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# Durian and Mangosteen Orchards– north Queensland nutrition survey

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by Yan Diczbalis and Darren Westerhuis

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# Foreword

Durian (*Durio zibethinus* Linn.) and Mangosteen (*Garcia mangostana* Linn.) are known throughout SE Asia respectively as the King and Queen of tropical fruits.

The durian is a tree native to the wet tropics of Peninsular Malaysia, Sumatra and Borneo and is now grown extensively through out SE Asia and northern Australia. The fruit is considered a delicacy and aphrodisiac by many dedicated consumers but is also renowned by some Europeans for its complex flavour and odour interactions. The mangosteen is a tree native to the wet tropics of Peninsular Malaysia, Sumatra and Borneo and is also grown extensively through out SE Asia and northern Australia. The fruit is highly esteemed and is favoured as a suitable antidote to the pungent durian.

The durian and mangosteen industries are in their infancy in Australia with current plantings believed to be in the order of 11,000 and 15,000 trees respectively. The value of these industries is currently estimated to be $0.5M for durian and $0.75M for mangosteen, with industry projected values by 2010 of $12M and $6.0M respectively. These projections are based on current bearing and newly planted trees, the bearing capacity of mature trees and wholesale prices of $6.50/kg and $8.00/kg for fresh fruit.

The industries lack basic agronomic information with many of the current management techniques used in Australia transferred from SE Asia. The industries representative body, Rambutan and Tropical Exotic growers Association (RTEGA), have a clear strategic plan and this project and its outcomes were developed to assist growers with basic information on leaf and soil standards suited to the north Queensland growing environment.

This project was funded from RIRDC Core Funds (New Plant Products) which are provided by the Australian Government

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# Contents

# Executive Summary

Durian (*Durio zibethinus* Linn.) and Mangosteen (*Garcia mangostana* Linn.) are known throughout SE Asia respectively as the King and Queen of tropical fruits.

The durian is a tree native to the wet tropics of Peninsular Malaysia, Sumatra and Borneo and is now grown extensively through out SE Asia and northern Australia. The large green thorny fruit requiring delicate handling is considered a delicacy and aphrodisiac by many dedicated consumers but is also renowned by some Europeans for its complex flavour and odour interactions which have been described as akin to eating custard in the lavatory.

The mangosteen is a tree native to the wet tropics of Peninsular Malaysia, Sumatra and Borneo and is grown extensively through out SE Asia and northern Australia. The purple tennis ball sized fruit topped with green stalk and calyx is highly esteemed and widely grown throughout the wet tropics of SE Asia. The delicate sweet white citrus like segments are favoured as a suitable antidote to the pungent durian.

The Australian durian and mangosteen industries are in their infancy in Australia with current plantings believed to be in the order of 11,000 and 15,000 trees respectively. The value of these industries is currently estimated to be $0.5M for durian and $0.75M for mangosteen, with industry projected values by 2010 of $12M and $6.0M respectively. These projections are based on current bearing and newly planted trees, the bearing capacity of mature trees and current values of $6.50/kg and $8.00/kg for fresh fruit.

The industries lack basic agronomic information with many of the current management techniques transferred from SE Asia. The industries representative body, Rambutan and Tropical Exotic growers Association (RTEGA), have strategic development plans for both crops and this project and its outcomes were developed to assist growers with basic information on leaf and soil standards suited to the north Queensland growing environment.

The project aims were to monitor changes in durian and mangosteen leaf and soil nutrient status over several 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.

This report details the findings of a leaf and soil sampling survey from September 2002 to October 2004. Through this project durian and mangosteen researchers, extension officers, growers and associated industry organizations are 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. It is important to note that all commercial orchards surveyed had relatively high leaf nutrient status. This suggests that within the range of nutrient status observed other factors such as 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 and has the potential to reduce fertiliser loss and hence contamination of ground waters.

As an outcome of the project durian and mangosteen 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 its use among industry members.
- Use the nutrient budget to develop a fertiliser program for the season, based on yield projections.
- Recommend the use of fertigation to improve the efficiency of fertiliser application and use. Gear fertiliser inputs to periods of maximum fertiliser demand (fruit filling).
- Monitor durian and mangosteen 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.

# Introduction

## Background

The durian and mangosteen are popular tropical fruits native to SE Asia. Both fruits have been introduced into north Australia since the early 1960's and have been commercially grown since the early 1980's. The durian and mangosteen industries are in their infancy in Australia with current plantings believed to be in the order of 11,000 and 15,000 trees respectively. The value of these industries is currently estimated to be $0.5M for durian and $0.75M for mangosteen, with industry projected values by 2010 of $12M and $6.0M respectively. These projections are based on current bearing and newly planted trees, the bearing capacity of mature trees and current values of $6.50/kg and $8.00/kg for fresh fruit.

Both tree crops are grown principally in north Queensland along the wet tropical coast from Daintree to Tully. A smaller but vibrant centre of production also occurs in the rural area adjacent to Darwin (12$^{o}$S).

### Durian

The durian's centre of origin is reported to be Borneo (Brown, 1997) and the genus Durio contains approximately 30 species of which *Durio zibethinus* L. is the main commercial species. Brown (1997) reports that the species *D. zibethinus* has been incorrectly attributed to Murray, but is more correctly attributed to Linnaeus. A number of other species are also edible, chiefly *D. dulcis*, *D. graveolens*, *D. kutejensis*, *D. oxleyanus* and *D. testudinarium* and are sold in local markets in Borneo. The centres of production in decreasing order are Thailand, Malaysia, Indonesia, Vietnam and Philippines. Durian was introduced into Australia in the early sixties and clonal material was first introduced in 1975 (Watson 1988). Over thirty clones of *D. zibethinus* and six Durio species have been introduced into Australia (Lim, 1997, Zappala *et al*. 2002).

The Australian durian industry strengths include;

- a world class gene pool introduced by government agencies and dedicated growers
- out of season production with neighbouring Asian production areas
- a dedicated domestic consumption base for Australian grown fresh fruit
- growing areas are currently free of the durian fruit borer, a major pest in Asian orchards.

Constraints to industry development include;

- a stall in investment by current and potential growers due to the recent (2001) approval by Biosecurity Australia to allow imports of fresh fruit from Thailand. NB. The approval has not been acted on by Thailand at the time of writing.
- rapidly increasing imports of whole frozen fruit (1000 tonnes in 2002)
- mature established orchards based on inferior cultivars
- mature tree die back due to environmental stress combined with soil pathogens such as Pythium and Phytophthora.

The production of durian in Australia is a challenge and should only be contemplated by experienced horticulturalists.

### Mangosteen

The mangosteen is a tree native to the wet tropics of Peninsular Malaysia, Sumatra and Borneo (Yaacob and Tindal, 1995) and is now grown extensively through out SE Asia (Macmillian, 1991, Nakasone and Paull 1998). The mangosteen is not found in the wild and the tree is believed to be a hybrid of two species, *Garcia. hombroniana* and *Garcia malaccensis*, (Richards 1990b cited by Yaacob and Tindal 1995). The resultant hybrid is parthenocarpic, that is produces seed without fertilisation, and many researchers believe that there is only one variety, however, recent genetic finger printing of Australian stock suggests that there are three distinct types (Ramage *et al*., 2004). The fruit is highly esteemed and is favoured in SE Asia as a "cooling" fruit following the consumption of durian.

Mangosteen was introduced into Australia as early as 1854 with the first successful planting occurring in Cairns from seed imported in 1891 (Stephens 1935).

The Australian mangosteen industry strengths include;

- ability to produce fruit counter seasonal to neighbouring Asian production areas
- fruit produced under quality assurance systems which insure a top quality product available to consumers
- a dedicated domestic consumption base for Australian grown fresh fruit.

Constraints to industry development include;

- long juvenile period (6-10 years) prior to production which impacts negatively on investment return
- a stall in investment by current and potential growers due to the recent (2003) approval by Biosecurity Australia to allow imports of fresh fruit from Thailand
- rapid increase in importation of fruit from Thailand.

The production of mangosteen in Australia may remain a small industry due to the long period to achieve financial return and it is best suited to existing orchards or orchardists with alternative sources of income.

This project reports on a survey of leaf and soil nutrition of durian and mangosteen orchards in the wet tropics of north Queensland. It has;

- developed recommendations for a standard leaf sampling technique based on minimum coefficient of variation of samples.
- developed recommendations for a desired nutrient range for durian and mangosteen trees grown in the wet tropics of north Queensland.
- tested a relationship between tree nutrient status and productivity
- improved understanding of the effect of micro-climate within north Queensland on tree phenology.
- develop industry awareness of the relationship between fertiliser inputs, tree nutrient status, tree phenology and yield.

# Literature Review

## 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 durian and mangosteen.

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<br>- Controls growth and fruiting in plants<br>- amino acid synthesis and protein formation<br>- primary building block for all plant parts |
| Phosphorus (P) | Macro | - accounts for 0.1 – 0.5% of the dry weight of plants<br>- involved in photosynthesis, respiration, root growth and flower and fruit development<br>- energy storage and transfer<br>- component of nucleic acid and phospholipids<br>- stimulates seed development and root formation |
| Potassium (K) | Macro | - accounts for 1.0 – 6.0% of the dry weight of plants<br>- regulates water relations of plants<br>- involved in photosynthesis and respiration<br>- promotes root growth |
| Sulphur (S) | Macro | - accounts for 0.1 – 0.5% of the dry weight of plants<br>- involved in the synthesis of protein and function<br>- electron transport in photosynthesis |

| Nutrient | Level required | Function |
|---|---|---|
| Calcium (Ca) | Macro | - plant species differ greatly in their Ca needs. A Ca content of 0.5% dry weight is generally considered adequate<br>- essential in cell wall and membrane construction<br>- regulates nutrient uptake by roots and movement in plants<br>- role in fruit ripening and quality |
| Magnesium (Mg) | Macro | - accounts for 0.1 – 0.5% of dry weight of plants<br>- important component of chlorophyll (the green pigment in plants)<br>- involved in CO2 assimilation<br>- involved in carbohydrate partitioning<br>- 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.<br>- important enzyme component in the production of Vitamin A<br>- role in photosynthesis, protein and carbohydrate metabolism<br>- maintenance of plant turgor |
| Sodium (Na) # | Micro | - important role in photosynthetic pathway in C4 plants<br>- 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<br>- stimulates lignification of cell walls<br>- pollen formation and fertilisation<br>- role in photosynthesis, protein and carbohydrate metabolism and respiration |
| Zinc (Zn) | Micro | - Zinc levels between 20 to 100 mg/kg are considered normal<br>- involved in nitrogen metabolism<br>- influences development of auxins (plant hormone)<br>- 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.<br>- enzyme activator<br>- assimilates CO2 in photosynthesis<br>- assists iron in chlorophyll formation<br>- essential for uptake of P and K |
| 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<br>- Required in the formation of chlorophyll<br>- Activator in many biochemical processes (oxidation-reduction reactions) |

| Nutrient | Level required | Function |
|---|---|---|
| Boron (B) | Micro | - range in plants 2.0 – 100.0 mg/kg<br>- regulates metabolism of carbohydrates<br>- involved in formation pollen tubes and feeder roots<br>- 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<br>- involved in nitrogen fixation and nitrate reduction |
| Silicon (Si) *# | Macro | – increase leaf chlorophyll content and plant metabolism,<br>– enhance plant tolerance to environmental stresses such as cold, heat and drought,<br>– prevent nutrient imbalance and metal toxicity in plants<br>– reinforce cell walls, increase plant mechanical strength thereby protecting plants against pathogens and insects. |

* - Sodium (Na) Silicon (Si) 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). #, Chen et al. (2000).

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.

## Durian - introduction

Durian (*Durio zibethinus* L.), is considered the “King of Tropical Fruits” by most Asian consumers. The durian is a tree native to the wet tropics of Peninsular Malaysia, Sumatra and Borneo (Kostermans, 1958) and is now grown extensively through out SE Asia (Macmillian, 1991, Subhadrabandhu and Ketsa 2001). The fruit is highly esteemed and widely grown throughout the wet tropics of SE Asia. The fruit is considered a delicacy and aphrodisiac by many dedicated consumers but is also renowned by some Europeans for its complex flavour and odour interactions which have been described as akin to eating custard in the lavatory. The durian tree is a member of the Bombacaceae family which includes economically important members such as; balsa wood, kapok and pachira. Forest trees in the same family include Australia’s northern Baobab (*Adansonia gregorii*).

The centres of production in decreasing order are Thailand, Malaysia, Indonesia, Vietnam and Philippines. In 2000 Thailand exported durian to the value of $67M. Durian was introduced into Australia in the early sixties and clonal material was first introduced in 1975 (Watson 1988). Over thirty clones of *D. zibethinus* and six Durio species have been introduced into Australia (Lim, 1997, Zappala *et al*. 2002). In Australia an industry has established along the wet tropical coast of north Queensland from Cape Tribulation (16$^{o}$S) to Tully (18$^{o}$S). There are 30 growers with 8,000 trees. A smaller, but geographically concentrated industry has developed in the rural environments around Darwin (12$^{o}$S). There are 6 growers with approximately 5,000 trees. Current Australian fruit production varies from 20 to 50 tonnes per annum with a maximum value of $0.5M.

Approximately 40 clones of *Durio zibethinus* and seven other *Durio* species have been introduced into Australia (Lim 1997). Varieties that are showing promise and being grown in commercial orchards include Monthong (Thailand), Luang (Thailand), D24 (Malaysia), D2 (Malaysia), Hew 2 and 7 (Malaysia), Hepe and Permasuri (Indonesia). A number of local seedling selections have been made and include Limberlost and Chong. A recently completed evaluation of Durian germplasm suggests that several other *D. zibethinus* clones (Hepe, D 175, DPI Monthong, Hawaiian Monthong, D190 and Kradum Thong) and *D. macrantha* should also be considered for commercial production in north Queensland (Zappala *et al*. 2002). In Malaysia clonal mixtures are a recommended management tool.

A number of authors have suggested planting mixtures suited to Malaysia eg. 60% D24, 25% D16, 5% each of D10, D8, D2 or 50% D24, 30% D99, 20% D98/D114 (Hassan 199?, Lim 1997). Mixtures appropriate to clones that perform in different growing regions will be established in Australia.

Nanthachai (1994) reports that durian in their native environment experience an average temperature range from 24-30$^{o}$C and high rainfall from 1600 – 4000 mm per year. Subhadrabandhu and Ketsa (2001) suggest that the most favourable regions for commercial durian cultivation as being within 12$^{o}$ north and south of the equator, at altitudes of up to 700m which experience a temperature range from 22$^{o}$C to 32$^{o}$C and an annual rainfall of 2,000 to 5,000 mm preferably distributed over six to eight months of the year. High humidity for most of the year is also essential. The production areas in Australia, Darwin and the wet tropical coast of far north Queensland do not have a climate that matches the ideal (Table 2). Darwin has a long dry season where irrigation is essential for at least 8 months of the year while the wet coast of far north Queensland experiences a cool winter well below that experienced in durians native growing area.

Durians can be grown on a range of soils with the correct nutrient and water management.. Well drained alluvial soils are preferred. Optimum growth and fruiting occurs on rich, deep, well drained sand to clay loams which are rich in organic matter. Excellent drainage is a most essential criteria as durian roots are susceptible to root rot. Clay soils with poor drainage should be avoided, unless extensive drainage and mounding works are incorporated in the orchard plan. Vietnamese farmers are successfully growing durian on water inundated delta soils through the use of extensive mounding. In Australia durian is successfully grown over a range of soil types Ferrosols (Krasnozems and Euchrozems) and Brown Kandosols (Yellow earths). Soil pH (water) is generally acidic and can be as low as pH 4 in ex sugar-cane growing regions.

Table 2. Climate comparisons between SE Asian and Australian growing areas

| | **Rainfall (mm/ annum)** | **Average Evaporation (mm/day)** | **Months experiencing water deficit (evaporation exceeds rainfall)** | **Mean annual maximum temperature ($^{o}$C) and monthly extremes** | **Mean annual minimum temperature ($^{o}$C) and monthly extremes** |
|---|---|---|---|---|---|
| Chanthaburi, Thailand (12.36$^{o}$N) | 3015 | 4.3 | 6 | 31.5<br>Apr – 33.4<br>Aug – 30.4 | 22.6<br>Aug – 24.0<br>Jan – 19.6 |
| Jakarta, Indonesia (6.11$^{o}$S) | 1823 | 2.8 | 4 | 31.9<br>Oct - 32.9<br>Jan - 30.1 | 23.5<br>May – 24.0<br>Jul - 22.9 |
| Darwin, Australia (12.25$^{o}$S) | 1664 | 7.4 | 8 | 31.9<br>Oct – 33.1<br>Jul – 30.4 | 23.2<br>Nov – 25.3<br>Jul – 19.3 |
| South Johnstone, Australia (17.36$^{o}$S) | 3308 | 4.3 | 4 | 28.1<br>Jan – 31.2<br>Jul – 23.8 | 19.0<br>Feb – 22.5<br>Jul - 14.4 |

## Durian - cultural practices/agronomy

Site preparation will vary depending on growing location. Windbreak trees are considered essential particularly in areas prone to prevailing winds. Species used include Jack fruit, which can be used to contribute to orchard income in the early years. Orchard spacing can range from 6 to 10 m within the row and 8 to 12 m between rows, depending on variety selected, growing environment and land availability. Durian trees can grow to 20 m tall with a diameter of 8-10 m within 15 to 20 years. Deep ripping along and across the intended tree lines is essential in some soils. Mounding should be carried out where water logging may be an issue and should be considered an essential input in the high rainfall growing areas of north Queensland.

The use of clean nursery stock from a recognised nursery which produces advanced planting material (trees six to twelve months old) is recommended. Lim (1997) recommends that orchards consist of mixed clonal stands to reduce the incidence of self-incompatibility. Where possible varieties should be planted within the same row to allow control of irrigation and hence flowering. Newly planted trees should be protected with shade cloth surrounds or alternatives such as dried palm fronds. Young trees in the NT and Queensland may benefit from the use of plastic covers during the cooler winter months. Trees should be mulched with non-compacting straw (eg. sugar-cane or spear grass), which remains well aerated under wet conditions. Application of regular small amounts of a well-composted chicken or alternative manure may be advantageous.

Irrigation is essential particularly during plant establishment and during the long dry season as experienced in the NT. Irrigation rates of up to 2,000 L/tree/week for trees 8 m in diameter from September to November have been recommended in the NT while Nuntagij *et al*. (2002) have reported water requirements of 250 to 300 L/day for eight year old trees during the dry season in Thailand. Subhadrabandhu and Ketsa (2001) suggest that frequent watering in small amounts is more beneficial than applying large amounts of water infrequently. The use of soil moisture monitoring devices eg tensiometers and moisture probes, is recommended. These devices assist in determining irrigation rates and scheduling.

First fruit can be expected five to seven years following planting of clonal material, with regular production occurring from 10 years and onwards. Withdrawal of irrigation for 10 to 14 days is reported to assist flowering. Heavy rain post-flowering is associated with flower drop and poor pollination and subsequent fruit set.

### *Durian nutrition*

Soil and plant nutrition plays a vital role in the productivity of tree crops, however, the interaction between nutrient levels and productivity is poorly understood in durian. Recommended plant nutrient levels exist in Thailand, Malaysia and the Northern Territory (Table 4). The Northern Territory Department of Primary Industry and Fisheries started soil and leaf monitoring work in the mid 90's (Lim 1997). However, the information is limited to a few farms and specific to the NT growing environment. The wet tropics of north Queensland, Cape Tribulation to Cardwell, is home to the larger part of the industry yet little research relevant to the area has occurred.

### *Durian fertiliser management*

The fertiliser management of durian varies according to country and growing region within the country. Table 4 shows documented fertiliser practices for durian in Vietnam, Thailand, Malaysia (mainland), Malaysia (Sabah), Phillipines and Australia.

In Australia fertiliser management research and information is limited and durian is managed similarly to many other tropical fruits with growers adopting strategies to suit their orchards. Based on the fertiliser regime used at the Centre for Wet Tropics Agriculture, South Johnstone, a 10 year old tree would receive a total of 5.0 kg of 13:2.2:13.3:18.7 (N:P:K:S) and 4.0 kg of Dolomite, which is equivalent to 650 g Nitrogen, 110 g Phosphorous, 665 g Potassium, 935 g Sulphur, 800 g Calcium and 320 g Magnesium. A foliar fertiliser spray to run-off, consisting of iron sulphate and zinc sulphate, each at a concentration of 1 g/litre four times per year (January, April, August and November) is also added. Appropriately less fertiliser should be applied evenly through out the year for young vegetative trees. Once trees reach reproductive maturity (5–7 years) the bulk of NPK should be applied from fruit set to just after harvest (Lim, 1997).

Most overseas recommendations are based on current farming practices rather then yield response trials. Only in a few instances are fertiliser recommendations based on leaf nutrient or cropping levels. Brown (1997) provides an excellent review of difficult to obtain un-abstracted research material in his bibliographic review of *Durio.* Little of the information is yield response related however the most potentially useful fertiliser recommendations come from nutrient removal studies. Ng and Thamboo (1967) performed nutrient removal studies on durian fruits. They provided the following estimate of nutrients removed from the soil to produce fruits (assuming a yield of 6720 kg/ha): N 16.1; P 2.72; K 27.9; Ca 1.99; Mg 3.26 (all amounts in kg/ha). Jamil (1968 cited by Brown 1997) reported the following results of nutrient removal studies on durian (in pounds of nutrient removed per 1000 lb of fruit): N 2.4; P 0.35; K 4.0; Ca 0.30; Mg 0.47. Both studies have generated similar results when compared on a kg per tonne basis (Table 3).

