.4	25.4	6.2	20.3	0.3	0.3	0.0	0.0	0.8
00/01		132.1	62.7	178.6	50.7	16.3	40.6	0.4	0.3	0.1	0.3	2.1
Exports												
Season	Yield/tree (kg)	N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
99/00	1	2.0	0.3	1.8	0.6	0.3	0.2	0.0	0.0	0.0	0.0	0.0
00/01	6	12.1	1.8	10.8	3.3	1.6	1.1	0.0	0.0	0.0	0.1	0.1
Difference												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99		0.2	0.1	3.1	0.1	0.0	0.1	0.1	0.3	0.0	0.0	0.0
99/00		60.9	26.7	77.6	24.8	5.9	20.1	0.3	0.3	0.0	0.0	0.8
00/01		120.0	60.8	167.7	47.4	14.6	39.5	0.4	0.3	0.1	0.2	2.0

* - Underlined values indicate that removal of nutrients exceeds inputs.

For grower E nutrient inputs generally exceed those removed by the crop, except in the 1999/2000 season where crop removal of Cu and Mn slightly exceeded that of fertiliser inputs.

Table 15. Nutrient budget (g/tree) for Grower N based on fertiliser input and tree yields provided.

Inputs												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99	Total	393.1	319.2	649.8	331.7	17.9	231.0	0.5	5.1	1.5	15.0	0.0
99/00	Total	369.2	362.7	900.3	0.3	7.6	405.3	0.0	7.2	1.5	32.5	0.0
00/01	Total	290.4	8.1	549.7	2005.1	0.1	231.4	0.0	15.4	4.5	50.0	0.0
Exports												
	Yield/tree											
Season	(kg)	N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99	6	12.1	1.8	10.8	3.3	1.6	1.1	0.0	0.0	0.0	0.1	0.1
99/00	4	8.0	1.2	7.2	2.2	1.1	0.7	0.0	0.0	0.0	0.1	0.0
00/01	1.5	3.0	0.5	2.7	0.8	0.4	0.3	0.0	0.0	0.0	0.0	0.0
Difference												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99		381.0	317.4	638.9	328.4	16.3	229.9	0.5	5.1	1.5	14.9	-0.0
99/00		361.1	361.4	893.0	-1.9	6.5	404.6	-0.0	7.2	1.5	32.4	-0.0
00/01		287.4	7.6	547.0	2004.3	-0.3	231.1	-0.0	15.4	4.5	50.0	-0.0

* - Underlined values indicate that removal of nutrients exceeds inputs.

For grower N nutrient inputs generally exceed those removed by the crop, except for Fe in 1999/2000 and Ca, Zn, Fe in 2000/2001and Mg, Zn and Fe in the 00/01 season where crop removal slightly exceeded that of fertiliser inputs. Over the duration of monitoring this site has been relatively low yielding, yet fertiliser inputs were moderate.

Table 16. Nutrient budget (g/tree) for Grower I (cv. R134) based on fertiliser input and tree yields provided.

INPUTS												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99		696.5	751.6	726.8	580.3	26.1	627.1	5.3	13.1	0.0	16.3	3.0
99/00		736.9	640.3	964.4	2915.0	280.0	988.8	9.8	2.0	3.6	11.9	504.0
00/01		744.3	646.0	984.0	2919.5	280.5	987.6	16.3	8.3	3.7	12.4	501.0
EXPORT												
	Yield/tree											
Season	(kg)	N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
99/00	20	40.2	6.2	36.1	11.1	5.3	3.7	0.1	0.1	0.1	0.4	0.2
00/01	70	140.9	21.6	126.5	38.8	18.7	12.9	0.3	0.2	0.2	1.3	0.7
Difference												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99		696.5	751.6	726.8	580.3	26.1	627.1	5.3	13.1	0.0	16.3	3.0
99/00		696.6	634.2	928.2	2903.9	274.7	985.1	9.7	2.0	3.5	11.6	503.8
00/01		603.5	624.5	857.5	2880.7	261.8	974.7	16.1	8.1	3.5	11.2	500.3

* - Underlined values indicate that removal of nutrients exceeds inputs.

For grower I (cv. R134) nutrient removal exceeded inputs to the crop, for all elements particularly in the 98/99 season when no cropping occurred. Over the duration of monitoring this site yielded a good crop only in the 2000/2001 season

Table 17. Nutrient budget (g/tree) for Grower K (cv. R134) based on fertiliser input and tree yields provided.

Inputs												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99		391.2	852.0	1713.0	6559.8	2403.6	953.3	58.6	0.6	46.9	16.2	420.6
99/00		1486.4	305.7	1800.6	172.0	97.5	915.8	22.0	24.6	50.6	217.0	0.1
00/01		2127.3	3255.8	4320.8	11186.9	3547.7	2497.4	16.8	61.6	4.1	167.4	1160.1
Exports												
Season	Yield/tree (kg)	N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
99/00	200	402.5	61.6	361.4	110.9	53.4	37.0	0.8	0.6	0.6	3.6	2.0
00/01	60	120.7	18.5	108.4	33.3	16.0	11.1	0.2	0.2	0.2	1.1	0.6
Difference												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99		391.2	852.0	1713.0	6559.8	2403.6	953.3	58.6	0.6	46.9	16.2	420.6
99/00		1083.9	244.1	1439.2	61.2	44.1	878.8	21.2	24.0	50.0	213.4	-1.9
00/01		2006.5	3237.4	4212.4	11153.7	3531.7	2486.3	16.5	61.4	3.9	166.3	1159.5

* - Underlined values indicate that removal of nutrients exceeds inputs.