Table 3. Durian fruit nutrient removal in kg/tonne

| Researcher | N | P | K | Ca | Mg |
|---|---|---|---|---|---|
| Ng and Thamboo (1967) | 2.4 | 0.4 | 4.2 | 0.3 | 0.5 |
| Jamil (1968) | 2.3 | 0.3 | 3.8 | 0.3 | 0.5 |

The nutrient removal studies have shown that nearly double the K is removed relative to N while the amount of P being removed is small in comparison. Jamil (1992c, cited by Brown 1997) examined the effects of N, P and K on young durian trees. Increasing N was found to have no visible effect on plant form, increased P increased the tree height, while increased K greatly affected tree form. Hence, of the fertiliser suggestions in Table 5, those recommending high potassium formulations are the most valid. Foliar sprays of KNO3 and other substances during fruit development have been shown to increase the overall size of fruits, the edible portion (aril) of the fruit, and seed abortion (Punnachit *et al.* 1992). These effects were presumably achieved by the reduction of competition for nutrients by inhibition of leaf flushing (Punnachit *et al.* 1992). In the Philippines Loquias *et al*. (1996) showed that foliar fertiliser containing 20 per cent N; 5 per cent $P_2O_{5;}$ 30 per cent $K_2O$ in combination with 5 kilograms granular 14-14-14 (N:P2O5:K2O) with microelements like, calcium, magnesium, boron, zinc and copper improved the yield and quality of durian with 158 fruits per tree as compared to 41 fruits per tree applied with granular fertiliser (14-14-14) alone while fruit quality, as measured by TSS and percentage edible portion, was improved with the use of foliar fertiliser with 4 per cent N and 48 per cent $K_2O$.

### *Durian 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 durian is a ramiflorous (ie. flowers are borne on major branches which can bear the weight) 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. Durian flowering usually occurs after vegetative growth slows down temporally ceases. Watson (1984) stated that flowering is not photoperiod or temperature responsive in equatorial regions. While Subhadrabandhu et al. (1991) state that in the equatorial regions of Indonesia and Malaysia flowering and fruiting are erratic because the environment does not impose a strict enough growth rythem. Chandraparnik *et al.* (1992) observed that flowering occurred in durian at six different sites when;

- there was a continuous dry period of 10-14 days
- the daily temperature dropped from 26 to 33°C to 20-25°C
- daily relative humidity decreased slightly to a range of 50 to 70%.

In durian, in its native environment, flower induction can occur through out the year, however it generally occurs after the dry season. Panicle emergence in durian usually occurs following a period of dry weather (Pascua and Cantilla (1991) cited by Brown, 1997). Low night temperatures have also been implicated in the initiation of flowering in rambutan (Salafsky 1994a). The harvesting and fruiting cycle of durian (Nakasone and Paull 1998) is shown in Figure 1.

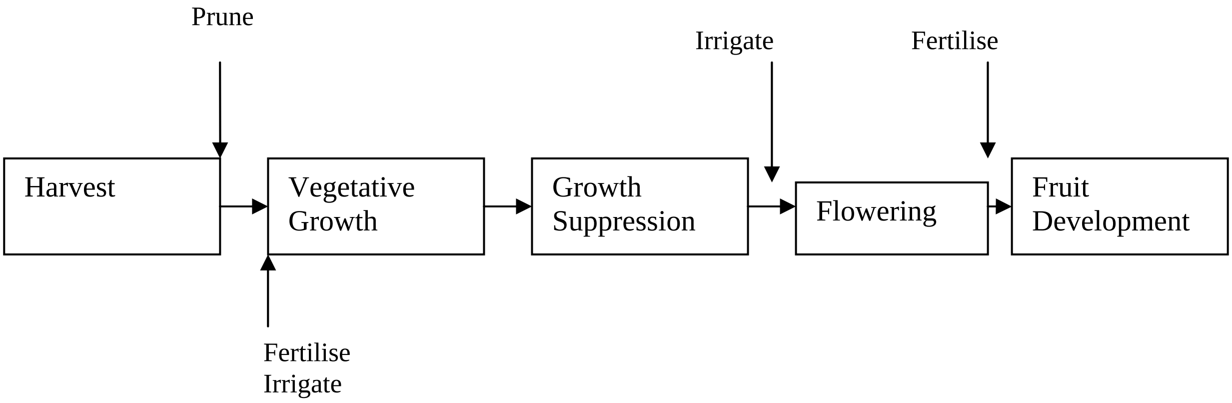



Figure 1. Fruiting cycle of durian. Flowering is triggered by a continuous dry period of 7-14 days (Nakasome and Paull 1998 as per Salakpetch 1996).

## Mangosteen

Mangosteen (*Garcinia mangostana* L.), is considered the "Queen of Tropical Fruits" by most Asian consumers. The mangosteen is a tree native to the wet tropics of Peninsular Malaysia, Sumatra and Borneo (Yaacob and Tindal, 1995) and is now grown extensively through out SE Asia (Macmillian, 1991, Nakasone and Paull 1998). The mangosteen is not found in the wild and the tree is believed to be a hybrid of two species, *G. hombroniana* and *G. malaccensis*, (Richards 1990b cited by Yaacob and Tindal 1995). The resultant hybrid is parthenocarpic, that is produces seed without fertilisation, and many researchers believe that there is only one variety while recent genetic finger printing of Australian stock suggests that there are three distinct types (Ramage *et al*., 2004) which are morphologically as well as genetically different. The fruit is highly esteemed and widely grown throughout the wet tropics of SE Asia. The mangosteen is favoured in SE Asia as a suitable antidote to the pungent durian. The mangosteen is a member of the Clusiaceae family which includes economically important members such as; St John's-Wort (*Hypericum perforatum*). Australia has five native species of Garcinia including the edible Native Mangosteen (*Garcinia warrenii*).

The centres of production in decreasing order are Thailand, Malaysia, Philippines, Indonesia and Vietnam. Mangosteen was introduced into Australia as early as 1854 with the first successful planting occurring in Cairns from seed imported in 1891 (Stephens 1935). In Australia an industry has established along the wet tropical coast of north Queensland from Cape Tribulation (16°S) to Tully (18°S). There are 60 growers with 13,000 trees. A smaller, but geographically concentrated industry has developed in the rural environments around Darwin (12°S). There are several growers with approximately 3,000 trees. Current Australian fruit production varies from 20 to 50 tonnes per annum with a maximum value of $0.5M.

Yaacob and Tindal (1995) report that mangosteen in their native environment experience an average temperature range from 24-30°C and high rainfall from 1600–4000 mm per year. The crop grows best in the humid tropics that have a short dry season (15–30 days) to stimulate flowering followed by rain. High humidity for most of the year is also essential. The production areas in Australia, Darwin and the wet tropical coast of far north Queensland do not have a climate that matches the ideal (Table 2). Darwin has a long dry season where irrigation is essential for at least 8 months of the year while the wet coast of far north Queensland experiences a cool winter well below that experienced in durians native growing area.

Mangosteen can be grown on a range of soils with the correct nutrient and water management. Optimum growth and fruiting occurs on rich, deep, well drained sand to clay loams which are rich in organic matter. Limestone and sandy soils low in organic matter should be avoided (Nakasome and Paull 1998). Excellent drainage is a most essential criterion as mangosteen does not tolerate prolonged long periods of root saturation. Clay soils with poor drainage should be avoided, unless extensive drainage and mounding works are incorporated in the orchard plan. In Australia mangosteen is successfully grown over a range of soil types Ferrosols (Krasnozems and Euchrozems) and Brown Kandosols (Yellow earths). Soil pH (water) is generally acidic and can be as low as pH 4 in ex sugar-cane growing regions.

## Mangosteen - Cultural practices/agronomy

Site preparation will vary depending on growing location. Windbreak and shade trees are considered essential particularly in areas prone to prevailing winds and low incidences of cloud cover. Orchard spacing can range from 6 to 10 m within the row and 8 to 10 m between rows, depending on growing environment and land availability. Mangosteen trees can grow to 25 m tall with a diameter of 6 to 8 m within 15 to 20 years.

Mangosteen seedlings are extremely sensitive to light. Research has shown that maximum seedling growth is achieved under 80% shade in the first year with shade levels reduced to 50% by year two and 20% by year 3 (Downton and Chacko 1997). Newly planted trees should be protected with shade cloth surrounds or alternatives such as dried palm fronds. Young trees in the NT and Queensland may benefit from the use of plastic covers during the cooler winter months. Trees should be mulched with non-compacting straw (eg. sugar-cane or spear grass), which remains well aerated under wet conditions. Application of regular small amounts of well-composted chicken or alternative manure may be advantageous.

Irrigation is essential particularly during plant establishment and during the long dry season as experienced in the NT. Lu (2002) reported weekly sap flow measurements of 210 L per week per plant for a 21 year old tree with a trunk diameter of 18 cm. Frequent watering in small amounts is more beneficial than applying large amounts of water infrequently. The use of soil moisture monitoring devices, tensiometers and moisture probes, is recommended. These devices assist in determining irrigation rates and scheduling. First fruit can be expected six to ten years following planting of seedling material, with regular production occurring from 10 years and onwards. As with durian and rambutan flowering in mangosteen is reported to be enhanced by a short (3-4 weeks) dry period (Tatt, 1976, Nakasone and Paull, 1998). Withdrawal of irrigation for 10 to 14 days is reported to assist flowering, whereas, heavy rain post-flowering and during fruit development is associated with poor fruit quality, including gamboge (latex pustules) and hard translucent flesh (Sdoodee and Limpun-Udom, 2002)

### *Mangosteen nutrition*

Soil and plant nutrition plays a vital role in the productivity of tree crops, however, the interaction between nutrient levels and productivity is poorly understood in mangosteen. Plant nutrient level recommendations exist for Cote d'Ivoire, Thailand and the Northern Territory (Table 4). The Northern Territory DPIF started soil and leaf monitoring work in the mid 90's. However, the information is limited to a few farms and is specific to the NT growing environment. The wet tropics of north Queensland, Cape Tribulation to Cardwell, is home to the larger part of the industry yet little research relevant to the area has occurred.

The mangosteen has extremely low leaf P concentrations, approximately 0.08% relative to 0.15-0.25% for many other fruit species. The mangosteen has a relatively simple root system with poor branching and no root hairs, often given as a reason for low leaf P concentrations. Low leaf photosynthetic rates and poor root systems are cited as a reasons for the trees slow growth, particularly as young seedlings (Downton and Chacko 1997, Poerwanto 2002). Boberg and Dyberg (2002) have shown that in Vietnamese production systems mangosteen roots are highly colonised by Abuscular mycorrhizal fungi (VAM) despite low pH and high fertiliser levels. Tinker (1975) has shown the colonisation of roots by VAM can greatly improve the uptake of P by increasing the surface area for P absorption.

In Thailand Poovarodom *et al*. (2002) showed that seasonal variations in mangosteen leaf nutrient concentrations are low relative to other crops. Despite the relative uniformity of leaf nutrient concentrations throughout the season they suggest that the ideal leaf sampling date, based on practicality, is immediately after harvest when leaves are 8 to 10 months old. Leaf position (low and middle canopy) and leaf direction (North, East, South, West) had little effect on the nutrient concentration.

### *Mangosteen fertiliser management*

The fertiliser management of mangosteen varies according to country and growing region within the country. Table 6 shows documented fertiliser practices for mangosteen in Vietnam, Thailand, Malaysia (mainland), Malaysia (Sabah), Philippines and Australia.

Most recommendations are based on current farming practices rather then yield response trials. Only in a few instances are fertiliser recommendations based on leaf nutrient or cropping levels. The use of manures on young developing trees is popular throughout growing areas in SE Asia. Commercial orchards do use various blends of compound fertiliser, generally based on the recommendations of local Departments of Agriculture.

*Mangosteen Tree phenology*

Poonnachit *et al*. (1996) cited by Salakpetch (2000) reports that plant vigour, age of apical buds and the duration of water stress are the three main factors involved in flowering. The apical buds can produce flowers from 9 weeks of age depending on climate, however, ideally they should be at least 21 weeks of age following the emergence of the latest flush when water stress conditions are imposed. Trees should be kept under stress conditions until the last internode is visibly wilted and the last pair of leaves visibly drooping. Nakasone and Paull (1998) diagrammatically represented mangosteen phenology (Figure 2).

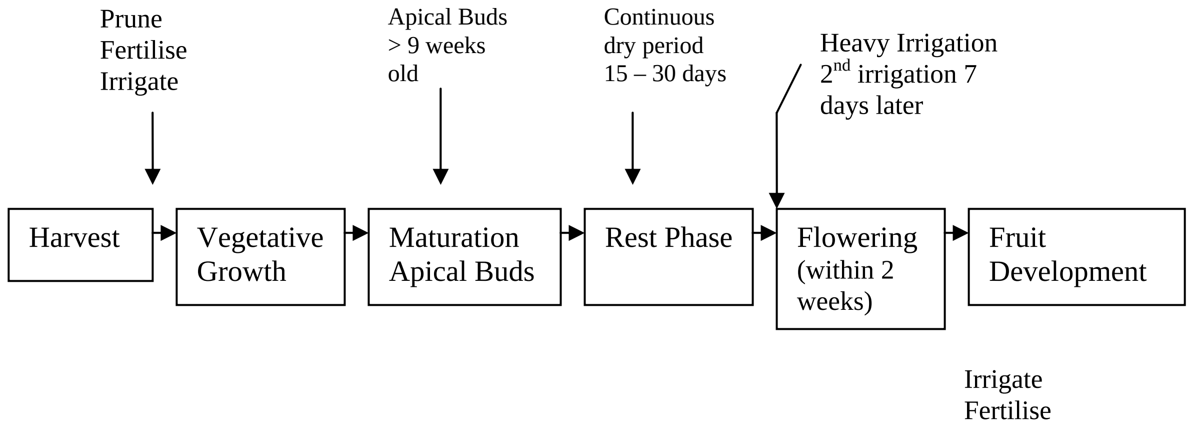



Figure 2. Steps required for flowering in mangosteen. Diagram modified from Nakasone and Paull (1998) and Salakpetch (2000).

***Summary***

Any interpretation of the effectiveness of fertiliser management on tree yield 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*".

Table 4. Published durian and mangosteen nutrient 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Durian** | | | | | | | | | | | | |
| Thailand cv. Monthong | 2.0-2.4 | 0.15-0.25 | 1.5-2.5 | 1.7-2.5 | 0.25-0.50 | na | 40-150 | 50-120 | 10-30 | 10-25 | na | Poovarodom, S *et al.* (2001) |
| Tahiland, cv. Monthong | 2.06-2.18 | 0.14-0.21 | 1.55-1.71 | 1.58-1.94 | 0.21-0.30 | na | na | na | 9.84-24.54 | na | na | Poovarodom and Chatupote (2002) |
| Malaysia | 1.8-2.3 | 0.12-0.25 | 1.6-2.2 | 0.9-1.8 | 0.25-0.50 | na | 50-150 | 25-50 | 15-40 | 6-10 | 15-80 | Zakarai, 1994 |
| Australia, NT | 1.58-1.98 | 0.18-0.22 | 1.48-1.96 | 1.11-1.88 | 0.83-1.13 | na | 15.02-30.86 | 6.25-27.65 | 11.92-14.64 | 5.82-12.47 | 33.29-38.52 | Lim *et al.* (1999) |
| | | | | | | | | | | | | |
| **Mangosteen** | | | | | | | | | | | | |
| Australia, Northern Territory | 1.14 | 0.06 | 0.76 | 1.20 | 0.26 | 0.32 | 95.2 | 166.3 | 42.24 | 11.17 | 86.99 | Luders and Lim (1998) |
| Cote d'Ivoire | 1.40 | 0.08 | 1.10 | 0.88 | 0.15 | na | 32.00 | 283.00 | 20.00 | 9.00 | na | Marchal (1972) |
| Thailand | 1.34 | 0.07 | 0.83 | 1.19 | 0.17 | na | 127.6 | 189.9 | 27.5 | 15.7 | na | Poovarodom *et al.* (2002) |

Table 5. Documented fertiliser practices for durian

| Location | Young trees | Mature bearing trees | Reference/ comment |
| --- | --- | --- | --- |
| Vietnam | For young trees during the first few years, the recommended dose is N: $P_2O_5$:$K_2O$: MgO in a proportion of 18:11:5:3 (or 15:15:6:4 in the Mekong delta), at a rate of 0.7 kg of NPK fertiliser per tree per year. This rate increases steadily to 3.5 kg/tree in the fourth year, spread over 3-5 applications per year (Chau 1997). In the southeast region, more potassium should be applied.<br><br>organic manure (usually composted on the farm) is at the rate of 10-15 kg/tree | During the fruit-bearing years, the level of fertiliser applied should be adjusted depending on the vigor and size of the tree, while the proportion of nutrients should be adjusted according to the developmental stage of the tree. For durian trees growing in orchards along the Saigon river, during their fruit bearing years (i.e. when they are at least six years old), the recommended fertiliser rate is 800 g N + 400 g $P_2O_5$ + 400 g $K_2O$ + 100 g MgO plus 40 kg compost per tree per year (Tan and Chau 2000). This fertiliser is divided into three applications. The first (1/2 N + ¼ $P_2O_5$ + ¼ $K_2O$ +1/2 MgO and all the compost) is applied straight after the harvest. The second (1/4 N + 1/2 $P_2O_5$ + ¼ $K_2O$) is applied before blooming and the third (1/4 N + ¼ $P_2O_5$ + 1/2 $K_2O$ +1/2 MgO) when the young fruit is beginning to develop. | Khoi, B.X and Tri, M.V. (2003). |
| Australia | At Planting 15 g of P in and around hole<br>Immature trees 0 to 6 years<br>150 g N, 30 g P and 100 g K per tree per year of age applied in split dressings (August, November, February and April). | Fruiting Mix from first flowering<br>130 g N, 15 g P, and 180 g K per tree per year of age up to 15 years, remaining constant thereafter. Split a third at early signs of flower growth and two thirds immediately after harvest. If tree lacks vigour, apply 5 kg of composted chicken manure per tree per year of age following harvest. If Ca, Mg and Zn are deficient apply gypsum, magnesium oxide and zinc sulphate respectively | Watson (1983) RFC document |
| Australia | For young vegetative trees appropriately less fertiliser then for mature trees should be applied evenly through out the year<br><br>Young trees (1-4 years) require a steady year round fertiliser program.<br>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. | 5.0 kg of 13:2.2:13.3:18.7 (N:P:K:S) and 4.0 kg of Dolomite, which is equivalent to 650 g Nitrogen, 110 g Phosphorous, 665 g Potassium, 935 g Sulphur, 800 g Calcium and 320 g Magnesium. A foliar fertiliser spray to run-off, consisting of iron sulphate and zinc sulphate, each at a concentration of 1 g/litre four times per year (January, April, August and November) is also added. | Mansfield (1995) |

Table 5. continued from previous page

| | | | |
|---|---|---|---|
| Malaysia | For the first five years a ratio of 15:15:6:4 (N:P2O5:K2O:MgO) is given annually.<br>Year one; 0.15 kg/application, 4 applications/year<br>Year two; 0.30 kg/application, 4 applications/year<br>Year three; 1.00 kg/application, 3 applications/year<br>Year four; 2.00 kg/application, 3 applications/year<br>Year five; 2.50 kg/application, 3 applications/year | From the sixth year onwards a ratio of 12:12:17:2+TE (N:P2O5:K2O:MgO) is recommended.<br>Year 6; 4.00 kg/application, 2 applications/year<br>Year 7; 5.00 kg/application, 2 applications/year<br>Year 8; 5.00 kg/application, 2 applications/year<br>Year >8; 6.00 kg/application, 2 applications/year | DOA (1997) |

| Location | Young trees | Mature bearing trees | Reference/ comment |
|---|---|---|---|
| Philippines | Apply as basal 50 grams (5 tbsp.) of complete fertiliser (14-14-14) or based on soil analysis and cover with thin layer of soil. Rate of application increases as tree matures. | | Department of Agriculture Web Site (1999) |
| Malaysia, Sabah | For the first five years a ratio of 14:13:9:2.5 (N:P2O5:K2O:MgO) is given annually.<br>Year one; 0.6 kg/tree/year, 4 applications/year<br>Year two; 1.0 kg/tree/year, 4 applications/year<br>Year three; 1.8 kg/tree/year, 3 applications/year<br>Year four; 3.6 kg/tree/year, 3 applications/year<br>Year five; 4.5 kg/tree/year, 3 applications/year | From year 6 onwards a ratio of 12:6:22:3 (N:P2O5:K2O:MgO) is recommended.<br>Year six; 6.0 kg/tree/year, 3 applications/year<br>Year seven; 7.5 kg/tree/year, 3applications/year<br>Year eight+; 9.0 kg/tree/year, 3applications/year | Sabah Department of Agriculture Web Site (2004). |
| Australia, Northern Territory | Young trees (1 – 4 years) receive 4 applications of 15:15:15 (N:P2O5:K2O) | NPK fertilisers should be applied at three crop stages;<br>• immediately after crop harvest just at the incipient stages of major vegetative flushing<br>• another smaller application a month or two before flowering<br>• around early stages of fruit development.<br>The quantity of fertilisers used should be adjusted yearly according to the results of leaf sampling and the crop load (yield) removed. Application of micronutrients as foliar spray should be done during early vegetative flushing. | Lim (1996). Durian Agnote 2<br><br>Lim (1997) RIRDC Handbook |
| Thailand | | A complete fertiliser, 12N-12$P_2O_3$,-17$K_2O$-2MgO or 8N-24$P_20_5$-24$K_2O$ or 13N-13$P_2O_3$-21$K_2O$ is applied when the fruits are at about 5 to 7 weeks after anthesis. When fruits are at 9 to 10 weeks after anthesis, 0-0-50$K_2O$ fertiliser should be applied. | Surmsuk Salakpetch (2000) |

Table 5 continued from previous page.

| | | | |
|---|---|---|---|
| Thailand, Eastern | | After harvest (July) apply 2 to 3 kg of 15N, 15 $P_2O5$ and 15 $K^2O$<br>similar quantity of 9N, 24 $P^2O5$ and 24 $K^2O$ applied in the September –October preflowering period | Yaacob and Subhadrabandhu (1995) |
| Thailand, Eastern and Southern districts | Compound N:P2O5:K2O fertiliser 15:15:15<br>1 to 2 years 300 to 500 g/tree split into 3 or 4 applications. Plus 5 kg of organic manure. | **After Harvest**<br>N:P2O5:K2O fertiliser 15:15:15 3 to 6 kg per tree with a supplementary application 3 to 4 months later<br>**Before Flowering**<br>N:P2O5:K2O fertiliser 9:24:24 at 3 to 6 kg per tree in August and September. Plus foliar application of a high phosphate fertiliser eg N:P2O5:K2O 10:52:17<br>**During Fruit Development**<br>Fertilisers high in potassium are recommended. Eg. N:P2O5:K2O 13:13:21 or 14:14:21. 1 to 2 kg per tree applied 3 times at four week intervals | Subhadrabandhu and Kesta (2001) |
| Australia, NQ orchard | Year 1<br>Nitrophoska Blue TE 250 g/tree<br>Long Life Chicken manure – 100 g/tree<br>Gypsum – 100 g/tree<br>Year 2<br>Nitrophoska Blue TE 400 g/tree<br>Long Life Chicken manure – 200 g/tree<br>Gypsum – 200 g/tree<br>Foliar Triple 10 50ml per 10L<br>Year 5<br>Nitrophoska Blue TE 1500 g/tree<br>Long Life Chicken manure – 1000 g/tree<br>Gypsum – 1000 g/tree<br>Foliar Triple 10 50ml per 10L | Year 6 and over<br>Nitrophoska Blue TE 2500 g/tree<br>Long Life Chicken manure – 1500 g/tree<br>Gypsum – 1500 g/tree<br>Foliar Triple 10 50ml per 10L<br><br>Note: Grass Hay or Cane mulch used regularly for weed control and to cover the area under the tree canopy. | Zappala *et al.* (2002) |

Note: All overseas fertiliser ratios are shown in the oxide form eg. N:$P_2O_5$:$K_2O$:MgO . To convert these to elemental N:P:K:Mg ratios as used in Australia the reader must be aware of the following conversions. Nitrogen remains the same.