For grower K (*cv*. R134) nutrient inputs exceeded export by the crop, for all elements, except Fe, in the 99/00 season. Over the duration of monitoring, this site has yielded an above average crop in two of three seasons, and fertiliser inputs are high.

Table 18. Nutrient budget (g/tree) for Grower L (*cv*. R134) based on fertiliser input and tree yields provided.

INPUTS												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99	Total	240.0	104.0	282.0	100.0	24.0	80.0	0.2	0.4	0.0	0.0	3.0
99/00	Total	1184.6	779.3	1562.7	2872.6	774.7	1070.3	3.7	45.2	0.9	21.6	285.7
00/01	Total	700.7	341.0	1108.4	5034.7	394.6	676.8	3.6	27.9	0.9	13.4	235.1
EXPORT												
Season	Yield/tree (kg)	N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
99/00	60	120.7	18.5	108.4	33.3	16.0	11.1	0.2	0.2	0.2	1.1	0.6
00/01	27	54.3	8.3	48.8	15.0	7.2	5.0	0.1	0.1	0.1	0.5	0.3
Difference												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99		240.0	104.0	282.0	100.0	24.0	80.0	0.2	0.4	0.0	0.0	3.0
99/00		1063.8	760.8	1454.2	2839.4	758.6	1059.2	3.5	45.0	0.7	20.5	285.1
00/01		646.4	332.6	1059.6	5019.7	387.4	671.8	3.4	27.8	0.8	12.9	234.9

* - Underlined values indicate that removal of nutrients exceeds inputs.

For grower L nutrient inputs exceed those removed by the crop for all elements in all seasons. Nil yields were recorded in the 98/99 season and good to moderate yields recorded in the 99/00 and 00/01 seasons respectively.

Table 19. Nutrient budget (g/tree) for Grower O (*cv*. R134) based on fertiliser input and tree yields provided.

Inputs												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99		388.7	363.0	467.2	701.5	39.2	137.8	1.0	0.7	0.8	0.0	4.5
99/00		816.3	530.9	1000.9	890.3	84.1	268.6	1.3	1.2	0.8	0.0	9.2
00/01		72.8	432.1	72.8	738.1	5.1	33.2	1.3	0.2	0.8	0.0	0.1
Exports												
Season	Yield/tree (kg)	N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
99/00	60	120.7	18.5	108.4	33.3	16.0	11.1	0.2	0.2	0.2	1.1	0.6
00/01	20	40.2	6.2	36.1	11.1	5.3	3.7	0.1	0.1	0.1	0.4	0.2
Difference												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99		388.7	363.0	467.2	701.5	39.2	137.8	1.0	0.7	0.8	0.0	4.5
99/00		695.6	512.4	892.4	857.1	68.1	257.5	1.0	1.0	0.6	-1.1	8.6
00/01		32.5	426.0	36.7	727.0	-0.2	29.6	1.2	0.2	0.7	-0.4	-0.1

* - Underlined values indicate that removal of nutrients exceeds inputs.

For grower O nutrient inputs generally exceed those removed by the crop, except for Mn in 99/00 and Mg, Mn and Fe in 00/01. Over the duration of monitoring this site has been moderate to high yielding, yet fertiliser inputs were relatively moderate.

Table 20. Nutrient budget (g/tree) for Grower D (*cv*. R134) based on fertiliser input and tree yields provided.

Inputs												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99	Total	1533.3	265.1	714.3	249.9	60.0	200.8	3.5	2.4	0.2	0.0	7.5
99/00	Total	1533.3	265.1	714.3	1529.9	420.0	200.8	3.5	2.4	0.2	0.0	7.5
00/01	Total	1533.3	265.1	714.3	889.9	240.0	200.8	3.5	2.4	0.2	0.0	7.5
Exports												
Season	Yield/tree (kg)	N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
99/00	60	120.7	18.5	108.4	33.3	16.0	11.1	0.2	0.2	0.2	1.1	0.6
00/01	40	80.5	12.3	72.3	22.2	10.7	7.4	0.2	0.1	0.1	0.7	0.4
Difference												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99		1533.3	265.1	714.3	249.9	60.0	200.8	3.5	2.4	0.2	0.0	7.5
99/00		1412.5	246.6	605.9	1496.6	404.0	189.7	3.2	2.3	0.0	-1.1	6.9
00/01		1452.8	252.7	642.0	867.7	229.3	193.4	3.3	2.3	0.1	-0.7	7.1

* - Underlined values indicate that removal of nutrients exceeds inputs.

For grower D, nutrient inputs generally exceed those removed by the crop, except for Mn in the 99/00 and 00/01 seasons where crop removal exceeded that of fertiliser inputs. Over the duration of monitoring this site has been moderate to high yielding. Fertiliser inputs, particularly for N, P and K are relatively high.

5. Discussion

The project objectives were to;

a. monitor changes in rambutan leaf and soil nutrient status over three seasons
b. measure grower fertiliser inputs in relation to the above
c. assess the effect of nutrient status on productivity
d. monitor tree phenology in relation to climate and irrigation management and quantify rambutan water/irrigation requirements

The following discussion is based on the key project objectives plus the addition of the development of a fertiliser management strategy.

5.1 Changes in rambutan leaf and soil nutrient status

Seasonal soil and leaf nutrient data from fourteen commercial rambutan orchards were monitored, recorded and presented. The data showed that mean soil and leaf nutrient concentrations varied over time, however, difference which occurred at sampling dates were often within the standard error of pre and post sample means.

5.1.1 Soil nutrient status

Soil nutrients were presented as mean ± se as well as the median value with associated range (Table 10). In most cases soil nutrient and chemical characteristics (pH, EC) were within optimum range for horticulture crops. Mean soil nutrient data generated from all farms over all sampling dates suggest that the soil cation balance is slightly biased toward magnesium. Ideal Ca:Mg ratios are reported to be in the range of 3.0-5.0 whereas the median Ca:Mg ratio reported in rambutans orchards was 4.4 with a range of 0.4 - 17.6. The importance of cation balance and in particular Ca:Mg ratio is now commonly raised as an important issue in horticulture industry publications, in particular via advertising literature supplied by some fertiliser companies. Conyers (1999) reports that although the ideal soil was considered to contain exchangeable cations in the proportions 65-85% Ca, 6-12% Mg and 2-5% K when expressed relative to CEC, it was noted that for Ca, Mg and K substantial departures from these ideal proportions could occur without detriment to yield, particularly for crops other than lucerne. Hence, Conyers (1999) suggests that it is best to regard these much quoted ‘ideal’ ratios as no more than a general guide and therefore do not form the basis for making fertiliser recommendations.

Current and new rambutan growers can now use the mean soil nutrient values presented as a source of comparison for their soil nutrient data records. The data should ideally be used as a guide to soil nutrient status of producing commercial orchards, with special note of the mean and median values and the range found in producing orchards. No overseas data is available for direct comparison.

5.1.2 Leaf nutrient status

The nutrient survey conducted as part of this project allows for the development of leaf standards which can be used by growers, fertiliser consultants and researchers to make recommendations on fertiliser management. The seasonal data collected and presented in this study is ideally suited to the development of nutrient standards. The process is based on the following parameters;

sampling a wide range of commercial orchards with yield being documented

identification of leaf standards based on orchard yields and tree health

determination of the ideal sampling time (nutrient concentrations are most stable)

selection of an easily recognizable leaf for sampling purposes.

This process has been successfully used for kiwifruit (Cresswell, 1998), lychee (Menzel *et al*. 1992), mango (Catchpoole and Bally, 1996), grapevines (Robinson and McCarthy, 1985), passion fruit (Menzel *et al*. (1993), persimmons (George *et al*. (2001) and form the basis of nutrition management in these crops. Leece (1976) states that a nutrient range (95% CV around the mean) has more merit than the presentation of a mean value alone.

Leaf nutrient concentrations are presented as overall and seasonal means with associated se, range data at 95% confidence interval and coefficient of variation (Table 9). The leaf nutrient concentrations of N, P, K, found in this study are generally similar to that presented by other researchers for producing orchards (Table 21). For the macronutrients N, P and K nutrient concentrations in this study are higher than overseas data and similar to Australian data. No overseas data is available for Ca, Mg, and S. Direct comparison cannot be made because of the lack of fertiliser input data presented in the overseas literature. Overseas data for S is not available to comment on.

Table 21. Rambutan leaf macronutrient range (95% confidence interval of the mean) from this study compared to data presented by other researchers.

Reference	N %	P %	K %	Ca %	Mg %	S %
This Study	**1.96-2.05**	**0.20-0.22**	**0.60-0.64**	**1.09-1.19**	**0.32-0.34**	**0.20-0.21**
Tindall (1994)	1.14 -1.32	0.25-0.42	0.66-0.82	-	-	-
Prasittikhet (1996)	1.61	0.17	0.40			
Lim et al. (1997) Mansfield (2000)	1.54-1.8	0.21-0.23	0.69-0.77	0.68-0.77	0.41-0.48	0.16-0.17
NQ survey 1986	na	0.18	0.65	0.96	0.29	-
NQ Survey 93-94	1.52	0.15	0.60	0.58	0.21	-

Leaf micronutrient concentrations found in this study are compared to reported data in Table 22. Overseas data is non-existent for leaf micronutrients, with the only data available being Australian presented by Lim et al. (1997) and Mansfield (2000).

Table 22. Rambutan leaf micronutrient range (95% confidence interval of the mean) from this study compared to data presented by other researchers.