P= $P_2O_5$ x 0.44; hence 15% $P_2O_5$ = 15 x 0.44 = 6.6

K = $K_2O$ x 0.83; hence 6% $K_2O$ = 6 x 0.83 =4.98

Mg = MgO x 0.6; hence 3% MgO = 3 x 0.6 = 1.8

Table 6. Documented fertiliser practices for mangosteen

| Location | Young trees | Mature bearing trees | Reference/ comment |
|---|---|---|---|
| Australia<br>Kamerunga, Qld, | | N:P:K – 10:2:17<br>100 g per tree per year of age in March, August and December<br>Urea – 100 g per tree per year of age applied in February<br>Dolomite – 500 g per tree per year of age applied in August<br><br>Trees over 10 years received the same fertiliser rates as 10 year old trees<br><br>Fertiliser and dolomite were hand broadcast in a 1 m band centred on the canopy line | Mansfield (1995) |
| Australia<br>South Johnstone, Qld. | N:P:K:S - 13:2.2:13.3:18.7<br>100 g per tree per year of age in January August and November<br>200 g per tree per year of age in April<br>Dolomite – 400 g per tree per year of age in August<br><br>Fertiliser and dolomite were hand broadcast under the canopy<br><br>Foliar fertilised (1g/L of iron sulphate and zinc sulphate) in January, April, August and November). | | Mansfield (1995) |
| Australia<br>Kamerunga, Qld. | Tree age (years) — Fertiliser/tree/year N – P – K<br>1 - 2 — 70 – 6 – 5<br>2 – 4 — 210 – 18 – 150<br>4 – 6 — 350 – 30 - 250<br>6 – 8 — 490 – 42 – 350<br>8 – 10 — 630 – 54 - 450 | Tree age (years) — Fertiliser/tree/year N – P – K<br>Bearing — 700 – 60 - 500 | Watson (1978) |

Table 6. continued from previous page

| Location | Young trees | Mature bearing trees | Reference/ comment |
|---|---|---|---|
| Puerto Rico | N:P2O5:K2O split in 2 applications (March & October)<br>Year 1 – 2 0.25 kg/tree<br>Year 2 – 4 0.50 kg/tree<br>Year 4 – 6 1.00 kg/tree<br>Year 6 – 8 2.0 kg/tree<br>Year 8 – 10 4.0 kg/tree | N:P2O5:K2O split in 2 applications (March & October)<br>Bearing trees in full production need approximately 7.0 kg tree per year. | Almeyda and Martin (1976) |
| Puerto Rico | Seedling Production<br>(N-P-K) 15-4.8-10.8% commercial fertiliser mixture. 9 g/pot at 3, 8 and 15 months after sowing. Plants grown under 50% shade | | Goenaga and Rivera-Amador (2005) |
| Philippines | Ammonium Sulphate<br>50 – 100 g applied a month after planting and an equal amount 6 months after planting<br>In succeeding years increase fertiliser gradually | Complete fertiliser high in N and K<br>500 g every six months<br>Increase fertiliser amount with age and production.<br>Fully grown trees should receive at least 2.0 kg complete fertiliser per year. | Coronel (1983) |
| Malaysia | Seeding production<br>Potting mix 3:2:1 (sand:soil:organic matter) | | Rukayah and Zabedah (1992) |
| Australia<br>Darwin, NT | Seedling production<br>Fresh seeds are germinated in small pots containing equal parts of peat moss and coarse sand. Two to four leaf seedlings are carefully removed with minimal root disturbance and transplanted into 10 L black polyethylene bags (160 mm diam, 500 mm length) containing a mix (1:1:1) peat moss, composted pine bark and coarse sand. acidic pH of 6.2 mixed with 10 g of a controlled release fertiliser (Osmocote Plus® ) Seedlings need fertilising every three months with a repeat application of Osmocote Plus and by fortnightly application of foliar nutrient spray (2 mL concentrate per litre of water; Wuxal Liquid Foliar Nutrient). The seedlings are irrigated by overhead sprinklers for 15 minutes, four times a day. Light levels to increase from 20% in year 1, 50% in year 2, 80% in year 3.<br><br>Young trees<br>Fertiliser (N:P2O5:K2O 15:15:15 + micronutrients) should be applied at three-monthly intervals at 0.5-1.0 kg/year for young trees (1-3 years). | Mature trees should receive an N:P2O5:K2O:MgO mixture (12:12:17:2) at the rate of 2.5 kg/tree. Foliar application of micronutrients may be required to correct deficiencies of zinc and iron which are common in Australian soils. In addition, regular mulching with organic manures is beneficial. | Downton and Chacko (1998?) |

Table 6. continued from previous page

| | | | |
|---|---|---|---|
| India | | Satisfactory results obtained using following inputs<br>100 to 150 lb/tree of cattle manure<br>10-15 lb/tree of bone meal or oil cake | Sing *et al.* (1963) |
| Vietnam | At planting, 20 kg of composted manure + 200 g N:P2O5:K2O (16-16-8) is put in each planting hole. During the first few years, 500 g of N:P2O5:K2O (15-15-15) is applied to each tree every year. In the sixth year, this is increased to 3 kg/tree/year, split into 3-4 applications. | 1200 g N + 600 g P2O5 + 1200 g K2O + 2 kg compost when the tree is 20 years old or more. This fertiliser is divided into three applications. The first (1/2 N + ¼ P2O5 + ¼ K2O +1/2 MgO and all the compost) is applied straight after the harvest. The second (1/4 N + 1/2 P2O5 + ¼ K2O) is applied before blooming and the third (1/4 N + ¼ P2O5 + 1/2 K2O +1/2 MgO) when the young fruit is beginning to develop.<br><br>A foliar fertiliser five times at intervals of seven days after fruit set helped to increase the fruit weight and yield of mangosteen in the Mekong delta. Composted manure should be applied (30 kg for each mature tree), and a mulch of hay or straw applied around the base of the trunk. | Khoi and Tri (2003) |
| Malaysia, Sabah | N:P2O5:K2O:MgO; rate split over 3 applications/year<br>Age (years) – Fertiliser Ratio – Rate kg/tree/year<br>1 – 15:15:15 – 0.6<br>2 – 15:15:15 – 0.9<br>3 – 15:15:15 – 1.5<br>4 – 15:15:15 – 1.8 | Age (years) – Fertiliser Ratio – Rate kg/tree/year<br>5 – 12:12:17:2 – 3.0<br>6 – 12:12:17:2 – 4.5<br>7+ – 12:12:17:2 – 6.0 | Wong (1993) |

Note: All overseas fertiliser ratios are shown in the oxide form eg. N:$P_2O_5$:$K_2O$:MgO . To convert these to elemental N:P:K:Mg ratios as used in Australia the reader must be aware of the following conversions. Nitrogen remains the same.

P= $P_2O_5$ x 0.44; hence 15% $P_2O_5$ = 15 x 0.44 = 6.6

K = $K_2O$ x 0.83; hence 6% $K_2O$ = 6 x 0.83 =4.98

Mg = MgO x 0.6; hence 3% MgO = 3 x 0.6 = 1.8

# Methodology

## Site Description

Twelve mangosteen and nine durian growers collaborated in the project. The orchards were located on the wet tropical coast of far north Queensland from Daintree in the north ($16^o$16.016'S, $145^o$27.840'E) to Murray Upper in the south ($18^o$06.028'S, $145^o$52.187'E).

## Leaf and soil sampling

Mangosteen and durian orchards were leaf sampled fourteen times (every two months) over three seasons (August 2002 to October 2004) and soil sampled six times over the same period. At each sampling time a phenological assessment was also performed on all sample trees. Soil sampling was carried out at key phenological stages; panicle emergence/early flowering, fruit set, fruit filling, harvest, post harvest mature flush.

Mangosteen nutrition sampling occurred predominately on the common purple mangosteen with one inclusion of the Borneo variety. Durian sampling was taken from a mixed gene pool. Results for all cultivars were pooled for analysis.

*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 soil analysis bag, labelled and dispatched within 24 hours to Incitec-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 leaf pair of the latest mature green flush or the last two mature green leaves before the current immature flush were chosen for sampling from durian and the youngest mature green leaf from mangosteen. From the durians ten pair of leaves were sampled per tree and from the mangosteens four leaves were samples per tree. The 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 $65^o$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 DPI&F CWTA South Johnstone. Soil and leaf analysis results were compiled and the 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.

## Climate and irrigation monitoring

Three solar powered, weather stations were commissioned in the mangosteen and durian nutrition and phenology project in early September 2002. 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®)
- Three Water Mark soil tension sensors (CS257®) placed at a depth of 20, 40 and 80 cm.
- Pyranometer (Apogee PYR-L).

The units were programmed to sense climatic and soil moisture variables every 15 seconds. Temperature, RH, soil temperature, rainfall, water 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 mangosteen orchards and the locations were chosen to capture the extreme differences in climate across a relatively small geographic area. The Daintree unit was placed in a rambutan block on the farm. Soil types are described by Murtha (1986).

Mangosteen Unit 1. Murry Upper (18°3.917'S, 145°51.808'E). Soil was a brown clay loam.

Mangosteen Unit 2. Silkwood (17°42.535'S, 145°58.518'E). Soil was a brown clay loam.

Rambutan Unit 3. Daintree (16°18.191'S, 145°18.175'E). The soil was a brown clay loam.

## Phenology monitoring

Detailed phenology monitoring (occurrence of leaf flushing, flowering and fruit development) occurred on all farms at each sampling time. At each assessment trees were rated for percentage new flush, hardening flush, mature flush, flower emergence, percentage fruit set and fruit development.

## Compilation of fertiliser inputs and yield data

During the projects inception the mangosteen and durian 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 was collected at the end of each season from all participants. 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.

## Fruit analysis

Fruit from various farms were sampled in the 2003, 2004 and 2005 seasons so that an analysis of fruit nutrients could be undertaken. Mangosteen fruit samples were all taken from the common purple mangosteen variety. Durian fruit samples were taken from a mixture of varieties. The samples taken from the durian included the whole fruit and the peduncle up to the abscission point. The mangosteen samples consisted of whole fruit including the calyx and peduncle. The fresh weight of the fruit was recorded and then the fruit was roughly chopped and oven dried at 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 then mixed and a sub-sample of approximately 50 g was sealed in 50 ml sample bottles and dispatched to CASCO Agritech 214 McDougall St., Toowoomba QLD 4350. Samples were analysed for N, P, K, Ca, Mg, Na and S (%) and Mn, Fe, Cu, Zn, B and Mo (mg/kg). The mean, maximum, minimum and standard error (se) data for each element are presented.

## 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 harvesting. The practical applications of the nutrient budget approach to fertiliser management are then discussed.

# Results

## Climate

Climate monitoring was conducted at four sites, Daintree, South Johnstone, Silkwood and Murray Upper. Temperature conditions were similar over all environments (Figure 3).

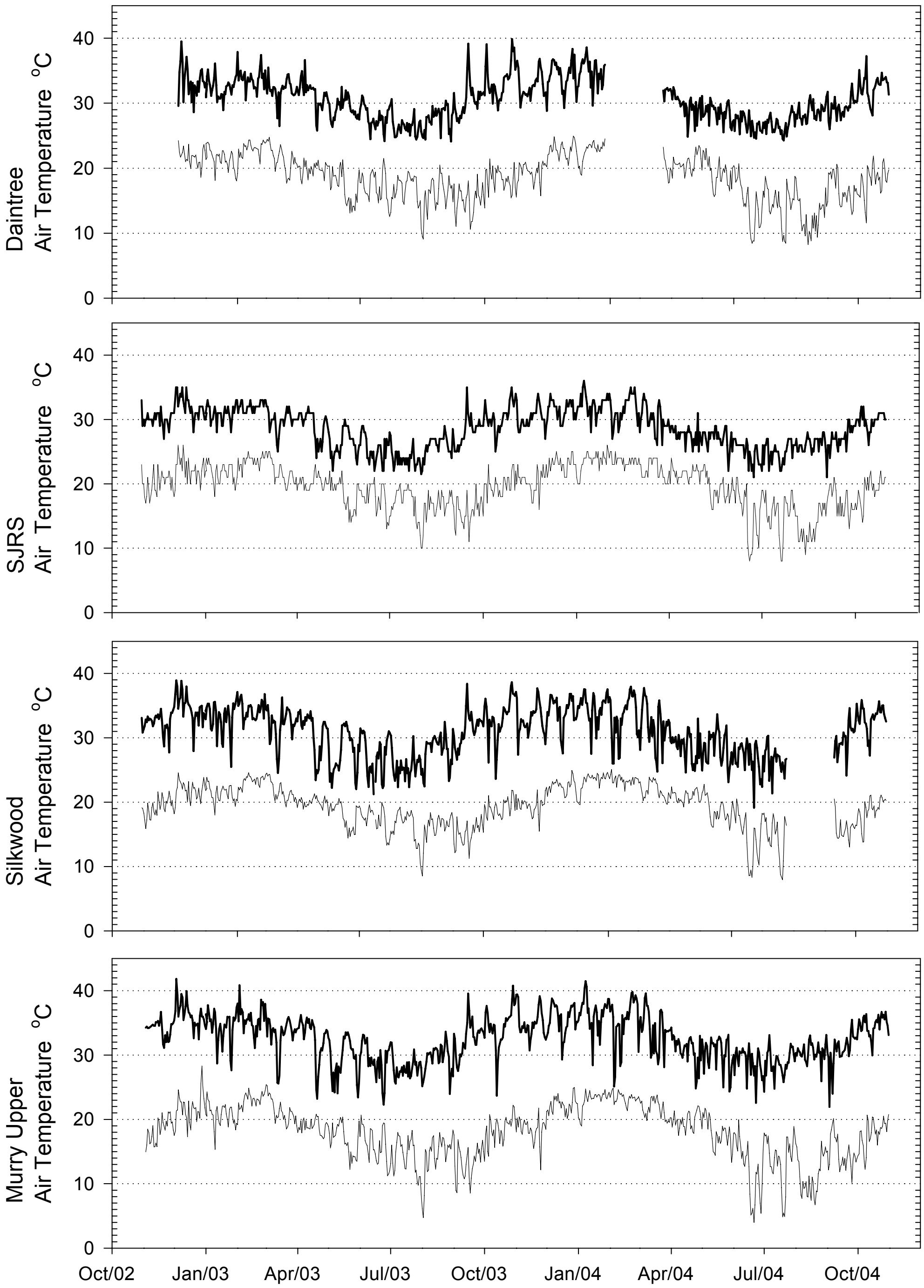



Figure 3. Air temperatures (daily maximum and minimums) for four locations ranging from Daintree to Murray Upper.

Overall rainfall was also similar between all sites, with similar seasonal trends (Figure 4). Peak rainfall at Daintree was lost due to weather station equipment failure from late January to early April Total rainfall amounts were greater at South Johnstone and Silkwood compared to Daintree in the north and Murray Upper at the southern extreme of monitoring sites.

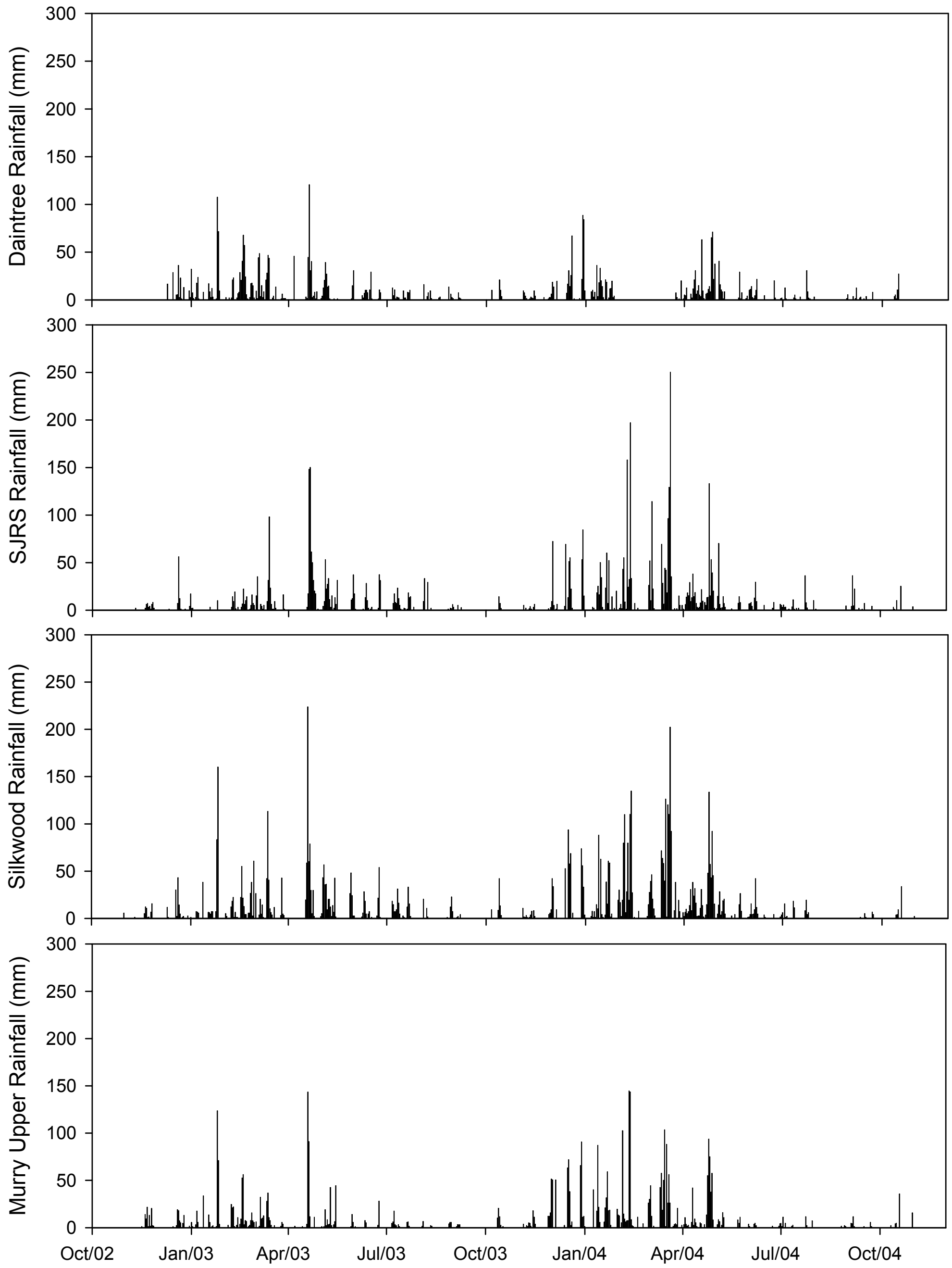



Figure 4. Daily rainfall for four locations ranging from Daintree to Murray Upper.

Due to the similarity of the climate and the similar crop phenology between crops and regions the following figures detail active leaf growth, flowering and fruit development period for Durian and Mangosteen (Figure 5).

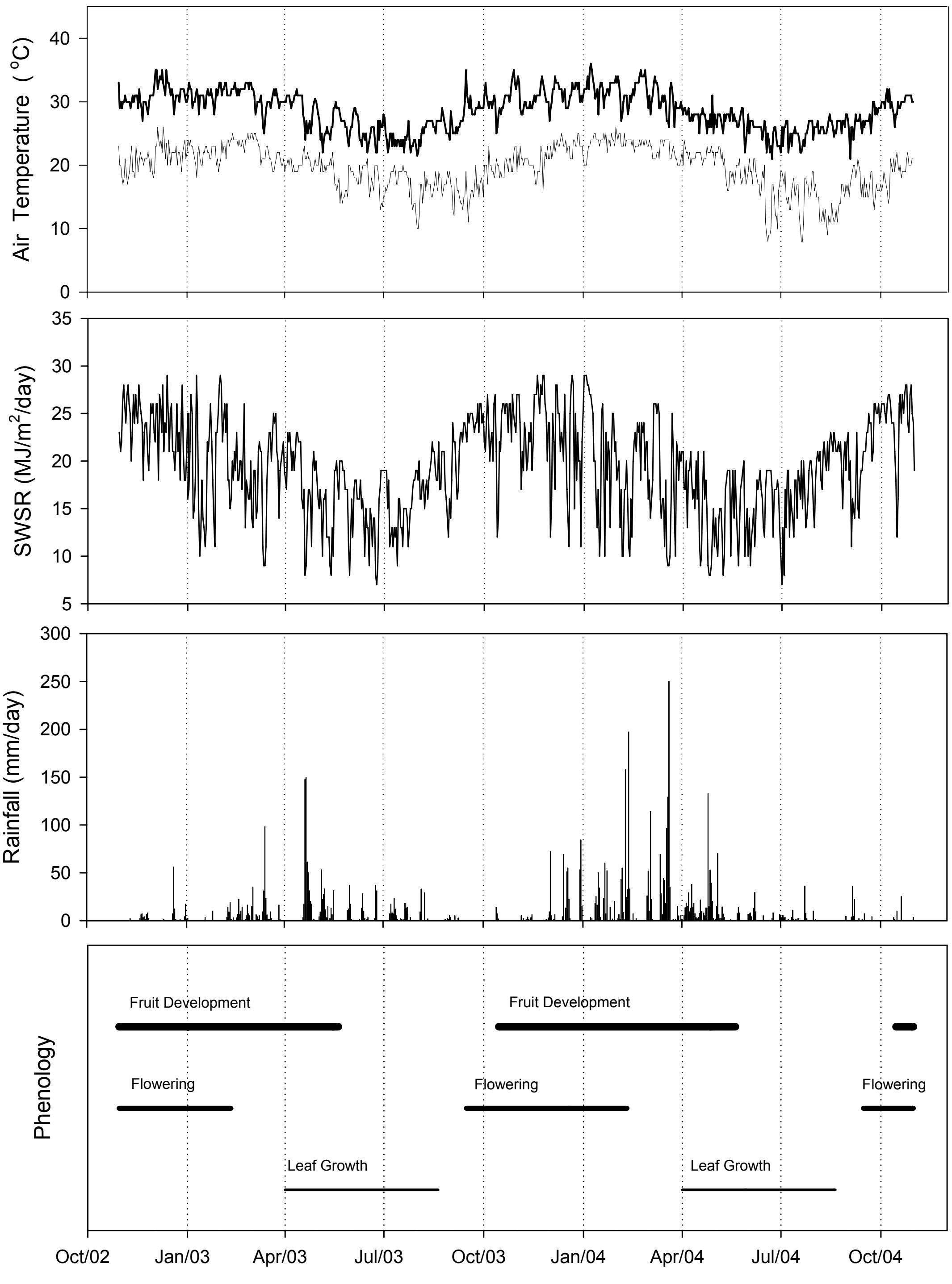
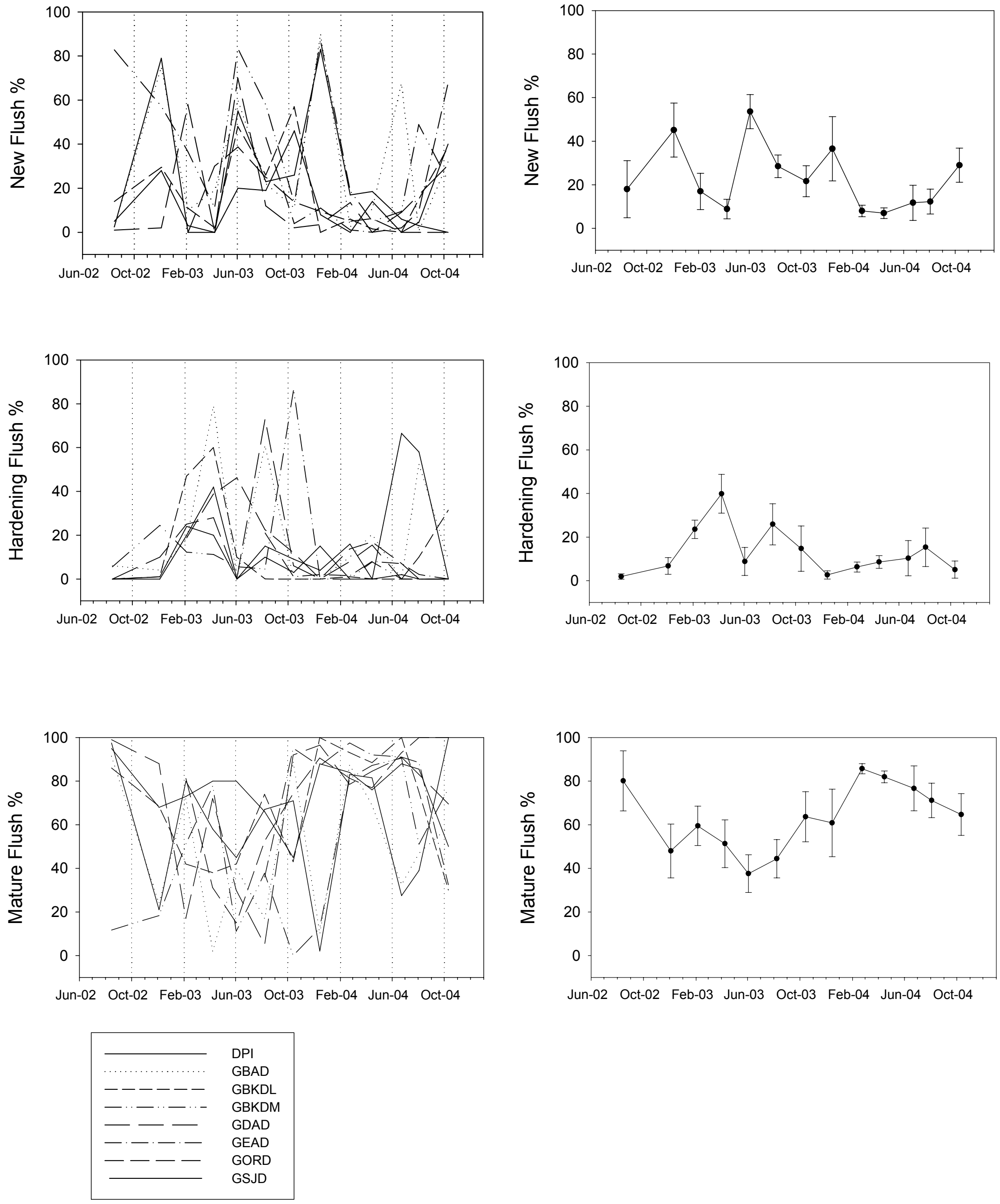



Figure 5. Mangosteen and Durian tree phenology in relation to air temperature, Short wave Solar Radiation (SWSR) and rainfall at South Johnstone.

# Tree phenology
## Durian
Durian tree phenology (shoot growth, flowering and fruiting patterns) are shown in Figure 6 and Table 7. Durian trees flush regularly during the year with the most pronounced break in flush activity occurring during late fruit filling and immediately after harvest. There is a great deal of variation between individual orchards, however peak activities (flushing, flowering and fruiting) generally occur at the same time.




a. All sites b. Mean of all sites

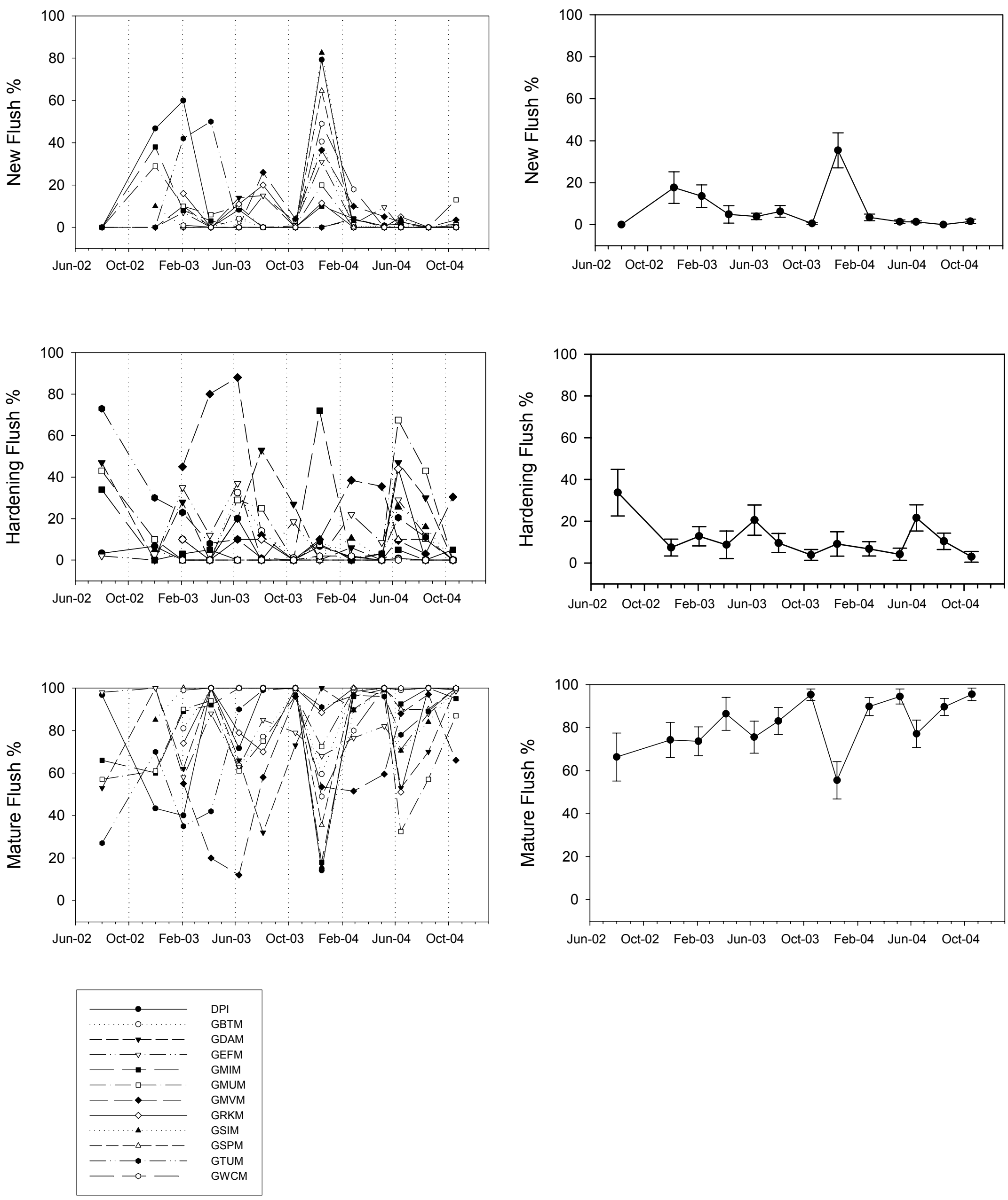
Figure 6. Durian Flush Phenology ; a. All sites, b. Mean of all sites, where vertical bars represent standard error.

Table 7. Durian flowering and fruit set periods recorded at individual farms.

| Grower | Aug 02 | Sep 02 | Oct 02 | Nov 02 | Dec 02 | Jan 03 | Feb 03 | Mar 03 | Apr 03 | May 03 | Jun 03 | Jul 03 | Aug 03 | Sep 03 | Oct 03 | Nov 03 | Dec 03 | Jan 04 | Feb 04 | Mar 04 | Apr 04 | May 04 | Jun 04 | Jul 04 | Aug 04 | Sep 04 | Oct 04 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DPI | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fl | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fruit | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| GBAD | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fl | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fruit | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| GBKDL | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fl | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fruit | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| GBKDM | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fl | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fruit | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| GDAD | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fl | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fruit | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| GSJD | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fl | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fruit | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| GORD | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fl | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fruit | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| GEAD | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fl | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fruit | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Aug 02 | Sep 02 | Oct 02 | Nov 02 | Dec 02 | Jan 03 | Feb 03 | Mar 03 | Apr 03 | May 03 | Jun 03 | Jul 03 | Aug 03 | Sep 03 | Oct 03 | Nov 03 | Dec 03 | Jan 04 | Feb 04 | Mar 04 | Apr 04 | May 04 | Jun 04 | Jul 04 | Aug 04 | Sep 04 | Oct 04 |

## Mangosteen

Mangosteen tree phenology (shoot growth, flowering and fruiting patterns) are shown in Figures 7 and Table 8. Mangosteen's flush 1 to 2 times during the year with the most pronounced break in flush activity occurring from May to October. Seasonal differences occur with more activity occurring during 2003 than 2004. There is variation between individual orchards, however peak activities(flushing, flowering and fruiting) generally occur at the same time.

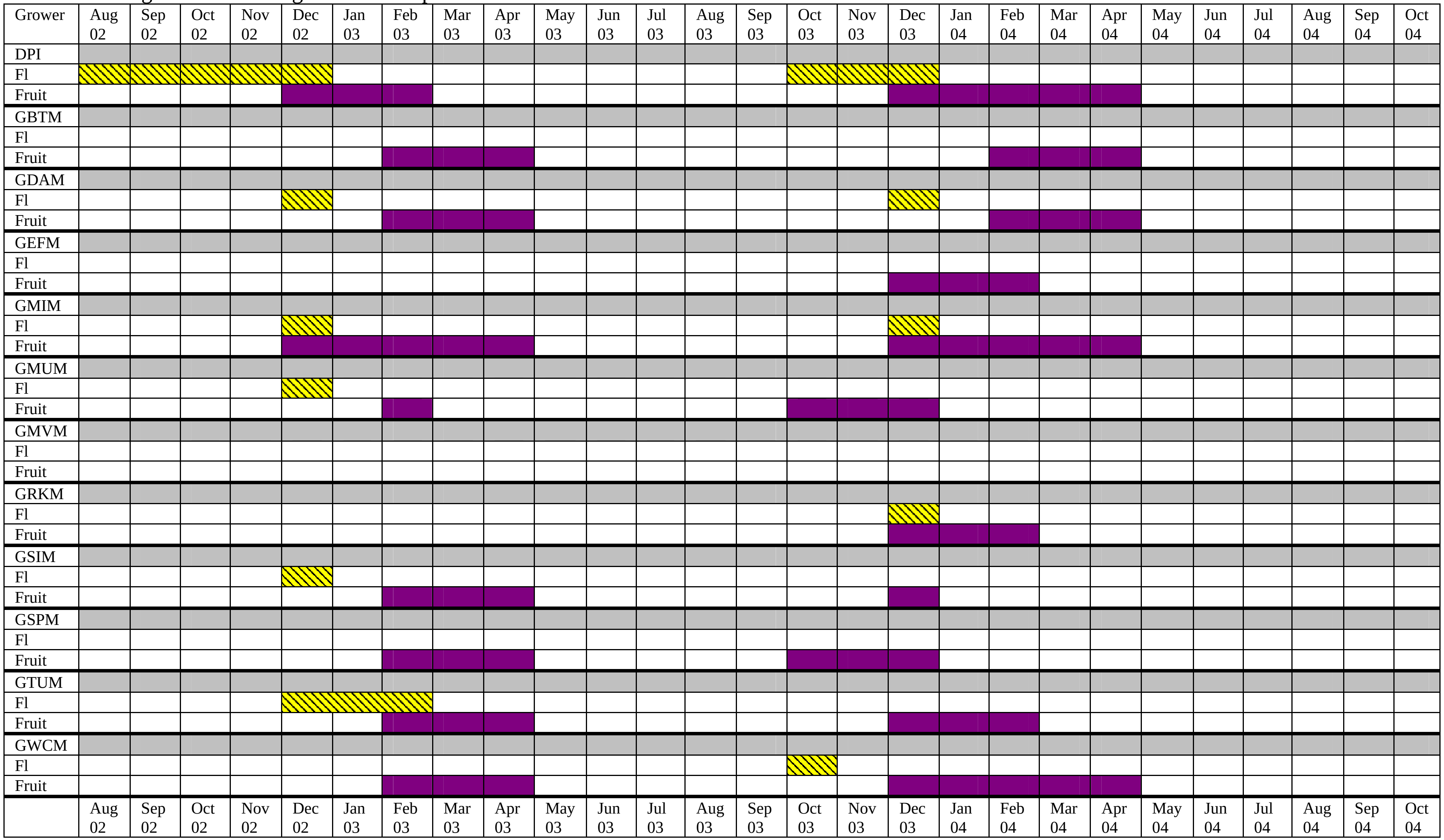



a. All sites

b. Mean of all sites

Figure 7. Mangosteen Flush Phenology ; a. all sites, b. mean of all sites, where vertical bars represent standard error.

Table 8. Mangosteen flowering and fruit set periods recorded at individual farms.



# Leaf nutrient monitoring
## Durian
*Mean leaf nutrient levels*
Mean leaf nutrient levels, across all varieties and sampling locations over the sampling period revealed that durian leaf 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 throughout the year with significant differences occurring between sampling months. Leaf N, P and K concentrations followed similar trends, with small exceptions. Common peaks occurred in February 03 and February 04. Leaf N concentrations gradually increased over the sampling period while leaf P concentrations declined after February 03.

*Leaf Mg, S, and Ca*: Concentrations of these elements also changed throughout the monitoring period. Leaf Mg and Ca both peaked in August 2003, while leaf S concentrations were declining at this time.

*Leaf micronutrients*: Seasonal trends for the macro-nutrients (N, P, K, Mg, Ca and S) are shown in Figure 9. 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 Zn, Fe and B. The concentration of elements Cu and Zn fluctuated greatly between sampling intervals and the standard error at individual sampling intervals was extremely large in some cases.

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 12.2% for N during fruit set and filling to 22.0% for Ca at post harvest sampling. Variability was much greater for the micro nutrients were CV's ranged from 20% for Zn at the post harvest sample to 138% for B at the post harvest sampling. This variability is within the range experienced in other nutrient research projects (Menzel *et al*. 1993, George *et al*. 1995). The fruit filling sampling was the phenological stage at which six 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, 0.04-0.06 % for Na and Cl respectively (Bergmann 1992).

Table 9. Mean durian leaf nutrient concentrations (with 95% confidence intervals in parenthesis) and coefficient of variation (CV%) for orchards sampled from 2002 – 2004 from eight orchards with a history of good production, management and the absence of nutrient deficiency or toxicity symptoms.

| Nutrient | Overall | Flowering | Fruit set and filling | Post harvest (winter) |
|---|---|---|---|---|
| N (%) | 1.93 (1.88-1.98) 13.7% | 1.87 (1.74-1.99) 14.1% | 2.04 (1.95-2.13) **12.2%** | 1.95 (1.86-2.04) 12.8% |
| P (%) | 0.23 (0.22-0.24) 18.1% | 0.22 (0.20-0.24) 18.1% | 0.24 (0.23-0.25) **11.7%** | 0.23 (0.21-0.25) 21.0% |
| K (%) | 1.45 (1.40-1.51) 20.8 % | 1.42 (1.29-1.55) 20.0% | 1.66 (1.56-1.76) **17.0%** | 1.34 (1.25-1.43) 19.5% |
| Ca (%) | 1.91 (1.82-1.99) 23.5% | 2.22 (2.05-2.38) **15.9%** | 1.49 (1.40-1.59) 17.3% | 1.94 (1.79-2.09) 22.0% |
| Mg (%) | 0.65 (0.63-0.68) 18.1% | 0.67 (0.62-0.72) 15.8% | 0.65 (0.61-0.69) 16.6% | 0.64 (0.59-0.69) 22.3% |
| S (%) | 0.22 (0.21-0.22) 17.7% | 0.20 (0.19-0.22) 16.5% | 0.24 (0.23-0.25) **13.9%** | 0.21 (0.20-0.23) 18.0% |
| Mn (mg/kg) | 83 (71-95) 76% | 92 (78-106) **32%** | 54 (46-62) 73% | 99 (63-135) 103% |
| Fe (mg/kg) | 79 (66-91) 80% | 100 (58-143) 89% | 61 (53-69) **37%** | 76 (59-93) 64% |
| Cu (mg/kg) | 53 (22-84) 303% | 57 | 48 | 62 |
| Zn (mg/kg) | 16 (9-22) 228% | 22 | 13 (12-14) 26% | 11 (10-12) **20%** |
| B (mg/kg) | 49 (40-58) 94% | 49 (40-57) 37% | 42 (37-47) **33%** | 58 (30-87) 138% |
| Na (%) | 0.05 (0.04-0.06) 47% | 0.07 (0.06-0.08) **32%** | 0.03 (0.03-0.04) 48% | 0.05 (0.04-0.06) 43% |
| Cl (%) | 0.05 (0.04-0.06) 85% | 0.05 (0.03-0.07) **84%** | 0.04 (0.03-0.05) 89% | 0.05 (0.04-0.07) 85% |

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

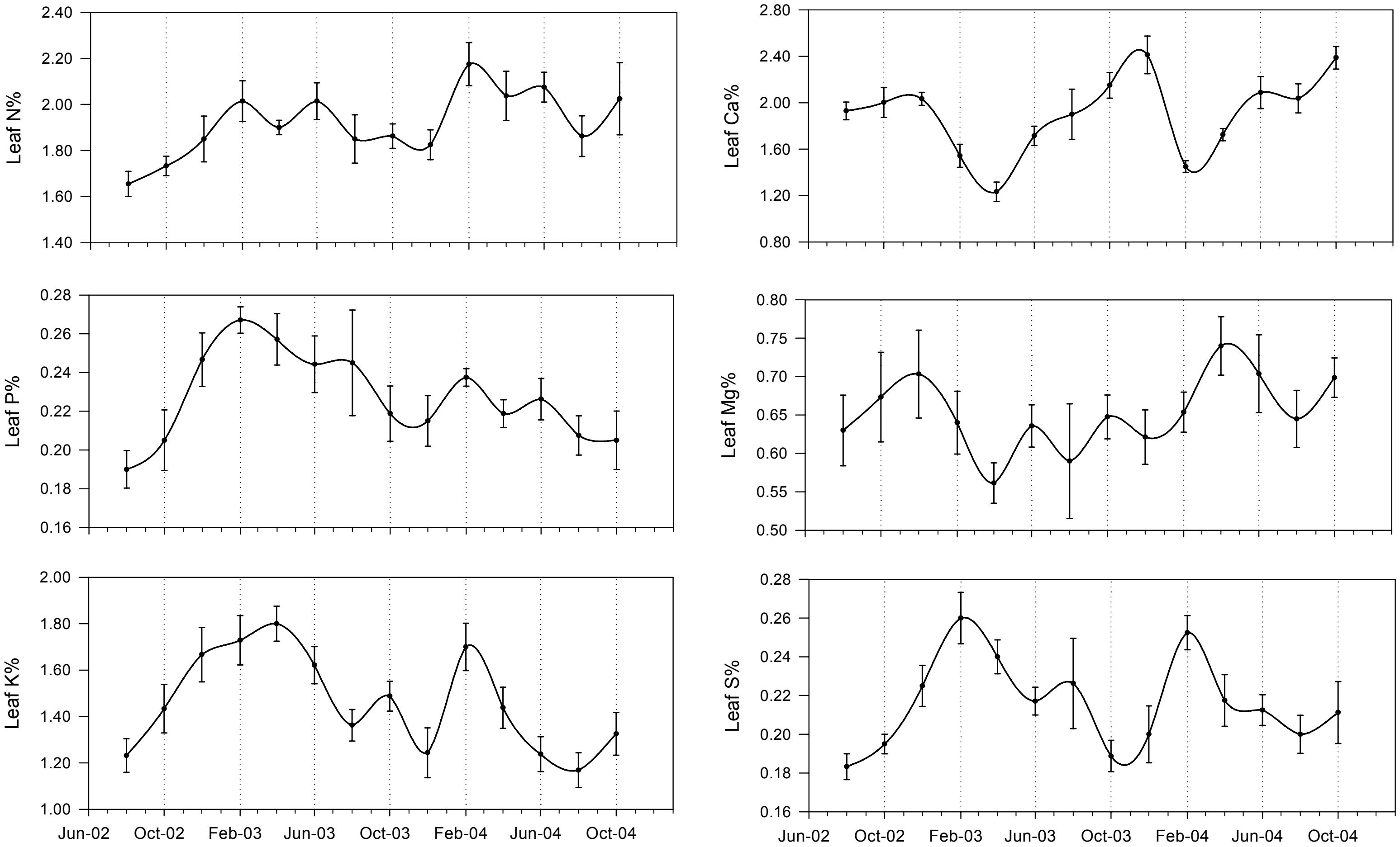



Figure 8. Seasonal variation in durian leaf macronutrients. Vertical lines represent Standard Error