Reference	Fe mg/kg	Mn mg/kg	Zn mg/kg	Cu mg/kg	B mg/kg
This Study	**73-82**	**405-491**	**23-31**	**39-58**	**43-47**
Tindall (1994)	na	na	na	na	na
Prasittikhet (1996)	na	na	na	na	na
Lim et al. (1997) Mansfield (2000)	77-98	104-150	43-54	16-25	43-54
NQ survey 1986	46.3	559	26.9	32.4	34
NQ Survey 93-94	25.8	296	16.0	9.5	90.6

Orchard micronutrient standard ranges from this study are higher than those presented from previous Queensland surveys for all elements. Leaf Mn in particular, is higher in this study than in past surveys. This may be a reflection of soil type, soil water status rather than an absolute requirement for Mn. The leaf Mn levels in north Queensland orchards are also considerably higher than those in the NT. This may be due to the fact that Mn is readily available in the acidic soils of north Queensland.

The mean seasonal leaf nutrient concentrations with associated coefficient of variation are presented in Table 7; indicate that sampling the mature summer flush resulted in five of eleven nutrients with the lowest coefficient of variation, relative to three of thirteen for the harvest and fruit filling samples. The sampling period in which the largest numbers of nutrients have the lowest CV is generally accepted as the best sampling period for analytical and fertiliser recommendation purposes (lychee - Menzel *et al.* 1992, mango - Catchpoole and Bally, 1996 and persimmons - George *et al*. 2001).

The survey data suggests that the post harvest mature summer flush is the ideal sampling time for north Queensland rambutans. Based on the above observations the ideal sampling time for the leaf standards are at post harvest mature summer flush.

If only one leaf sample a year is to be made then sampling at early panicle emergence is suggested as an ideal time. Although not a sampling period which possessed the lowest coefficient of variation for any of the eleven major macro and micronutrients, mean nutrient levels and associated CV's for macronutrients were not dissimilar to those at the post harvest mature flush. Another advantage of this sampling period is the ease of which sample leaves can be collected. The mature leaf below the emerging panicle is easily identifiable unlike the mature post harvest summer flush. This is a common sampling time for a number of crops.

Increased frequency of sampling will enable growers to more quickly fine tune their fertiliser management program. Hence growers are encouraged to undertake leaf sampling more frequently than once per year.

5.2 Fertiliser inputs

Full fertiliser inputs were provided by seven of the fourteen cooperative growers (Table 11). This data clearly showed that fertiliser inputs varied widely between orchards and between years on the same orchard. For example elemental N inputs varied from a low of 0 to a high of 2127 g/tree/season. Similarly inputs of elemental Pvaried from 0 to 3256 g/tree/season while elemental potassium inputs varied from 3 to 4321 g/tree/season. Likewise, micronutrient inputs were also highly variable with large differences occurring between orchards and seasons. The variability in fertiliser input is less dramatic but still highly variable, due to different tree density, when shown in kg/ha (Table 24).

In terms of the three major macronutrients N inputs ranged from 0 to 225 kg/ha while P inputs ranged from 0 to 265 kg/ha and K inputs ranged from 0 to 298 kg/ha. Like wise inputs for Ca, Mg and S were also highly variable. Mean nitrogen, potassium and magnesium inputs (g/tree), in this survey, compare favourably with inputs reported from overseas and Australian publications (Table 23), while inputs of phosphorus and calcium are more than double the maximum reported.

Table 23. Survey mean macronutrient input (g/tree) compared with that recommended by other sources.

	Macro nutrients (g/tree)				
Location	N	P	K	Ca	Mg
This study	**735**	**504**	**929**	**1893**	**415**
North Queenland (Watson *et al*. 1988)	1014	172	1037	660	400
Northern Territory (Lim *et al*. 1997)	550	275	495	135	72
Malaysia (Tindall, 1994)	480	208	564	56	-
Hawaii (Zee, 1995)	2000	250	1300	660	400

Elemental micronutrient inputs also varied widely and ranged from 0 kg/ha to highs of 15 and 105 kg/ha for Mn and Fe. The micronutrient inputs of Cu, Zn and B were less than 5 kg/ha. Its clear from the fertiliser input data that the key micronutrient inputs were considered to be Fe and Mn, whereas very few growers actively added Cu, B and Zn.

Generally the bulk of fertiliser inputs occurred from flowering through to harvest with smaller, although still substantial amounts applied immediately after harvest and pruning. Little to no fertiliser was added in the month prior to flowering. This suggests that orchard managers are applying fertilisers when they are most needed, during fruit filling and immediately post harvest and pruning. Many fertilisers, in particular N, K, Mg and micronutrients are applied via the irrigation system further improving the efficiency of fertiliser uptake.

Table 24. Seasonal nutrient inputs (kg/ha) occurring on seven rambutan orchards over three seasons.

Grower	Season	Tree	kg/ha

Code		density (t/ha).	N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Mo	Fe
D	98/99	166	255	44	119	41	10	33	0.58	0.40	0.04	0.00	0.02	1.24
D	99/00	166	255	44	119	254	70	33	0.58	0.40	0.04	0.00	0.02	1.24
D	00/01	166	255	44	119	148	40	33	0.58	0.40	0.04	0.00	0.02	1.24
E	98/99	139	0	0	0	0	0	0	0.02	0.05	0.00	0.00	0.00	0.00
E	99/00	139	9	4	11	4	1	3	0.04	0.04	0.00	0.00	0.00	0.11
E	00/01	139	18	9	25	7	2	6	0.06	0.05	0.01	0.04	0.00	0.29
I	98/99	208	145	156	151	121	5	130	1.09	2.73	0.00	3.38	0.00	0.63
I	99/00	208	153	133	201	606	58	206	2.03	0.42	0.74	2.48	0.20	104.83
I	00/01	208	155	134	205	607	58	205	3.40	1.73	0.77	2.58	0.20	104.21
K	98/99	69	27	59	118	453	166	66	4.05	0.04	3.23	1.12	0.01	29.02
K	99/00	69	103	21	124	12	7	63	1.52	1.70	3.49	14.97	0.27	0.00
K	00/01	69	147	225	298	772	245	172	1.16	4.25	0.28	11.55	0.34	80.05
L	98/99	111	27	12	31	11	3	9	0.02	0.04	0.00	0.00	0.00	0.33
L	99/00	111	131	87	173	319	86	119	0.41	5.02	0.10	2.40	0.30	31.71
L	00/01	111	78	38	123	559	44	75	0.39	3.10	0.10	1.49	0.01	26.10
N	98/99	140	55	45	91	46	2	32	0.07	0.72	0.21	2.10	0.00	0.00
N	99/00	140	52	51	126	0	1	57	0.00	1.00	0.21	4.55	0.00	0.00
N	00/01	140	41	1	77	281	0	32	0.00	2.15	0.63	7.00	0.27	0.00
O	98/99	208	81	76	97	146	8	29	0.20	0.15	0.16	0.00	0.25	0.94
O	99/00	208	170	110	208	185	17	56	0.26	0.25	0.16	0.01	0.01	1.91
O	00/01	208	15	90	15	154	1	7	0.28	0.04	0.16	0.00	0.00	0.01

The relationship between macronutrient input (N, P and K) and yield was examined for the seven orchards which provided fertiliser input and yield data over the three seasons. This suggests that significant relationships (P 0.05) exist for P, K and total N + P + K inputs and accumulated yield (Table 25).

Table 25. Relationship between accumulated macronutrient (N, P and K) inputs and accumulated yield over three seasons.

Macronutrient	Equation	R^2	Regression Significance Level
Nitrogen (N)	Y = 21.512 x + 4759.7	0.472	P = 0.087
Phosphorus (P)	Y = 41.113 x + 3313.4	0.614	P = 0.037
Potassium (K)	Y = 33.369 x – 164.1	0.606	P = 0.039
N + P + K	Y = 14.215 x– 720.8	0.783	P = 0.008

The positive relationships between P and K inputs and N+P+K inputs and yield are surprising given that leaf nutrient status varied little with inputs (Table 25). The relationship may be circumstantial and a reflection of other management and environmental variables.

5.3 Effect of nutrient status on productivity

Tree productivity varied widely between orchards and within orchards across seasons (Table 7). This is not unexpected given that flowering in rambutan is usually associated with dry conditions (Tatt, 1976, Wanichkul *et al*. 1990, Diczbalis and Watson, 1997) and the climatic variability between seasons at any one survey location and the variability between locations over the three monitoring seasons.

Average yields over the three seasons of monitoring are compared with average macro and micro nutrient concentrations (Table 26).

Table 26. Average macro and micro leaf nutrient concentrations for seven rambutan orchards with corresponding accumulated yields (t/ha) over three seasons of monitoring.

Grower Code	N %	P %	K %	Ca %	Mg %	S %	Mn mg/kg	Fe mg/kg	Cu mg/kg	Zn mg/kg	B mg/kg	Accumulative Yield (t/ha)
D	2.21	0.21	0.71	0.87	0.28	0.18	327	75	5	18	53	16.60
E	2.24	0.24	0.53	1.33	0.30	0.18	299	72	24	22	30	0.97
I	1.97	0.23	0.54	1.36	0.40	0.20	592	99	75	42	60	18.72
K	2.10	0.20	0.71	1.06	0.29	0.21	219	65	76	23	64	17.94
L	2.04	0.20	0.68	1.07	0.32	0.22	220	68	63	22	61	9.66
N	1.93	0.21	0.65	1.20	0.30	0.18	151	70	65	36	47	1.53
O	1.94	0.19	0.68	1.03	0.28	0.20	1199	118	125	61	38	16.64

There is no clear association between mean nutrient status and fruit yield over the three seasons. This is a reflection of the other key factors that control yield potential, such as pruning management and climate. For the sake of this discussion we presume that water inputs (rain or irrigation) were sufficient and no yield decline occurred due to water deficits. In three of fourteen orchards this was confirmed *via* irrigation monitoring.

Soil nutrient and chemical status are all critical to maintaining tree nutrient status. Selected soil nutrient and chemical properties are shown in Table 27. Soils properties in low yielding orchards do not appear to be different from soils in higher yielding orchards. In the sample available the two low yielding orchards are the only ones with pH's greater than 6.0.