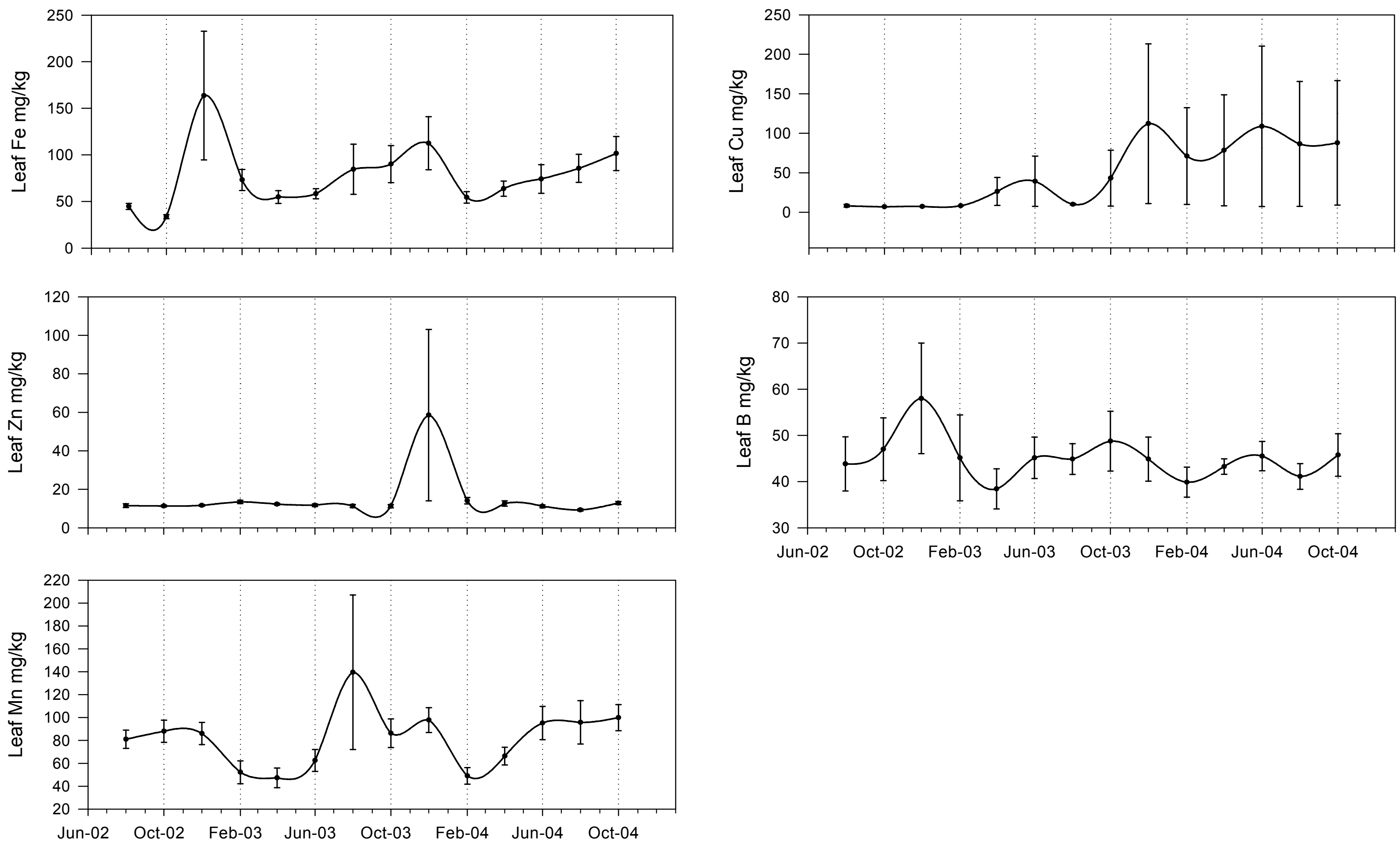



Figure 9. Seasonal variation in durian leaf micronutrients. Vertical lines represent Standard Error

## Mangosteen

*Mean leaf nutrient levels*

Mean leaf nutrient levels, across all varieties and sampling locations over the sampling period revealed that mangosteen leaf nutrient composition varied with season. The seasonal cycle of leaf nutrients varied with the nutrient. Seasonal trends for the macro-nutrients are shown in Figure 10 and micro-nutrients in Figure 11.

*Leaf N, P and K*: Concentrations of these nutrients changed greatly throughout the year with significant differences occurring between sampling months, particularly from the fourth sampling period onwards. Leaf N, P and K followed similar trends, with small exceptions. Common peaks occurred in Feb 03.

*Leaf Mg, S, and Ca*: Concentrations of these elements also changed throughout the monitoring period. Leaf Ca concentrations started at 1.4% and decreased by the fourth sampling to approximately 1.2%. Leaf Mg concentrations started low and increased to a peak Aug 03. Leaf S concentrations varied continuously over the sampling period with high SE's at each sampling occasion.

*Leaf micronutrients*: Seasonal trends for the micro-nutrients in Figure 11. 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 generally the least for Zn and B. The concentration of Cu fluctuated greatly between sampling intervals and the standard error at individual sampling intervals was large from February to December 2003. Concentration of leaf Mn dropped after the first three sampling intervals and than stabilised over the remainder of the monitoring period.

The overall mean leaf nutrient concentrations and means at distinct phenological stages (flowering, fruit set and filling, and post-harvest) and their coefficient of variation (CV) and confidence limits (95%) are shown in Table 10. The variability in concentration was least for the macro-nutrients with CV ranging from 8.9% for N during fruit filling to 48.8% for P during the post-harvest sampling sampling. Variability was much greater for the micro nutrients were CV's ranged from 26% for B for the fruit filling sample to 170% for Cu at the flowering sampling. This variability is within the range experienced in other nutrient research projects (Menzel *et al.* 1993, George *et al*. 1995). The fruit filling sampling was the phenological stage at which eleven of thirteen elements showed the least variation (CV).

Nutrient concentrations of Cl and Na, elements which, although essential are only required in small amounts was stable at 0.01 % for Na and in the high range of 0.26-0.28 % for Cl.

Table 10. Mean mangosteen leaf nutrient concentrations (with 95% confidence intervals in parenthesis) and coefficient of variation (CV%) for orchards sampled from 2002 – 2004 from twelve orchards with a history of good production, management and the absence of nutrient deficiency or toxicity symptoms.

| Nutrient | Overall | Flowering | Fruit set and filling | Post harvest (winter) |
|---|---|---|---|---|
| N (%) | 1.34 (1.32-1.37) 11.7% | 1.30 (1.26-1.34) 12.4% | 1.39 (1.36-1.43) **8.9%** | 1.34 (1.29-1.38) 12.8% |
| P (%) | 0.10 (0.10-0.11) 43.1% | 0.09 (0.08-0.10) 40.8% | 0.11 (0.10-0.12) **36.5%** | 0.11 (0.09-0.12) 48.8% |
| K (%) | 1.10 (1.06-1.15) 23.7 % | 0.97 (0.91-1.04) 24.5% | 1.23 (1.18-1.29) **15.8%** | 1.12 (1.04-1.19) 24.9% |
| Ca (%) | 1.20 (1.16-1.23) 19.8% | 1.27 (1.20-1.34) 19.8% | 1.12 (1.07-1.16) **15.2%** | 1.20 (1.13-1.27) 21.3% |
| Mg (%) | 0.18 (0.17-0.18) 31.4% | 0.17 (0.15-0.18) 23.5% | 0.18 (0.17-0.19) **17.7%** | 0.18 (0.16-0.20) 43.3% |
| S (%) | 0.34 (0.34-0.35) 12.9% | 0.34 (0.33-0.35) 12.4% | 0.35 (0.34-0.36) **11.1%** | 0.34 (0.33-0.36) 14.8% |
| Mn (mg/kg) | 256 (219-294) 93% | 300 (223-376) 92% | 204 (155-253) **85%** | 253 (191-315) 93% |
| Fe (mg/kg) | 36 (33-39) 49% | 42 (37-48) 48% | 30 (27-32) **34%** | 36 (31-41) 52% |
| Cu (mg/kg) | 22 (16-28) 163% | 25 (13-37) 170% | 21 (11-30) 166% | 21 (13-30) **152%** |
| Zn (mg/kg) | 22 (9-22) 228% | 26 (18-33) 104% | 23 (20-27) 49% | 18 (17-20) **32%** |
| B (mg/kg) | 50 (20-25) 77% | 53 (47-59) 38% | 45 (41-48) **26%** | 51 (47-55) 31% |
| Na (%) | 0.01 (0.01-0.01) 56% | 0.01 (0.01-0.01) 25% | 0.01 (0.01-0.01) **0%** | 0.01 (0.01-0.01) 86% |
| Cl (%) | 0.27 (0.26-0.28) 22% | 0.28 (0.27-0.30) 21% | 0.25 (0.24-0.26) **12%** | 0.26 (0.25-0.28) 25% |

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

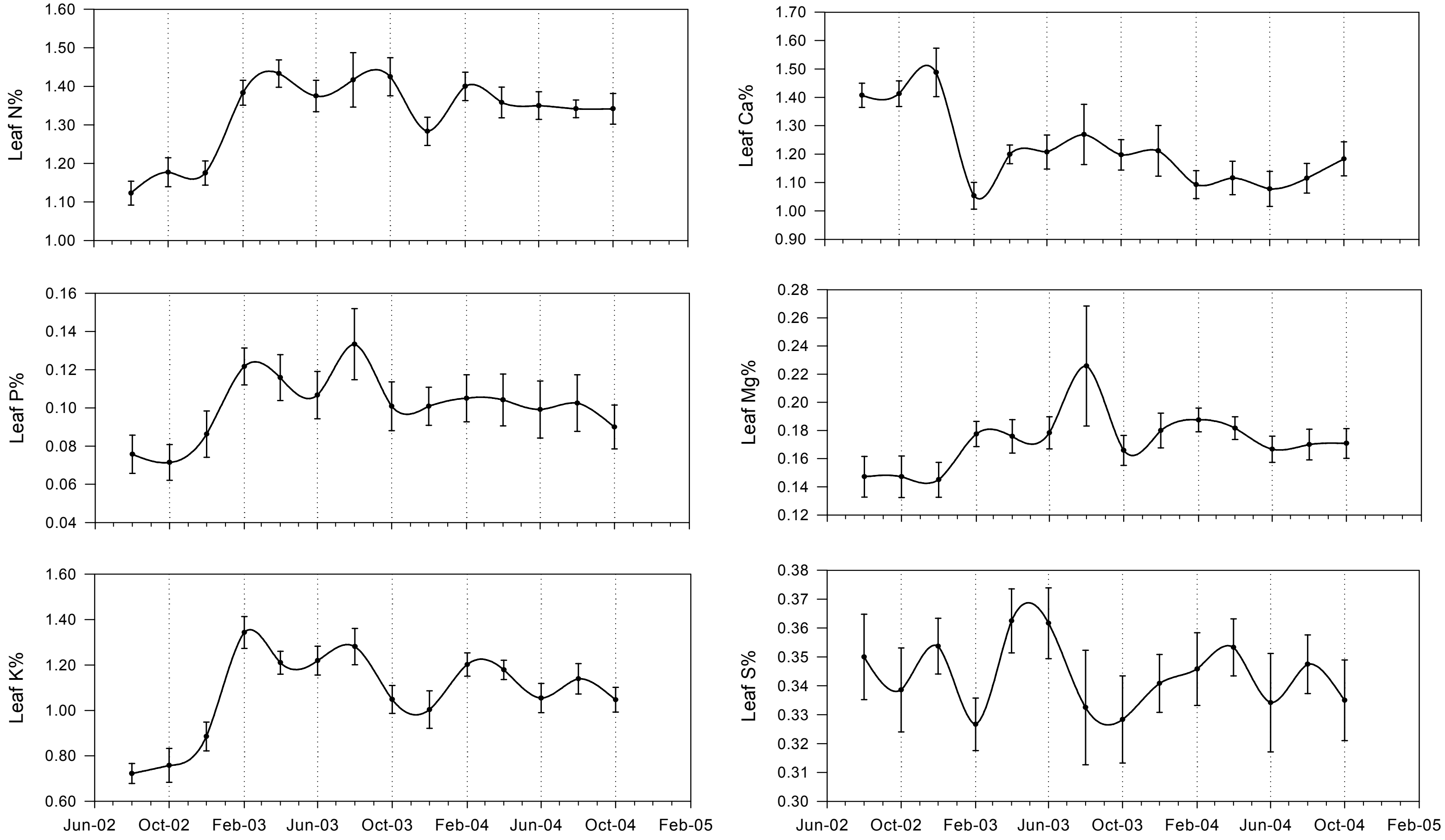



Figure 10. Seasonal variation in mangosteen leaf macronutrients. Vertical lines represent Standard Error

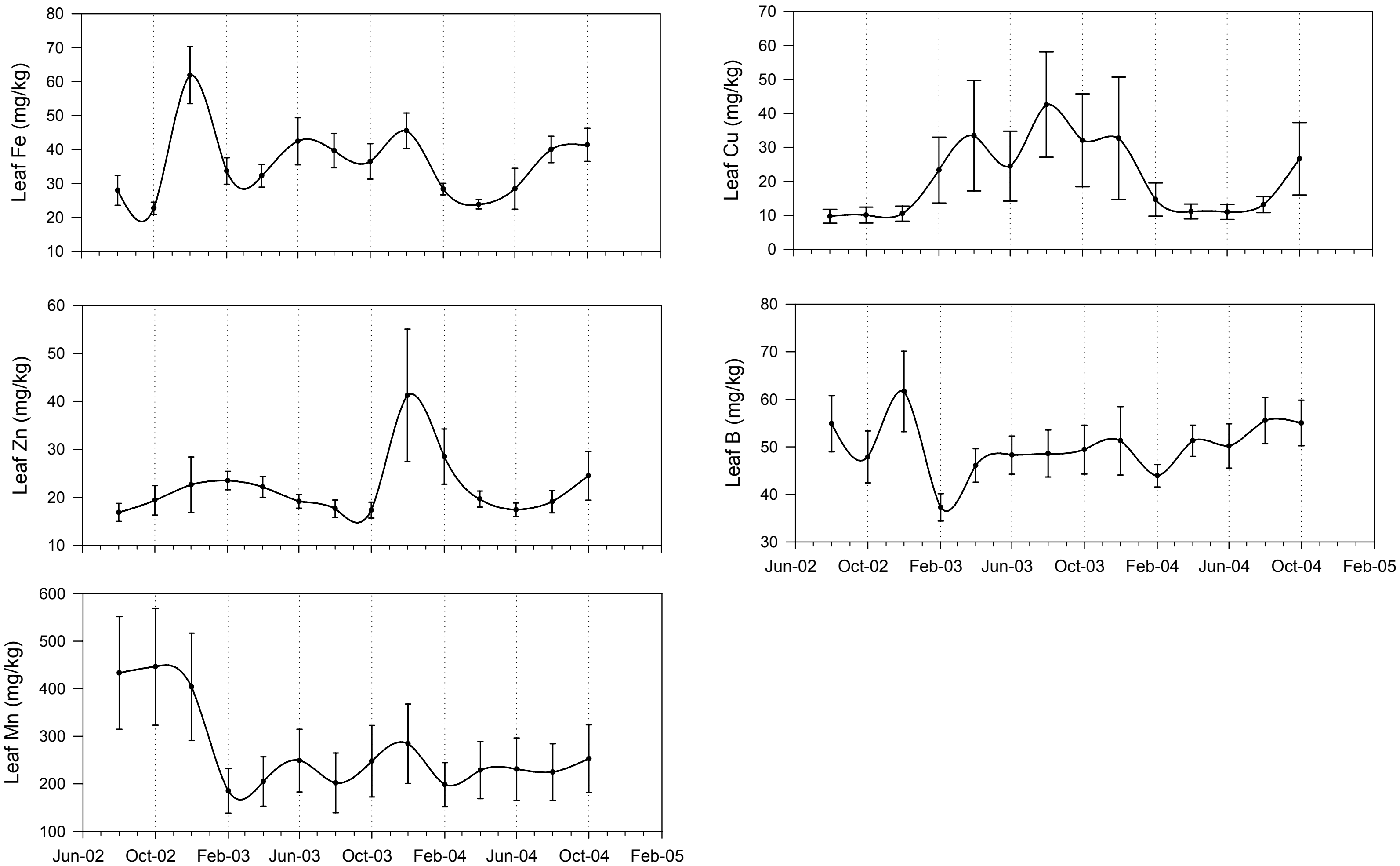



Figure 11. Seasonal variation in mangosteen leaf micronutrients. Vertical lines represent Standard Error

## 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 regularly for a number of years.

### *Durian*

Mean macronutrient levels by grower code are shown in Figure 12. For elements such as N and S mean nutrient concentrations are relatively similar among growers, whereas for P, K, Mg and Ca 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. There are inverse relationship between leaf K and Ca ($y = -0.2905x + 2.3491$; $r2 = 0.0756$) and leaf K and Mg ($y = -0.2108x + 0.9565$; $r2 = 0.2804$) although significant they are not overly strong. These differences may be due to interactions with soil type and the ratio of soil cations (K, Ca and Mg).

For micronutrients the variability in mean leaf concentrations between growers is much larger, particularly for Fe, Mn and B (Figure 13). Leaf concentrations of Cu and Zn are relatively similar except for high readings on individual orchards. High manganese concentrations in some orchards may be due to the ready availability of Mn 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 an 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 notify the laboratory of any recent foliar nutrient or pesticide applications.

### *Mangosteen*

Mean macronutrient levels by grower code are shown in Figure 14. Nitrogen nutrient concentrations are relatively similar among growers, whereas for P, K, Ca, and Mg and S 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. There is a relatively strong and significant inverse relationship between leaf K and Ca ($y = -0.0532x + 0.1207$; $R2 = 0.3932$). A similar but weaker inverse relationship exists for leaf K and Mg ($y = -0.0248x + 0.2037$; $R2 = 0.014$). These differences may be due to interactions with soil type and the ratio of soil cations (K, Ca and Mg). The DPI site had the highest N and Ca concentrations but had medium to low levels of the remaining macro nutrients relative to the other orchards.

For micronutrients the variability in mean leaf concentrations between growers is much larger, particularly for Mn, Cu, Zn and B (Figure 15). For leaf Mn, high levels in a few orchards are associated with low pH. Manganese is more readily available at low soil pH. The high concentrations of Cu and Zn in a few orchards are directly due to the high foliar inputs either as an 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 notify the laboratory of any recent foliar nutrient or pesticide applications.

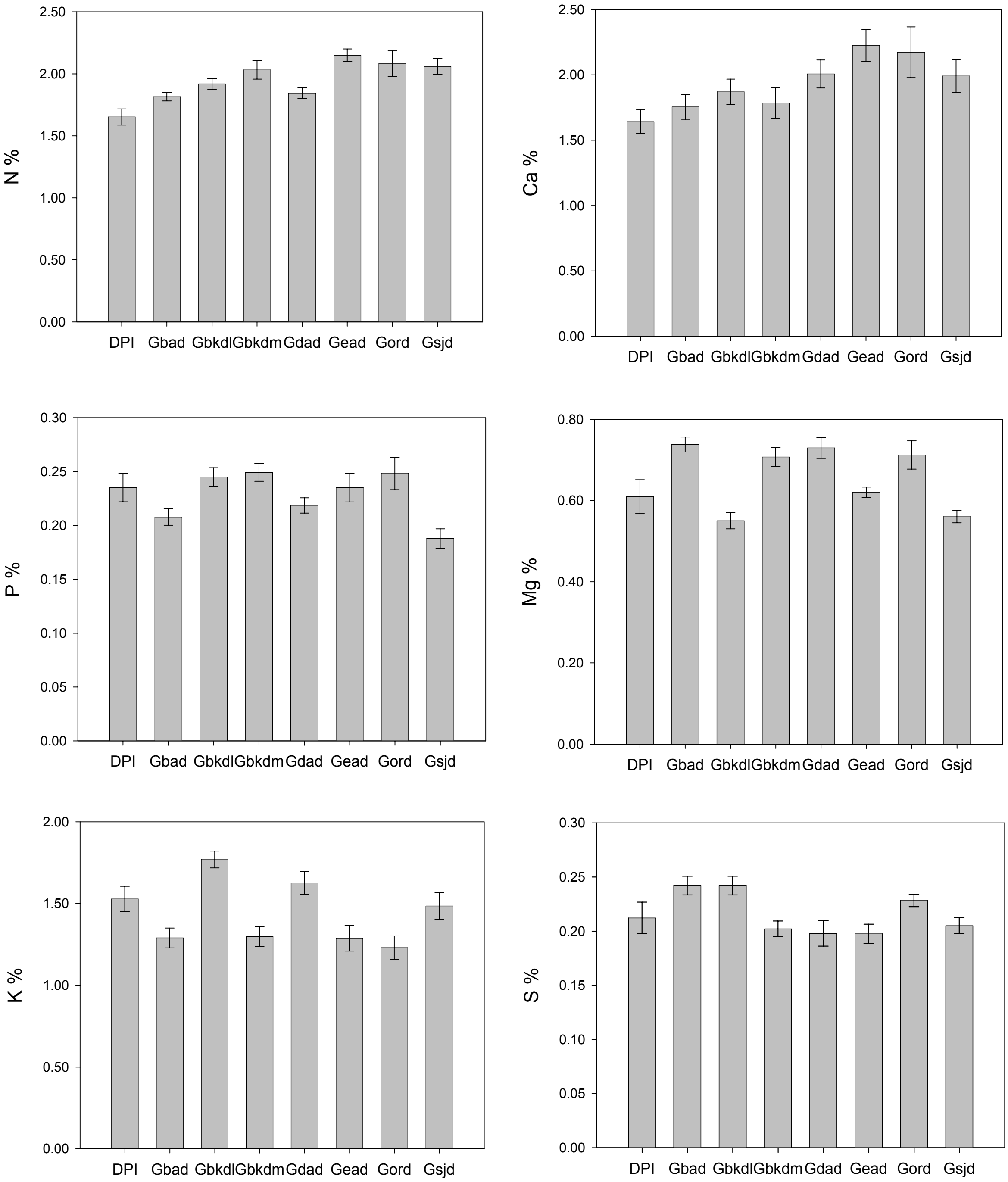



Figure 12. Durian mean leaf macronutrient concentrations by orchard. Vertical bars represent the standard error.