Like leaf nutrient concentrations there does not appear to be any direct relationship between the major soil and chemical characteristics and tree yield.

Table 27. Rambutan accumulated yield over three seasons for seven orchards and corresponding mean soil nutrient and chemical properties (pH, NO3, P , K, Ca:Mg ratio, O.M. and CEC)

Grower Code	Accumulate Yieldd(t/ha)	pH Water	NO_3 (mg/kg)	P-(Colwell) (mg/kg)	K (meq/100g)	Ca/Mg Ratio	OM (%)	CEC (meq/100g)
D	16.60	5.30	14.84	482.86	0.22	3.83	2.71	3.60
E	0.97	6.14	6.01	367.14	0.26	8.88	3.36	5.82
I	18.72	5.74	10.56	56.00	0.29	3.18	3.91	6.37
K	17.94	5.68	5.45	40.50	0.24	6.21	3.36	4.13
L	9.66	5.60	4.40	56.86	0.19	4.22	2.58	2.84
N	1.53	6.53	2.30	97.57	0.12	6.76	2.78	4.68
O	16.64	5.35	3.98	121.00	0.38	2.17	2.92	3.30

5.4 Tree phenology, climate and irrigation

Tree phenology was monitored and presented in Table 6 and yield data (per tree and per hectare) are presented in Table 7.

Individual orchard and average seasonal yields are shown in Table 28. The data shows that the 98/99 season was an "off year" for most of the orchards and production was similar in the 99/00 and 00/01 seasons. Rambutan production is variable with lower yielding seasons generally following high yielding seasons. In SE Asia rambutan trees flower following a short period of dry weather. Commercial orchards are situated in locations where three to four weeks of low or no rainfall during the "winter months" is the norm (Diczbalis, 1997). During the period of this study flowering usually occurred following a dormant period brought on by low day/night temperatures (20-28^{o}C/8-16^{o}C) rather than dry soil conditions. Wanichukul *et al*. (1990) state that in Thailand floral bud formation began one month after the end of the wet season. They concluded that flowering might be dependent on the accumulation of starch in the terminal shoots as a result of either reduced soil moisture or a reduction in night temperature. Mansfield (2000) reports that production in north Queensland is more evenly distributed throughout the year. This is partly due to the range in environments and climate between Cooktown and Tully, which encompasses the bulk of the growing area and that rainfall, can occur through out the year in the major growing region of Bellenden Ker to Tully.

Table 28. Orchard yield (t/ha) over three seasons.

Grower Code	1998/1999	1999/2000	2000/2001
D	0	9.96	6.64
E	0	0.14	0.83
I	0	4.16	14.56
K	0	13.8	4.14
L	0	6.66	3.00
N	0.83	0.50	0.20
O	0	12.48	4.16
Average Yield (t/ha)	**0.12**	**6.81**	**4.79**

Although flowering usually occurs following a dormant period in the winter months there appears to be no direct relationship between yield and seasonal temperatures over all orchards in a region. Although “off years” in terms of flowering is a common experience, it’s clear from experience gained outside of the term of this study that individual orchards have the ability to perform in so called “off years”. The relationship between temperature, vegetative shoot age and flowering is complicated. Pruning management further complicates this relationship. Menzel *et al*. (1999) suggest, from limited work on flushing cycles in the Northern Territory, that pruning should occur as soon as possible after harvesting. Observations during this project suggest that early pruning (February/March) allows two flushes to develop and a dormant period (no shoot growth) to occur from late May to September when panicle emergence normally occurs. Where a crop is harvested late (May/June) due to a late flowering and a cooler growing environment and pruning takes place as a result of harvesting there is no opportunity for new shoot growth to occur until the following spring (September/October), hence flowering and cropping become biennial.

Irrigation inputs vary between sites, dependent on tree size, rainfall, season, soil type and management. The lowest irrigation inputs coincided with the wet season while the highest inputs coincided with fruit filling. Soil tensions increased during periods when rainfall is less than 30 mm/week and irrigation inputs are less than 50 L/tree/day (or 350 L/week). In general irrigation inputs were more than sufficient to maintain tree growth. It is highly unlikely that trees were stressed at any occasion during the monitoring period. In most cases over irrigation, which potentially promotes leaching of fertiliser, is more of an issue than under irrigation.

5.5 Fertiliser management strategy

Although not a prescribed aim of the project the development of a fertiliser management strategy is the natural outcome of a nutrient monitoring project. The information collected on tree and fruit nutrient status, nutrient inputs and fruit yield has allowed the development of a nutrient budget to occur. The concept of a nutrient budget or of crop nutrient removal as a basis for fertiliser management has been previously raised by Moody and Aitken (1996) and more recently by Huett and Dirou (2000). The basic tenant is best described by the following relationship;

Nutrient Requirements = Crop Nutrient Removal + other losses (leaching, runoff, volatilization, fixation)

Analysis of fruit nutrient content (dry weight basis) allows nutrient removal (g/tree) to be calculated, based on a fresh/dry weight ratio and tree yield (Table 29). Fruit harvest and removal is prime source of nutrient loss, as shown in the above formula. Fortunately it is easily calculated.