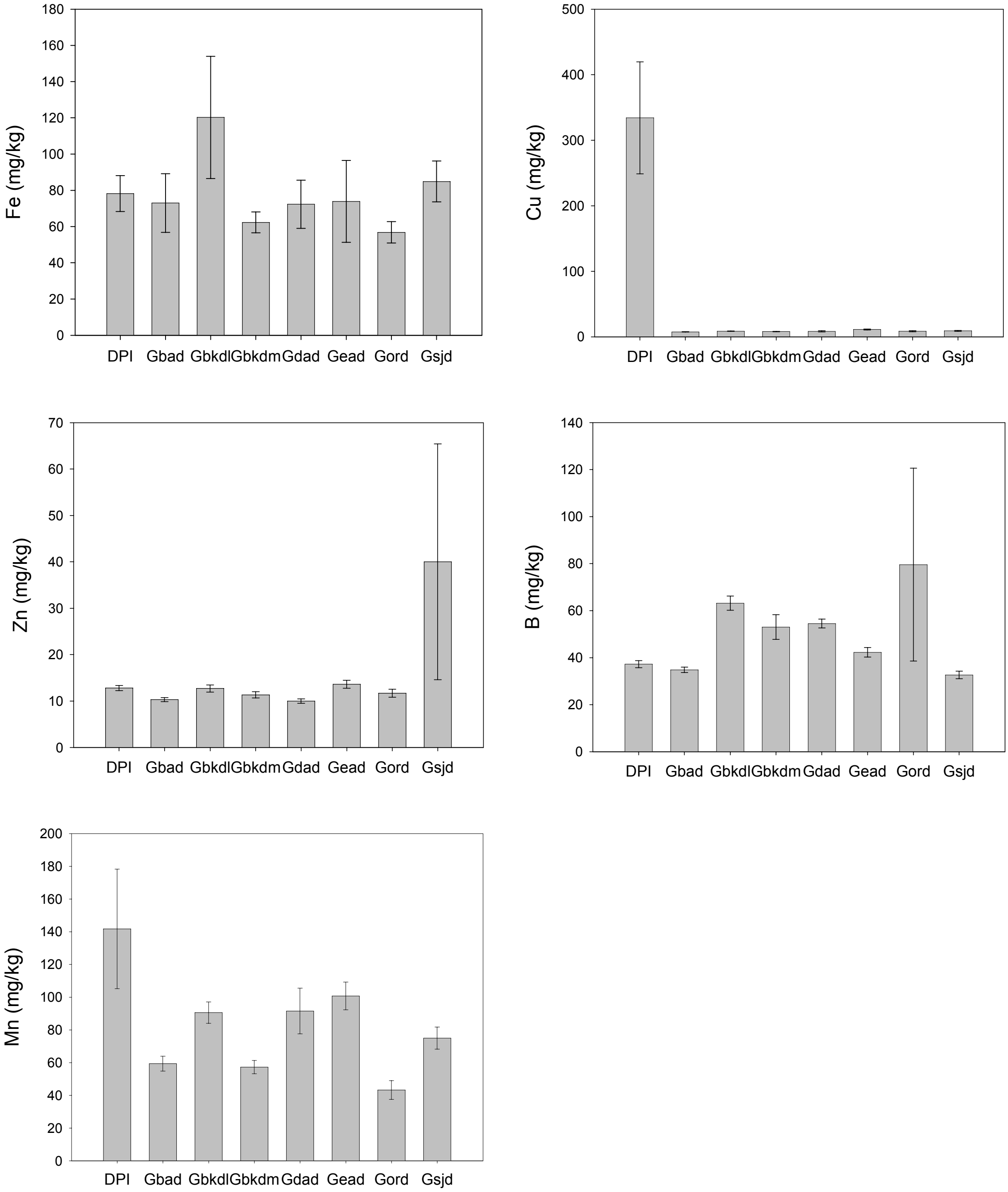



Figure 13. Durian mean leaf micronutrient levels by orchard. Vertical bars represent the standard error.

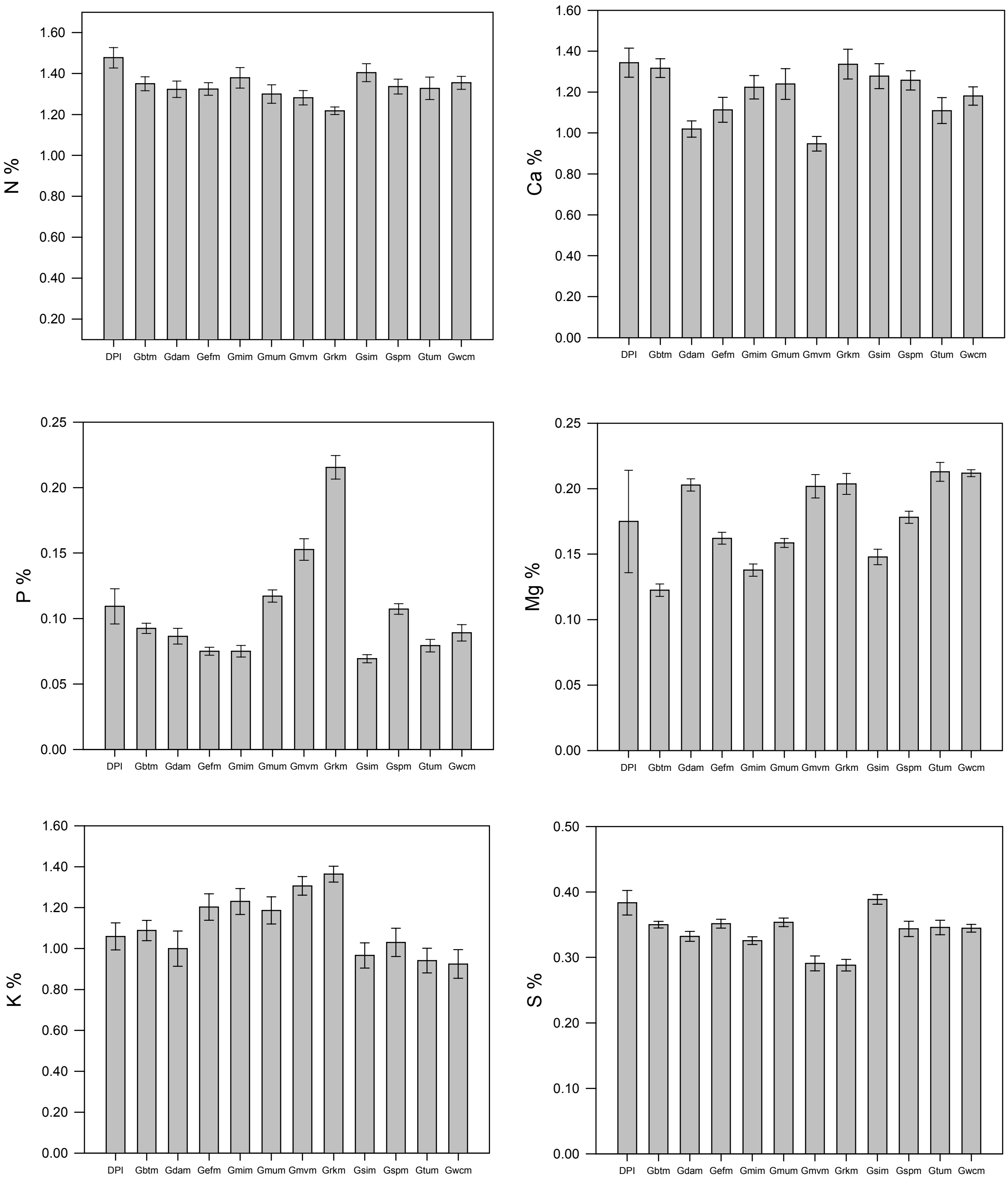



Figure 14. Mangosteen mean leaf macronutrient concentrations by orchard. Vertical bars represent the standard error.

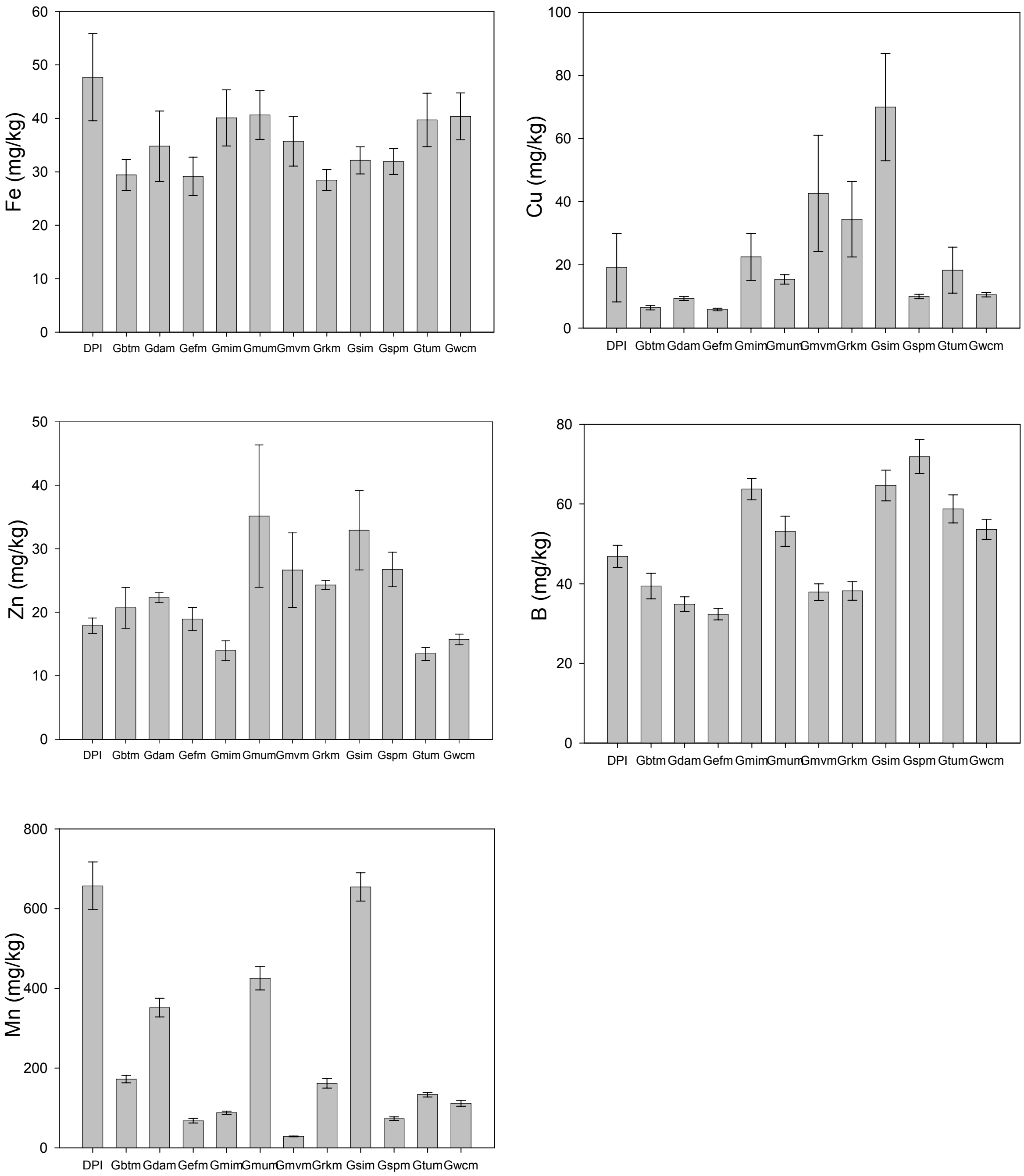



Figure 15. Mangosteen mean leaf micronutrient levels by orchard. Vertical bars represent the standard error.

## Soil chemical characteristics and nutrient monitoring

*Soil pH, EC and Organic Matter*
Average Soil pH, EC and Organic Carbon for both Durian and Mangosteen are shown in Table 11 and 12 and variations over time in Figure 16. Soil pH varied over time from 5.6 to 6.0. The range measured was well within optimum soil specifications. Likewise soil EC also varied over time, (0.065–0.096 dS/m) with seasonal differences apparent, however, the range remained within optimum soil levels. Organic carbon percentage measured ranged from 1.3–2.2 % and also varied with season. These levels are at the low end expected for horticultural soils. Conversion to organic matter % and comparisons to optimal values are shown in Tables 11 and 12.

*Mean soil chemical and nutrient values*
Soil nutrient levels (0-20 cm), their range and the variation are shown in Table 11 for durian and Table 12 for mangosteen. 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.

For durian and mangosteen orchards the levels of exchangeable cations (K, Ca, Mg) were low relative to optimum values. Na and Al were below critical levels. This was reflected in the cation balance which indicated that median Ca% (64.5%) was just below the optimum range of 65-80%. The cations Mg, K, Na and Al were all at high end of the preferred range. The Total CEC (cation exchange capacity) was low, which is typical of tropical soils.

Nitrate nitrogen levels were generally on the low end of the optimum range, although how accurately these values reflect total soil N availability and fertiliser management in tree crops is still under debate. Soil P values were generally at the high end or above the optimum range, this is typical of soil which in most cases had a previous history under sugar cane. How much of the soil P is available is questionable and is a topic for more research.

Soil B levels (0.48–0.57 mg/kg) were generally well below the recommended range of 1 to 2 mg/kg.

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.

Seasonal variations in mean soil nutrients for durian and mangosteen are shown in Figures 17 and 18.

Table 11. Durian orchards - Mean soil nutrient levels/ chemical characteristic and median and ranges encountered.

| Nutrient/Chemical characteristic | Mean ± se | Median (range) | Generalised optimum values[#] |
|---|---|---|---|
| pH (1:5 water) | 5.81 ± 0.08 | 5.70 (5.00-7.00) | 5.5-6.5 |
| pH (1:5 $CaCl_2$) | 5.11 ± 0.09 | 5.10 (4.40-6.60) | |
| EC (1:5 aqueous) dS/m | 0.08 ± 0.01 | 0.07 (0.02-0.30) | <0.4 |
| Organic Carbon (%) | 2.06 ± 0.09 | 2.10 (1.10-3.40) | |
| Organic Matter (%) | 3.54 | 3.61 (1.89-5.85) | 3.4-6.9 |
| Nitrate nitrogen (mg/kg) | 11.25 ± 1.52 | 8.45 (1.90-59.00) | 10-60 |
| Phosphorus (Colwell) (mg/kg) | 178.05 ± 21.49 | 137.50 (31.00-470.00) | 20-120 |
| Sulphur (KCl) (mg/kg) | 20.47 ± 3.88 | 12.50 (1.70-120.00) | |
| Potassium (exchangeable) (meq/100g) | 0.95 ± 0.61 | 0.29 (0.10-26.00) | >0.4 |
| Calcium (exchangeable) (meq/100g) | 4.07 ± 0.52 | 2.90 (0.60-19.00) | >5.0 |
| Magnesium (exchangeable) (meq/100g) | 1.21 ± 0.12 | 0.90 (0.36-2.92) | >1.6 |
| Sodium (exchangeable) (meq/100g) | 0.08 ± 0.01 | 0.07 (0.01-0.35) | <0.5 |
| Aluminium (exchangeable) (meq/100g) | 0.44 ± 0.07 | 0.18 (0.00-1.56) | <0.5 |
| Chloride (1:5 aqueous) (mg/kg) | 20.33 ± 3.57 | 15.00 (5.00-120.00) | <300 |
| Manganese (DTPA) (mg/kg) | 47.73 ± 6.04 | 47.50 (2.53-130.00) | 4-45 |
| Iron (DTPA) (mg/kg) | 98.07 ± 4.22 | 102.50 (29.00-150.00) | Meaningless test (McFarlane 1999) |
| Copper (DTPA) (mg/kg) | 3.95 ± 0.52 | 2.40 (0.57-16.00) | 0.3-10.0 |
| Zinc (DTPA) (mg/kg) | 5.84 ± 0.91 | 4.95 (0.72-28.00) | 2.0-10.0 |
| Boron (calcium chloride) (mg/kg) | 0.58 ± 0.04 | 0.57 (0.23-1.03) | 1.0-2.0 |
| *Cation balance* | | | |
| Ca:Mg ratio | 3.40 ± 0.28 | 3.00 (1.39-7.61) | 3.0-5.1 |
| Calcium (%) | 60.19 ± 2.80 | 64.50 (25.00-86.00) | 65-80 |
| Magnesium (%) | 19.71 ± 0.86 | 18.00 (11.00-35.00) | 10-15 |
| Potassium (%) | 6.55 ± 0.62 | 5.50 (2.00-22.00) | 1-5 |
| Sodium (%) | 1.57 ± 0.20 | 1.00 (0.00-8.00) | < 1.0 |
| Aluminium (%) | 12.12 ± 2.42 | 3.00 (0.00-47.00) | < 1.0 |
| C.E.C. | 6.13 ± 0.58 | 5.14 (2.26-22.02) | > 7.0 |

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

Table 12. Mangosteen orchards - Mean soil nutrient levels/ chemical characteristic and median and ranges encountered.

| Nutrient/Chemical characteristic | Mean ± se | Median (range) | Generalised optimum values[#] |
|---|---|---|---|
| pH (1:5 water) | 6.00 ± 0.09 | 6.00 (4.8–7.6) | 5.5-6.5 |
| pH (1:5 $CaCl_2$) | 5.33 ± 0.09 | 5.20 (4.1–7.0) | |
| EC (1:5 aqueous) dS/m | 0.08 ± 0.00 | 0.07 (0.03–0.19) | <0.4 |
| Organic Carbon (%) | 1.6 ± 0.09 | 1.4 (0.89-4.60) | |
| Organic Matter (%) | 2.75 | 2.41 (1.5-7.9) | 3.4-6.9 |
| Nitrate nitrogen (mg/kg) | 7.88 ± 0.77 | 7.00 (0.90-44.00) | 10-60 |
| Phosphorus (Colwell) (mg/kg) | 179.0 ± 20.8 | 110 (7.0-590.0) | 20-120 |
| Sulphur (KCl) (mg/kg) | 18.23 ± 2.45 | 8.10 (1.5-96.0) | |
| Potassium (exchangeable) (meq/100g) | 0.37 ± 0.03 | 0.26 (0.09-1.39) | >0.4 |
| Calcium (exchangeable) (meq/100g) | 4.31 ± 0.48 | 3.30 (0.00-18.50) | >5.0 |
| Magnesium (exchangeable) (meq/100g) | 1.18 ± 0.08 | 1.08 (0.32-2.75) | >1.6 |
| Sodium (exchangeable) (meq/100g) | 0.06 ± 0.0 | 0.05 (0.01-0.13) | <0.5 |
| Aluminium (exchangeable) (meq/100g) | 0.50 ± 0.11 | 0.20 (0.00-6.00) | <0.5 |
| Chloride (1:5 aqueous) (mg/kg) | 18.74 ± 1.38 | 16.0 (6.0-68.0) | <300 |
| Manganese (DTPA) (mg/kg) | 14.71 ± 2.65 | 6.21 (1.0-84.0) | 4-45 |
| Iron (DTPA) (mg/kg) | 94.51 ± 4.63 | 86.0 (38.0-190.0) | Meaningless test (McFarlane 1999) |
| Copper (DTPA) (mg/kg) | 4.16 ± 0.53 | 2.50 (0.84-23.00) | 0.3-10.0 |
| Zinc (DTPA) (mg/kg) | 4.80 ± 0.47 | 3.20 (0.90-15.00) | 2.0-10.0 |
| Boron (calcium chloride) (mg/kg) | 0.48 ± 0.02 | 0.45 (0.23-0.86) | 1.0-2.0 |
| *Cation balance* | | | |
| Ca:Mg ratio | 3.82 ± 0.26 | 3.65 (0.59-8.87) | 3.0-5.1 |
| Calcium (%) | 61.11 ± 2.51 | 66.0 (0.0-88.0) | 65-80 |
| Magnesium (%) | 19.08 ± 0.94 | 18.0 (9.0-45.0) | 10-15 |
| Potassium (%) | 6.68 ± 0.52 | 6.0 (2.0-25.0) | 1-5 |
| Sodium (%) | 1.26 ± 0.13 | 1.0 (0.0-7.0) | < 1.0 |
| Aluminium (%) | 11.98 ± 2.38 | 3.00 (0.0-69.0) | < 1.0 |
| C.E.C. | 6.43 ± 0.50 | 5.48 (2.22-20.97) | > 7.0 |

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

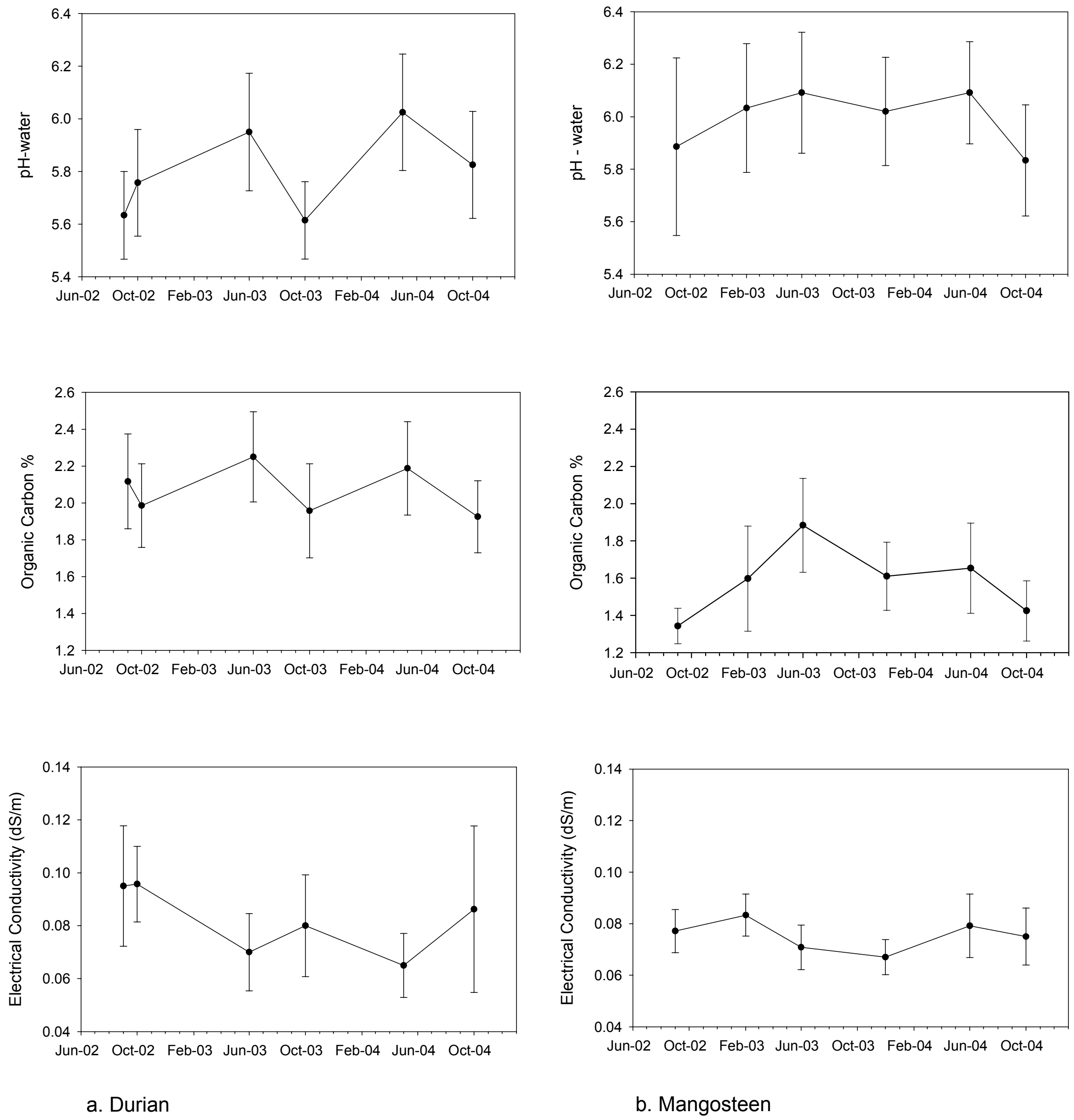



Figure 16. Average soil pH, EC and Organic Matter (0-20 cm) in **a**. Durian and **b**. Mangosteen orchards monitored from September 2002 to October 2004. Vertical bars represent standard errors at each sampling period.

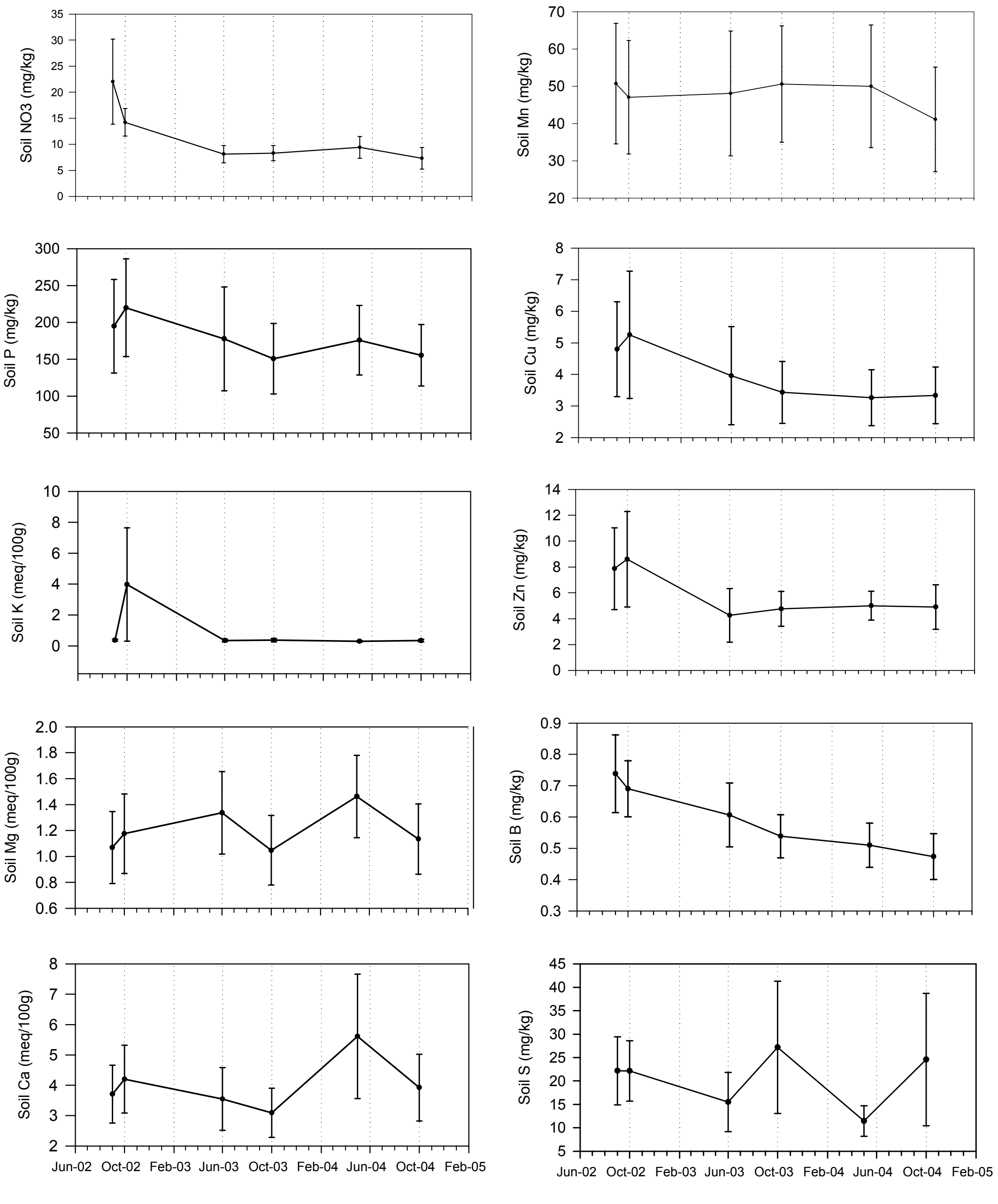



Figure 17. Mean seasonal variation in durian orchards soil nutrient concentrations ($NO_3$-, P, K, Mg and Ca, Mn, Cu, Zn, B and S), Vertical bars represent standard errors at each sampling.

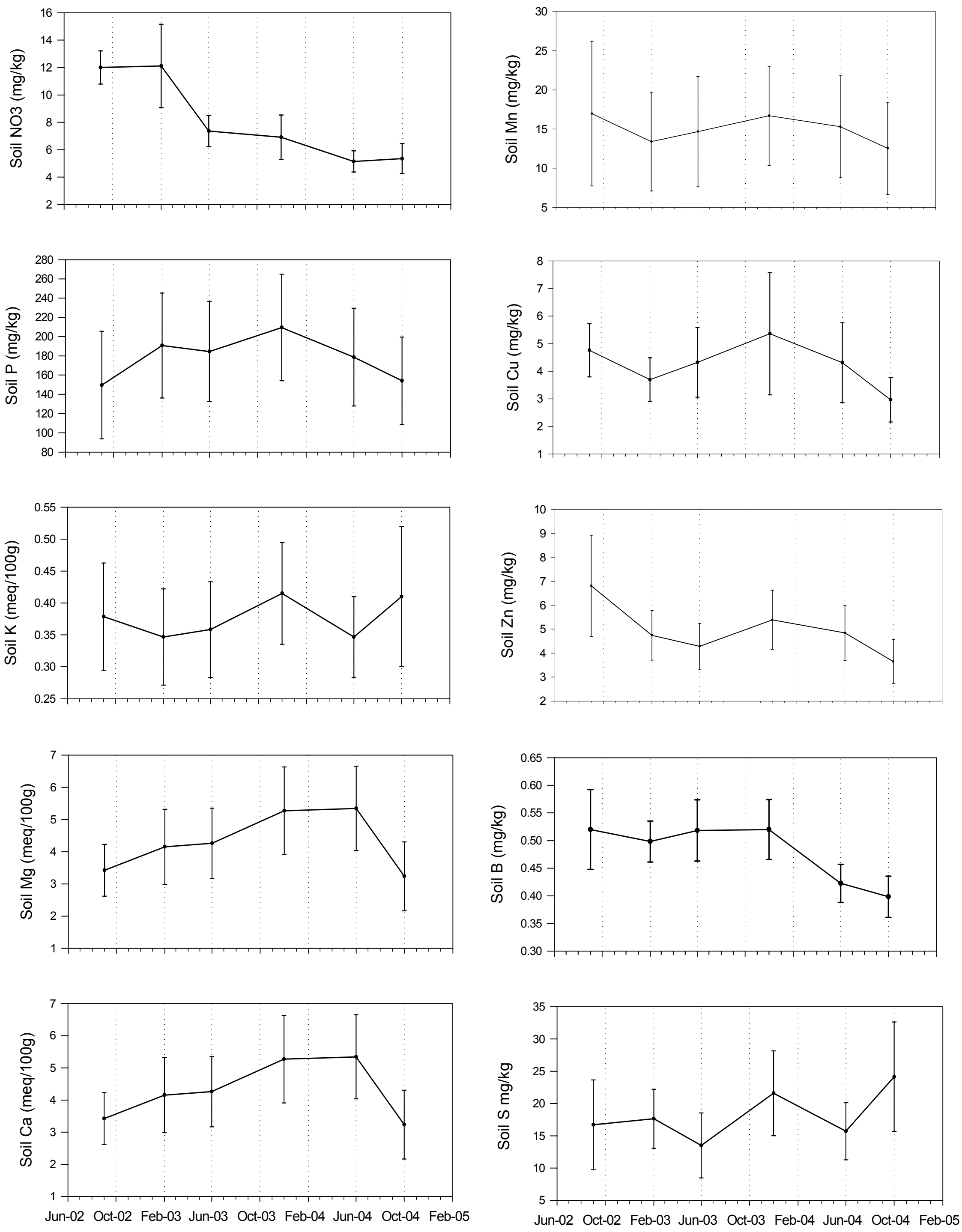



Figure 18. Mean seasonal variation in mangosteen orchards soil nutrient concentrations ($NO_3$-, P, K, Mg and Ca, Mn, Cu, Zn, B and S), Vertical bars represent standard errors at each sampling.

## Fertiliser inputs

Details on fertiliser inputs were collected for two full seasons (2003/2004 and 2004/2005). Fertiliser inputs were converted to kg/ha for each element and are presented in Tables 13 and 14.

Seasonal inputs were calculated by summing all inputs from early post harvest to the following harvest. Fertiliser inputs varied considerably among orchards and seasons.

Fertiliser inputs were generally low. In durian, nitrogen inputs ranged from 0 to 158 kg/ha with the median input varying from 12.5 to 15.7 kg/ha. Phosphorous inputs ranged from 0 to 17 kg/ha with a median of 2.9 to 6.2 kg/ha. Potassium inputs ranged from 0 to 129 kg/ha with a median of 8.7 to 12.5 kg/ha. Fertiliser inputs of calcium and magnesium and the microelements were also similarly variable. Inputs of micro nutrient were generally negligible, however a few growers did apply micronutrients during the season.

In mangosteen nitrogen inputs ranged from 0 to 65.4 kg/ha with the median input varying from 0 to 10 kg/ha. Phosphorous inputs ranged from 0 to 117 kg/ha with a median of 0 to 3.8 kg/ga. Potassium inputs ranged from 0 to 332 kg/ha with a median of 0 to 17.6 kg/ha. Fertiliser inputs of calcium and magnesium varied more and the microelements were also similarly variable. Inputs of micro nutrient was generally negligible, however a few growers did apply micronutrients during the season.

The documentation of fertiliser inputs suggests that management of fertiliser inputs for both durian and mangosteen is a somewhat haphazard affair.

Table 13. Durian orchard fertiliser (foliar, granular, fertigated) inputs (kg/ha) over two seasons.

| Season | Grower | N | P | K | Ca | Mg | S | Zn | B | Cu | Mn | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2003/04 | DPI | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2003/04 | GBAD | 14.40 | 6.24 | 16.92 | 5.16 | 1.44 | 7.20 | 0.01 | 0.02 | 0.00 | 0.00 | 0.06 |
| 2003/04 | GBKDL | 35.00 | 17.25 | 38.15 | 51.05 | 3.90 | 31.00 | 0.07 | 0.05 | 0.00 | 0.06 | 0.38 |
| 2003/04 | GBKD M | 35.00 | 17.25 | 38.15 | 51.05 | 3.90 | 31.00 | 0.07 | 0.05 | 0.00 | 0.06 | 0.38 |
| 2003/04 | GDAD | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2003/04 | GSJD | 158.40 | 0.00 | 129.60 | 46.80 | 0.00 | 56.70 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2003/04 | GORD | 13.60 | 6.20 | 6.40 | 7.20 | 2.00 | 1.76 | 0.02 | 0.01 | 0.04 | 0.02 | 0.01 |
| 2003/04 | GEAD | 17.00 | 7.75 | 8.00 | 9.00 | 2.50 | 2.20 | 0.02 | 0.02 | 0.05 | 0.02 | 0.01 |
| Mean | | 34.18 | 6.84 | 29.65 | 21.28 | 1.72 | 16.23 | 0.02 | 0.02 | 0.01 | 0.02 | 0.10 |
| ***Median*** | | ***15.70*** | ***6.22*** | ***12.46*** | ***8.10*** | ***1.72*** | ***4.70*** | ***0.01*** | ***0.01*** | ***0.00*** | ***0.01*** | ***0.01*** |
| Min | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Max | | 158.40 | 17.25 | 129.60 | 51.05 | 3.90 | 56.70 | 0.07 | 0.05 | 0.05 | 0.06 | 0.38 |
| 2004/05 | DPI | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2004/05 | GBAD | 8.04 | 3.484 | 9.447 | 2.881 | 0.804 | 4.02 | 0.0067 | 0.0134 | 0 | 0 | 0.0335 |
| 2004/05 | GBKDL | 35.00 | 17.25 | 38.15 | 51.05 | 3.90 | 31.00 | 0.07 | 0.05 | 0.00 | 0.06 | 0.38 |
| 2004/05 | GBKD M | 35.00 | 17.25 | 38.15 | 51.05 | 3.90 | 31.00 | 0.07 | 0.05 | 0.00 | 0.06 | 0.38 |
| 2004/05 | GDAD | 5.1 | 2.325 | 2.4 | 2.7 | 0.75 | 0.66 | 0.006 | 0.0045 | 0.0135 | 0.006 | 0.0024 |
| 2004/05 | GSJD | 158.4 | 0 | 129.6 | 441.8 | 0 | 56.7 | 0 | 0 | 0 | 0 | 0 |
| 2004/05 | GORD | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2004/05 | GEAD | 17 | 7.75 | 8 | 9 | 2.5 | 2.2 | 0.02 | 0.015 | 0.045 | 0.02 | 0.008 |
| Mean | | 32.32 | 6.01 | 28.22 | 69.81 | 1.48 | 15.70 | 0.02 | 0.02 | 0.01 | 0.02 | 0.10 |
| ***Median*** | | ***12.52*** | ***2.90*** | ***8.72*** | ***5.94*** | ***0.78*** | ***3.11*** | ***0.01*** | ***0.01*** | ***0.00*** | ***0.00*** | ***0.01*** |
| Min | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Max | | 158.40 | 17.25 | 129.60 | 441.80 | 3.90 | 56.70 | 0.07 | 0.05 | 0.05 | 0.06 | 0.38 |

Table 14. Mangosteen orchard fertiliser (foliar, granular, fertigated) inputs (kg/ha) over two seasons.

| Season | Grower | N | P | K | Ca | Mg | S | Zn | B | Cu | Mn | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2003/2004 | GSPM | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2003/2004 | GWCM | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2003/2004 | GMVM | 13.16 | 5.58 | 19.20 | 2.16 | 0.61 | 3.83 | 0.02 | 0.03 | 0.00 | 0.02 | 0.06 |
| 2003/2004 | GBTM | 0.01 | 0.00 | 5.88 | 0.00 | 0.29 | 2.88 | 0.11 | 0.03 | 0.15 | 0.00 | 0.00 |
| 2003/2004 | GTUM | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2003/2004 | GSIM | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2003/2004 | GMUM | 52.60 | 166.33 | 344.77 | 353.30 | 5.18 | 313.62 | 0.20 | 0.07 | 0.00 | 0.00 | 0.17 |
| 2003/2004 | GMIM | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2003/2004 | GEFM | 0.00 | 0.00 | 41.50 | 0.00 | 0.00 | 17.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2003/2004 | GDAM | | | | | | | | | | | |
| 2003/2004 | DPI | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2003/2004 | GRKM | 0.75 | 0.63 | 8.70 | 1.93 | 0.15 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 |
| Mean | | 6.05 | 15.69 | 38.19 | 32.49 | 0.57 | 30.75 | 0.03 | 0.01 | 0.01 | 0.00 | 0.02 |
| Median | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Min | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Max | | 52.60 | 166.33 | 344.77 | 353.30 | 5.18 | 313.62 | 0.20 | 0.07 | 0.15 | 0.02 | 0.17 |
| 2004/2005 | GSPM | 11.63 | 0.00 | 41.00 | 1001.60 | 2.40 | 23.18 | 4.13 | 0.00 | 3.16 | 0.00 | 0.00 |
| 2004/2005 | GWCM | | | | | | | | | | | |
| 2004/2005 | GMVM | 9.12 | 3.82 | 9.74 | 1.08 | 0.30 | 8.57 | 0.00 | 0.01 | 1.00 | 0.01 | 0.02 |
| 2004/2005 | GBTM | 2.40 | 1.04 | 11.22 | 1.00 | 0.43 | 4.63 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 |
| 2004/2005 | GTUM | 2.65 | 0.34 | 4.71 | 160.00 | 100.01 | 1.08 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 |
| 2004/2005 | GSIM | 14.38 | 5.55 | 14.60 | 6.40 | 2.40 | 4.00 | 0.51 | 0.24 | 0.00 | 0.00 | 0.16 |
| 2004/2005 | GMUM | 135.87 | 219.98 | 576.13 | 873.89 | 13.55 | 271.77 | 1.01 | 0.20 | 0.00 | 0.00 | 0.50 |
| 2004/2005 | GMIM | 14.88 | 23.28 | 332.40 | 3.50 | 12.10 | 126.33 | 0.01 | 0.02 | 0.00 | 0.02 | 0.20 |
| 2004/2005 | GEFM | 0.00 | 0.00 | 41.50 | 0.00 | 0.00 | 17.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2004/2005 | GDAM | 15.00 | 6.50 | 17.63 | 6.25 | 1.50 | 5.00 | 0.01 | 0.03 | 0.00 | 0.00 | 0.19 |
| 2004/2005 | DPI | 19.92 | 8.63 | 23.41 | 7.14 | 1.99 | 9.96 | 0.02 | 0.03 | 0.00 | 0.00 | 0.08 |
| 2004/2005 | GRKM | 0.75 | 0.63 | 8.70 | 1.93 | 0.15 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 |
| Mean | | 20.60 | 24.52 | 98.28 | 187.53 | 12.26 | 42.95 | 0.52 | 0.05 | 0.38 | 0.00 | 0.11 |
| Median | | 11.63 | 3.82 | 17.63 | 6.25 | 1.99 | 8.57 | 0.01 | 0.01 | 0.00 | 0.00 | 0.03 |
| Min | | 0.00 | 0.00 | 4.71 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Max | | 135.87 | 219.98 | 576.13 | 1001.60 | 100.01 | 271.77 | 4.13 | 0.24 | 3.16 | 0.02 | 0.50 |

## Fruit nutrient content

Fruit (durian and mangosteen) were collected from a number of orchards for analysis. Tables 15 and 16 display the individual orchard fruit nutrient contents and the associated mean, minimum, maximum and standard error.