Table 29. Mean rambutan fruit nutrient analysis and amount of element removed (g/tree) for various tree yields. Note FW/DW is the fresh weight/dry weight ratio.

		%	%	%	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
Fruit nutrient status		0.983	0.151	0.876	0.2692	0.1337	0.091	18.57	14.27	14.57	87.6	47.7
Yield							g/tree					
kg/tree	FW/DW	N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
10	4.87	20.18	3.10	17.99	5.53	2.75	1.87	0.04	0.03	0.03	0.18	0.10
20	4.87	40.37	6.20	35.98	11.06	5.49	3.74	0.08	0.06	0.06	0.36	0.20
30	4.87	60.55	9.30	53.96	16.58	8.24	5.61	0.11	0.09	0.09	0.54	0.29
40	4.87	80.74	12.40	71.95	22.11	10.98	7.47	0.15	0.12	0.12	0.72	0.39
50	4.87	100.92	15.50	89.94	27.64	13.73	9.34	0.19	0.15	0.15	0.90	0.49
80	4.87	161.48	24.80	143.90	44.22	21.96	14.95	0.31	0.23	0.24	1.44	0.78
100	4.87	201.85	31.01	179.88	55.28	27.45	18.69	0.38	0.29	0.30	1.80	0.98
140	4.87	282.59	43.41	251.83	77.39	38.44	26.16	0.53	0.41	0.42	2.52	1.37
180	4.87	363.33	55.81	323.78	99.50	49.42	33.63	0.69	0.53	0.54	3.24	1.76
210	4.87	423.88	65.11	377.74	116.08	57.65	39.24	0.80	0.62	0.63	3.78	2.06

The more difficult issue is accounting for other forms of nutrient loss via leaching, runoff and volatilisation.

The order of nutrient removal in rambutan fruit is N K > Ca > P > Mg > S > Mn > Fe > Zn > Cu >B. Hence any fertiliser replacement program should ideally be based on the order and amount of nutrient removal.

Further nutrient requirements are needed due to nutrient loss and unavailability (volatilisation, leaching, runoff and fixation). Slack *et al*. (1996) recommended increasing fertiliser rates to compensate for these factors by 30-50% for N, 20-30% for K, Mg and Ca to compensate for leaching and runoff loss. For P they suggested that an additional 50-80% is required to compensate for runoff loss and fixation. Slack and Dirou (2002) have used the following 'other loss' factors in their subtropical fruit crop fertiliser requirement program (Excel spreadsheet) for northern NSW coast orchards.

N – 30-40% (volatilisation, runoff and leaching)

P – 80-100% (fixation and runoff)

K – 30% (leaching and runoff)

Ca – 10% (leaching and runoff)

Mg – 25% (leaching and runoff)

These rates compare favourably with the 30-50% fertiliser N loss reported to occur in bananas in north Queensland (Moody *et al*. 1996, Rasiah and Armour, 2001). Similarly work carried out on the effect of nitrogen applications in cashew orchards in north Queensland suggest that fertiliser N can be rapidly leached from the root zone with high nitrate concentrations (128 mg N/L) found in leachate at a depth of 1 m (O'Farrell *et al*. 1999). Any estimate of nutrient loss via volatilisation, leaching, runoff and fixation will remain a generalisation because of the specific interactions between loss, soil type, climate and irrigation management (Moody *pers. com*, 2001).

Nutrient replacements required for rambutan based on fruit nutrient concentrations and the above ‘other loss’ factors are shown in Table 30. No additional loss factors have been used for S and the micronutrients.

Table 30. Rambutan fruit nutrient loss (g/kg) and nutrient replacement based on generalised ‘other loss’ factors.

	N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
Fruit loss (g/kg)	2.02	0.31	1.80	0.55	0.27	0.19	0.004	0.003	0.003	0.018	0.010
Other loss %	40	100	30	10	25	0	0	0	0	0	0
Total replacement (g/kg)	2.83	0.62	2.34	0.61	0.34	0.19	0.004	0.003	0.003	0.018	0.010

Hence for a high yielding rambutan crop (14 tonne/ha) the macronutrient inputs per hectare required to replace total nutrient loss are 39.6 kg N, 32.7 K, 8.7 kg P, 8.5 kg Ca, 4.8 kg Mg, 2.6 kg S. For micronutrients where no ‘other loss’ factors are available estimates of loss based on fruit nutrient content only are 0.04 kg for Cu and B, 0.05 kg for Zn, 0.14 kg for Fe and 0.25 kg for Mn. In most rambutan orchards monitored macro and micro-nutrient inputs exceeded outputs by 100%.

6. Implications

6.1 Rambutan fertiliser management

Through this project rambutan researchers, extension officers, growers and associated industry organisations are now able to access an improved understanding of the effect of nutrition on yield and tentative leaf and soil standards to use as a management guide.

Over the duration of the project the data collected as part of the nutrient survey was unable to identify any direct links between tree nutritional status, fertiliser inputs and yield. This suggests that other factors such as pruning practices and climate play a more important role in flowering and subsequent yield.

A guide to fertiliser requirements was developed using a nutrient budget approach where nutrient inputs are based on fruit production and removal and take into account additional nutrient loss via leaching, runoff and fixation.

As a result of the development of a nutrient budget, inputs can now be geared to production rather than based on an ad-hoc approach. This allows for potential savings on fertiliser inputs, however, more importantly the nutrient budget approach has the potential to reduce fertiliser loss and hence contamination of sub-soils and drainage systems.

Although the nutrient budget concept is seen as a major step forward in managing fertiliser inputs it does not imply that leaf and soil analysis are not useful. In fact the nutrient budget should be used in conjunction with the tentative leaf and soil nutrient standards determined in this project. The combination of techniques will be the preferred management option.

6.2 Rambutan irrigation requirements

Rambutan irrigation requirements during fruit filling were monitored at three sites. Climatic conditions during the monitoring period were wet through out with little opportunity to monitor tree water requirements without the interference of rainfall. As a general recommendation an evaporation replacement method of irrigation requirements can be used to establish replacement rates during the year. Based on work carried out in the NT by Diczbalis (1997b) it is suggested that a “crop factor” of 0.5 – 0.6 can be used in the months preceding flowering while a crop factor of 0.8 – 1.0 should be used during fruit filling. Hence irrigation requirements can be calculated using a simple evaporation based calculation;

Irrigation Requirements = canopy area (m^2) * Evaporation Rate (mm/week) * Crop Factor

Growers are advised to monitor the above irrigation inputs recommendations with readily available soil moisture sensing technology and where possible the addition of a water meter. These simple tools allow the orchard manager to fine tune irrigation inputs to their crop, season and soil type.

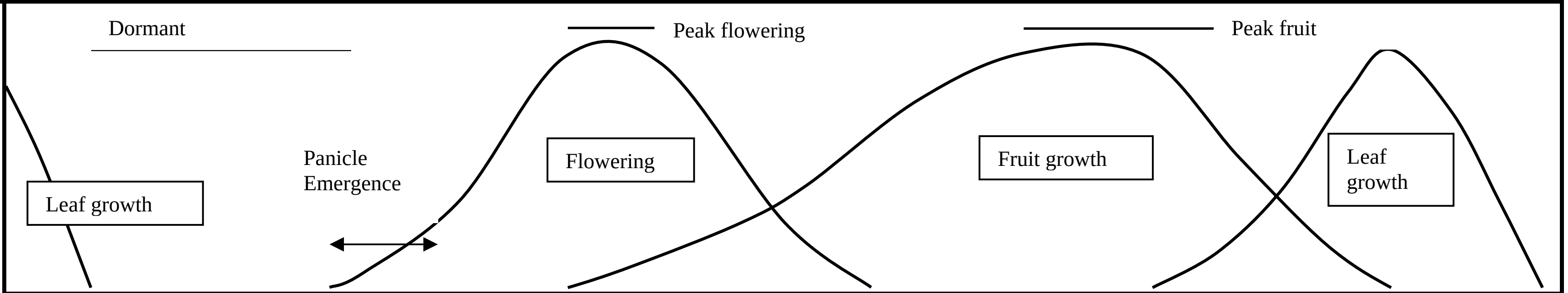
6.3 Rambutan phenology based management calendar

The recommendations arising from the data collected during this survey has been summarised in a draft management calendar (Figure 15).

The calendar can be used to plan major management inputs. Growers should be aware that the calendar cannot replace their observation, however, it can be a useful guide to crop management, particularly for new growers.

Draft Rambutan Management Calender – Wet Tropics

Crop Phenology



	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Fertiliser													
N						Majority of N to be applied during fruit filling and immediately post harvest							
P													
K						Majority of K to be applied during fruit filling and immediately post harvest							
pH/Ca/Mg													
Trace elements						Add as foliar or via fertigation as required (leaf test)							
Leaf Analysis			Pre or early panicle emergence					Optional					
Soil Analysis			Pre or early panicle emergence										
Irrigation		Withdraw if possible		Critical time to maintain soil moisture. 30 mm/wk during winter, 50 mm/wk during summer									
Pruning		Major branch removal							Immediately after harvest				
	Major branch removal is best done in winter to minimise regrowth								Prune at or immediately harvest to maintain tree shape and size				

Figure 15. Draft rambutan management calendar for rambutan grown in the wet tropics region of north Queensland (Bellenden Ker to Murray Upper)

7. Recommendations

Rambutan growers should be encouraged to monitor fertiliser inputs in conjunction with regular leaf and soil analysis and yield records. This is the only way in which fertiliser inputs can be geared more closely to nutrient outputs. The following key points should be included in a monitoring system;

- Develop fertiliser input worksheets that can be easily transferred to spread sheet software packages.
- Use of the tentative leaf and soil standards as a guide to current fertiliser management strategy.
- Develop a fertiliser management spreadsheet based on nutrient removal through fruit and other loss factors.
- Use the nutrient budget to develop a fertiliser program for the season, based on yield projections.
- Monitor rambutan yields in conjunction with fertiliser management records to validate the nutrient budget approach over a minimum of 5 seasons, to reduce the effects of climate and other management issues (pruning) on yield.

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