### Durian

Table 15. Nutrient concentration (dry weight basis) of durian fruit (petiole, skin, aril, seed). Data is presented as mean ± se and maximum and minimum values.

| | Fruit macro and micro nutrients | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Grower** | **N** | **P** | **K** | **Ca** | **Mg** | **Na** | **S** | **Zn** | **Fe** | **Cu** | **Mn** | **B** |
| DPI 0404 | 0.70 | 0.16 | 1.64 | 0.10 | 0.22 | 0.01 | 0.10 | 21.00 | 62.00 | 11.00 | 12.00 | 12.00 |
| DPI 0305 | 0.70 | 0.17 | 1.60 | 0.10 | 0.24 | 0.01 | 0.12 | 16.00 | 52.00 | 3.70 | 13.00 | 15.00 |
| Gbkdm 0405 | 0.90 | 0.17 | 1.98 | 0.09 | 0.20 | 0.01 | 0.11 | 12.00 | 33.00 | 8.80 | 14.00 | 22.00 |
| Gbkdl 0405 | 1.20 | 0.21 | 2.58 | 0.08 | 0.27 | 0.01 | 0.15 | 28.00 | 84.00 | 15.00 | 17.00 | 27.00 |
| Chanee 0405 | 1.10 | 0.19 | 2.57 | 0.19 | 0.27 | 0.01 | 0.01 | 22.00 | 62.00 | 12.00 | 20.00 | 27.00 |
| | | | | | | | | | | | | |
| Mean | 0.92 | 0.18 | 2.07 | 0.11 | 0.24 | 0.01 | 0.10 | 19.80 | 58.60 | 10.10 | 15.20 | 20.60 |
| SE | 0.10 | 0.01 | 0.21 | 0.02 | 0.01 | 0.00 | 0.02 | 2.73 | 8.27 | 1.89 | 1.46 | 3.08 |
| Min | 0.70 | 0.16 | 1.60 | 0.08 | 0.20 | 0.01 | 0.01 | 12.00 | 33.00 | 3.70 | 12.00 | 12.00 |
| Max | 1.20 | 0.21 | 2.58 | 0.19 | 0.27 | 0.01 | 0.15 | 28.00 | 84.00 | 15.00 | 20.00 | 27.00 |

### Mangosteen

Table 16. Nutrient concentration (dry weight basis) of mangosteen fruit (petiole, calyx, skin, aril, seed). Data is presented as mean ± se and maximum and minimum values.

| | Fruit macro and micro nutrients | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Grower** | **N** | **P** | **K** | **Ca** | **Mg** | **Na** | **S** | **Zn** | **Fe** | **Cu** | **Mn** | **B** |
| DPI 0405 | 0.50 | 0.07 | 1.02 | 0.14 | 0.06 | 0.04 | 0.15 | 21.00 | 64.00 | 1.50 | 41.00 | 8.80 |
| GSIM 0405 | 0.50 | 0.06 | 1.04 | 0.13 | 0.74 | 0.03 | 0.16 | 22.00 | 51.00 | 4.50 | 40.00 | 20.00 |
| GDAM 0405 | 0.30 | 0.06 | 0.83 | 0.09 | 0.07 | 0.03 | 0.10 | 28.00 | 130.00 | 1.00 | 19.00 | 16.00 |
| GBTM 0504 | 0.30 | 0.06 | 1.04 | 0.11 | 0.06 | 0.06 | 0.13 | 21.00 | 190.00 | 0.01 | 14.00 | 11.00 |
| GWCM 0304 | 0.40 | 0.07 | 0.88 | 0.08 | 0.08 | 0.01 | 0.11 | 20.00 | 280.00 | 5.70 | 7.60 | 17.00 |
| GMUM 0304 | 0.30 | 0.07 | 1.12 | 0.12 | 0.07 | 0.03 | 0.12 | 33.00 | 110.00 | 7.40 | 33.00 | 16.00 |
| GWCM 0305 | 0.40 | 0.06 | 1.02 | 0.12 | 0.08 | 0.01 | 0.13 | 61.00 | 68.00 | 3.40 | 19.00 | 16.00 |
| GSIM 0305 | 0.50 | 0.07 | 1.14 | 0.14 | 0.09 | 0.01 | 0.14 | 24.00 | 110.00 | 5.60 | 25.00 | 17.00 |
| GBTM 0405 | 0.60 | 0.07 | 1.13 | 0.14 | 0.07 | 0.02 | 0.14 | 19.00 | 40.00 | 0.01 | 14.00 | 16.00 |
| | | | | | | | | | | | | |
| Mean | 0.42 | 0.07 | 1.02 | 0.12 | 0.15 | 0.03 | 0.13 | 27.67 | 115.89 | 3.24 | 23.62 | 15.31 |
| SE | 0.04 | 0.00 | 0.04 | 0.01 | 0.07 | 0.01 | 0.01 | 4.42 | 25.73 | 0.91 | 3.99 | 1.12 |
| Min | 0.30 | 0.06 | 0.83 | 0.08 | 0.06 | 0.01 | 0.10 | 19.00 | 40.00 | 0.01 | 7.60 | 8.80 |
| Max | 0.60 | 0.07 | 1.14 | 0.14 | 0.74 | 0.06 | 0.16 | 61.00 | 280.00 | 7.40 | 41.00 | 20.00 |

## 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 (Table 17) were used to calculate nutrient removal based on an average fresh to dry weight ratio of 4.69 and 4.03 for durian and mangosteen respectively. Nutrient budget in its simplest form is the difference between nutrient inputs and crop removal, in this case expressed as the difference.

Table 17. Mean durian and mangosteen fruit nutrient concentrations (dry weight basis) used for nutrient removal calculations.

| **Whole Fruit Analysis** | | % N | % P | % K | % Ca | % Mg | % Na | % S | mg/kg Zn | mg/kg Fe | mg/kg Cu | mg/kg Mn | mg/kg B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Durian | Mean | 0.92 | 0.18 | 2.07 | 0.11 | 0.24 | 0.01 | 0.10 | 19.80 | 58.60 | 10.10 | 15.20 | 20.60 |
| Mangosteen | Mean | 0.42 | 0.07 | 1.02 | 0.12 | 0.15 | 0.03 | 0.13 | 27.67 | 115.89 | 3.24 | 23.62 | 15.31 |

## Durian

Nutrients budgets were calculated for participating growers who provided full details of their nutrient inputs and crop yields (Tables 18, 19 and 20)

Table 18. Nutrient inputs (kg/ha) and associated yields for durian orchards over two seasons. The record is based on fertiliser input data provided.

| Grower | Season | Yield kg/ha | N | P | K | Ca | Mg | S | Zn | Fe | Cu | Mn | B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GBAD | 2003/04 | 0 | 14.40 | 6.24 | 16.92 | 5.16 | 1.44 | 7.20 | 0.01 | 0.06 | 0.00 | 0.00 | 0.02 |
| GBAD | 2004/05 | 0 | 8.04 | 3.48 | 9.45 | 2.88 | 0.80 | 4.02 | 0.01 | 0.03 | 0.00 | 0.00 | 0.01 |
| GBKDL | 2003/04 | 2766 | 35.00 | 17.25 | 38.15 | 51.05 | 3.90 | 31.00 | 0.07 | 0.38 | 0.00 | 0.06 | 0.05 |
| GBKDL | 2004/05 | 4150 | 35.00 | 17.25 | 38.15 | 51.05 | 3.90 | 31.00 | 0.07 | 0.38 | 0.00 | 0.06 | 0.05 |
| GBKDM | 2003/04 | 0 | 35.00 | 17.25 | 38.15 | 51.05 | 3.90 | 31.00 | 0.07 | 0.38 | 0.00 | 0.06 | 0.05 |
| GBKDM | 2004/05 | 0 | 35.00 | 17.25 | 38.15 | 51.05 | 3.90 | 31.00 | 0.07 | 0.38 | 0.00 | 0.06 | 0.05 |
| GDAD | 2003/04 | | | | | | | | | | | | |
| GDAD | 2004/05 | 160 | 5.10 | 2.33 | 2.40 | 2.70 | 0.75 | 0.66 | 0.01 | 0.00 | 0.01 | 0.01 | 0.00 |
| GEAD | 2003/04 | 100 | 17.00 | 7.75 | 8.00 | 9.00 | 2.50 | 2.20 | 0.02 | 0.01 | 0.05 | 0.02 | 0.02 |
| GEAD | 2004/05 | 250 | 17.00 | 7.75 | 8.00 | 9.00 | 2.50 | 2.20 | 0.02 | 0.01 | 0.05 | 0.02 | 0.02 |
| GORD | 2003/04 | 2000 | 13.60 | 6.20 | 6.40 | 7.20 | 2.00 | 1.76 | 0.02 | 0.01 | 0.04 | 0.02 | 0.01 |
| GORD | 2004/05 | 10000 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| GSJD | 2003/04 | 0 | 158.40 | 0.00 | 129.60 | 46.80 | 0.00 | 56.70 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| GSJD | 2004/05 | 0 | 158.40 | 0.00 | 129.60 | 441.80 | 0.00 | 56.70 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Table 19. Nutrient exports (kg/ha) durian orchards over two seasons. The record is based on average tree yield data provided.

| Grower | Season | Yield kg/ha | N | P | K | Ca | Mg | S | Zn | Fe | Cu | Mn | B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GBAD | 2003/04 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| GBAD | 2004/05 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| GBKDL | 2003/04 | 2766 | 25.45 | 4.98 | 57.37 | 3.10 | 6.64 | 3.65 | 0.16 | 0.16 | 0.03 | 0.04 | 0.06 |
| GBKDL | 2004/05 | 4150 | 38.18 | 7.47 | 86.07 | 4.65 | 9.96 | 5.48 | 0.25 | 0.24 | 0.04 | 0.06 | 0.09 |
| GBKDM | 2003/04 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| GBKDM | 2004/05 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| GDAD | 2003/04 | | | | | | | | | | | | |
| GDAD | 2004/05 | 160 | 1.47 | 0.29 | 3.32 | 0.18 | 0.38 | 0.21 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 |
| GEAD | 2003/04 | 100 | 0.92 | 0.18 | 2.07 | 0.11 | 0.24 | 0.13 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 |
| GEAD | 2004/05 | 250 | 2.30 | 0.45 | 5.19 | 0.28 | 0.60 | 0.33 | 0.01 | 0.01 | 0.00 | 0.00 | 0.01 |
| GORD | 2003/04 | 2000 | 18.40 | 3.60 | 41.48 | 2.24 | 4.80 | 2.64 | 0.12 | 0.12 | 0.02 | 0.03 | 0.04 |
| GORD | 2004/05 | 10000 | 92.00 | 18.00 | 207.40 | 11.20 | 24.00 | 13.20 | 0.59 | 0.59 | 0.10 | 0.15 | 0.21 |
| GSJD | 2003/04 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| GSJD | 2004/05 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Table 20. The differences between nutrient inputs and yield (kg/ha) for durian orchards over two seasons. The calculation is based on fertiliser input and average tree yield data provided.

| Grower | Season | Yield kg/ha | N | P | K | Ca | Mg | S | Zn | Fe | Cu | Mn | B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GBAD | 2003/04 | 0 | 14.40 | 6.24 | 16.92 | 5.16 | 1.44 | 7.20 | 0.01 | 0.06 | 0.00 | 0.00 | 0.02 |
| GBAD | 2004/05 | 0 | 8.04 | 3.48 | 9.45 | 2.88 | 0.80 | 4.02 | 0.01 | 0.03 | 0.00 | 0.00 | 0.01 |
| GBKDL | 2003/04 | 2766 | 9.55 | 12.27 | -19.22 | 47.95 | -2.74 | 27.35 | -0.10 | 0.21 | -0.02 | 0.02 | -0.01 |
| GBKDL | 2004/05 | 4150 | -3.18 | 9.78 | -47.92 | 46.40 | -6.06 | 25.52 | -0.18 | 0.13 | -0.04 | 0.00 | -0.03 |
| GBKDM | 2003/04 | 0 | 35.00 | 17.25 | 38.15 | 51.05 | 3.90 | 31.00 | 0.07 | 0.38 | 0.00 | 0.06 | 0.05 |
| GBKDM | 2004/05 | 0 | 35.00 | 17.25 | 38.15 | 51.05 | 3.90 | 31.00 | 0.07 | 0.38 | 0.00 | 0.06 | 0.05 |
| GDAD | 2003/04 | | | | | | | | | | | | |
| GDAD | 2004/05 | 160 | 3.63 | 2.04 | -0.92 | 2.52 | 0.37 | 0.45 | 0.00 | -0.01 | 0.01 | 0.00 | 0.00 |
| GEAD | 2003/04 | 100 | 16.08 | 7.57 | 5.93 | 8.89 | 2.26 | 2.07 | 0.01 | 0.00 | 0.04 | 0.02 | 0.01 |
| GEAD | 2004/05 | 250 | 14.70 | 7.30 | 2.82 | 8.72 | 1.90 | 1.87 | 0.01 | -0.01 | 0.04 | 0.02 | 0.01 |
| GORD | 2003/04 | 2000 | -4.80 | 2.60 | -35.08 | 4.96 | -2.80 | -0.88 | -0.10 | -0.11 | 0.02 | -0.01 | -0.03 |
| GORD | 2004/05 | 10000 | -92.00 | -18.00 | -207.40 | -11.20 | -24.00 | -13.20 | -0.59 | -0.59 | -0.10 | -0.15 | -0.21 |
| GSJD | 2003/04 | 0 | 158.40 | 0.00 | 129.60 | 46.80 | 0.00 | 56.70 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| GSJD | 2004/05 | 0 | 158.40 | 0.00 | 129.60 | 441.80 | 0.00 | 56.70 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Note: Negative underlined values represent situations where nutrients exported in fruit exceed inputs from fertilisers.

In most cases inputs exceed exports with nutrient exports exceeding inputs in a few cases but most pointedly when the seasonal yield was high (10,000 kg/ha).

## Mangosteen

Nutrients budgets were calculated for participating growers who provided full details of their nutrient inputs and crop yields (Tables 21, 22 and 23)

Table 21. Nutrient inputs (kg/ha) and associated yields for mangosteen orchards over two seasons. The record is based on fertiliser input data provided.

| Grower | Season | Yield kg/ha | N | P | K | Ca | Mg | S | Zn | Fe | Cu | Mn | B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GBTM | 2003/04 | 279 | 0.01 | 0.00 | 5.88 | 0.00 | 0.29 | 2.88 | 0.11 | 0.00 | 0.15 | 0.00 | 0.03 |
| GBTM | 2004/05 | 706 | 2.40 | 1.04 | 11.22 | 1.00 | 0.43 | 4.63 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 |
| GDAM | 2003/04 | | | | | | | | | | | | |
| GDAM | 2004/05 | 590 | 15.00 | 6.50 | 17.63 | 6.25 | 1.50 | 5.00 | 0.01 | 0.19 | 0.00 | 0.00 | 0.03 |
| GEFM | 2003/04 | 0 | 0.00 | 0.00 | 41.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| GEFM | 2004/05 | 0 | 0.00 | 0.00 | 41.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| GMIM | 2003/04 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| GMIM | 2004/05 | 0 | 14.88 | 23.28 | 332.40 | 3.50 | 12.10 | 126.33 | 0.01 | 0.20 | 0.00 | 0.02 | 0.02 |
| GMUM | 2003/04 | 1660 | 52.60 | 166.33 | 344.77 | 353.30 | 5.18 | 313.62 | 0.20 | 0.17 | 0.00 | 0.00 | 0.07 |
| GMUM | 2004/05 | 0 | 135.87 | 219.98 | 576.13 | 873.89 | 13.55 | 271.77 | 1.01 | 0.50 | 0.00 | 0.00 | 0.20 |
| GRKM | 2003/04 | 50 | 0.75 | 0.63 | 8.70 | 1.93 | 0.15 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 |
| GRKM | 2004/05 | 180 | 9.26 | 0.73 | 14.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| GSIM | 2003/04 | 6383 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| GSIM | 2004/05 | 700 | 2.65 | 0.34 | 4.71 | 160.00 | 100.01 | 1.08 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 |
| GSPM | 2003/04 | | | | | | | | | | | | |
| GSPM | 2004/05 | 1330 | 11.63 | 0.00 | 41.00 | 1001.60 | 2.40 | 23.18 | 4.13 | 0.00 | 3.16 | 0.00 | 0.00 |
| GTUM | 2003/04 | | | | | | | | | | | | |
| GTUM | 2004/05 | 335 | 2.65 | 0.34 | 4.71 | 160.00 | 100.01 | 1.08 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 |

Table 22. Nutrient exports (kg/ha) for mangosteen orchards over two seasons. The record is based on average tree yield data provided.

| Grower | Season | Yield kg/ha | N | P | K | Ca | Mg | S | Zn | Fe | Cu | Mn | B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GBTM | 2003/04 | 279 | 0.29 | 0.05 | 0.71 | 0.08 | 0.10 | 0.09 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 |
| GBTM | 2004/05 | 706 | 0.74 | 0.11 | 1.79 | 0.21 | 0.26 | 0.23 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 |
| GDAM | 2003/04 | | | | | | | | | | | | |
| GDAM | 2004/05 | 590 | 0.62 | 0.10 | 1.50 | 0.17 | 0.21 | 0.19 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 |
| GEFM | 2003/04 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| GEFM | 2004/05 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| GMIM | 2003/04 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| GMIM | 2004/05 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| GMUM | 2003/04 | 1660 | 1.74 | 0.27 | 4.22 | 0.49 | 0.60 | 0.54 | 0.01 | 0.05 | 0.00 | 0.01 | 0.01 |
| GMUM | 2004/05 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| GRKM | 2003/04 | 50 | 0.05 | 0.01 | 0.13 | 0.01 | 0.02 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| GRKM | 2004/05 | 180 | 0.19 | 0.03 | 0.46 | 0.05 | 0.07 | 0.06 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 |
| GSIM | 2003/04 | 6383 | 6.68 | 1.04 | 16.21 | 1.88 | 2.32 | 2.07 | 0.04 | 0.18 | 0.01 | 0.04 | 0.02 |
| GSIM | 2004/05 | 700 | 0.73 | 0.11 | 1.78 | 0.21 | 0.25 | 0.23 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 |
| GSPM | 2003/04 | | | | | | | | | | | | |
| GSPM | 2004/05 | 1330 | 1.39 | 0.22 | 3.38 | 0.39 | 0.48 | 0.43 | 0.01 | 0.04 | 0.00 | 0.01 | 0.01 |
| GTUM | 2003/04 | | | | | | | | | | | | |
| GTUM | 2004/05 | 335 | 0.35 | 0.05 | 0.85 | 0.10 | 0.12 | 0.11 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 |

Table 23. The differences between nutrient inputs and yield (kg/ha) for mangosteen orchards over two seasons. The calculation is based on fertiliser input and average tree yield data provided.

| Grower | Season | Yield kg/ha | N | P | K | Ca | Mg | S | Zn | Fe | Cu | Mn | B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GBTM | 2003/04 | 279 | -0.28 | -0.05 | 5.17 | -0.08 | 0.19 | 2.79 | 0.11 | -0.01 | 0.15 | 0.00 | 0.03 |
| GBTM | 2004/05 | 706 | 1.66 | 0.93 | 9.43 | 0.79 | 0.18 | 4.40 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 |
| GDAM | 2003/04 | | | | | | | | | | | | |
| GDAM | 2004/05 | 590 | 14.38 | 6.40 | 16.13 | 6.08 | 1.29 | 4.81 | 0.01 | 0.17 | 0.00 | 0.00 | 0.02 |
| GEFM | 2003/04 | 0 | 0.00 | 0.00 | 41.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| GEFM | 2004/05 | 0 | 0.00 | 0.00 | 41.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| GMIM | 2003/04 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| GMIM | 2004/05 | 0 | 14.88 | 23.28 | 332.40 | 3.50 | 12.10 | 126.33 | 0.01 | 0.20 | 0.00 | 0.02 | 0.02 |
| GMUM | 2003/04 | 1660 | 50.86 | 166.06 | 340.55 | 352.81 | 4.58 | 313.08 | 0.19 | 0.12 | 0.00 | -0.01 | 0.06 |
| GMUM | 2004/05 | 0 | 135.87 | 219.98 | 576.13 | 873.89 | 13.55 | 271.77 | 1.01 | 0.50 | 0.00 | 0.00 | 0.20 |
| GRKM | 2003/04 | 50 | 0.70 | 0.62 | 8.57 | 1.91 | 0.13 | -0.02 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 |
| GRKM | 2004/05 | 180 | 9.07 | 0.70 | 13.63 | -0.05 | -0.07 | -0.06 | 0.00 | -0.01 | 0.00 | 0.00 | 0.00 |
| GSIM | 2003/04 | 6383 | -6.68 | -1.04 | -16.21 | -1.88 | -2.32 | -2.07 | -0.04 | -0.18 | -0.01 | -0.04 | -0.02 |
| GSIM | 2004/05 | 700 | 1.92 | 0.23 | 2.94 | 159.79 | 99.75 | 0.86 | 0.00 | -0.02 | 0.00 | 0.00 | 0.00 |
| GSPM | 2003/04 | | | | | | | | | | | | |
| GSPM | 2004/05 | 1330 | 10.23 | -0.22 | 37.62 | 1001.21 | 1.92 | 22.74 | 4.12 | -0.04 | 3.16 | -0.01 | -0.01 |
| GTUM | 2003/04 | | | | | | | | | | | | |
| GTUM | 2004/05 | 335 | 2.30 | 0.29 | 3.86 | 159.90 | 99.88 | 0.97 | 0.00 | -0.01 | 0.00 | 0.00 | 0.00 |

Note: Negative underlined values represent situations where nutrients exported in fruit exceed inputs from fertilisers.

In most cases inputs exceed exports with nutrient exports exceeding inputs in a few cases but most pointedly when the seasonal yield was high (6,383 kg/ha).

# Discussion

## Objectives

A survey of leaf and soil nutrition of durian and mangosteen orchards in the wet tropics of north Queensland will;

1. develop recommendations for a standard leaf sampling technique based on minimum coefficient of variation of samples.
2. develop recommendations for a desired nutrient range for durian and mangosteen trees grown in the wet tropics of north Queensland.
3. test for a relationship between tree nutrient status and productivity
4. improve understanding of the effect of micro-climate within north Queensland on tree phenology.
5. develop industry awareness of the relationship between fertiliser inputs, tree nutrient status, tree phenology and yield.

The discussion will apply directly to the above objectives.

### Objective 1

*Develop recommendations for a standard leaf sampling technique based on minimum coefficient of variation of samples.*

As detailed in the literature review, there is no ideal leaf age for sampling all nutrients. Young immature leaves are generally the most sensitive for nutrients that are immobile (Ca, B, Mn and Fe) or variably mobile (S, Cu and Zn) while older leaves are the most sensitive for those, which are phloem mobile (N, P, K and at times Mg).

Durian

In durian, trees flush actively and non synchronously throughout the year with only short periods, usually associated with dry cool spring/early summer, when leaf shoots are dormant (Diczbalis *et al.* 2004). This was confirmed during this project. The durian tree and its continuous non-synchronous flushing habit present a challenge to leaf nutrient sampling. Previous work by Lim *et a*l. (1999) in the Northern Territory reported that the preferred sampling method was taking the 5$^{th}$ and 6$^{th}$ mature green leaves from the shoot tip, while Poovarodun *et al.* (2001) showed that N, P and K decreased with leaf age while Ca, Mg, Fe and Mn increased with leaf age. Their preferred sampling target was leaves that are 5-7 months old which generally occurred between October and December in the northern hemisphere (April to June in the southern hemisphere). We chose a compromise between the two recommendations which was the middle leaf pair of the latest mature green flush or the last two mature green leaves before the current immature flush. These leaves are readily identifiable (Plate 1). Ten leaf pairs were sampled per tree.

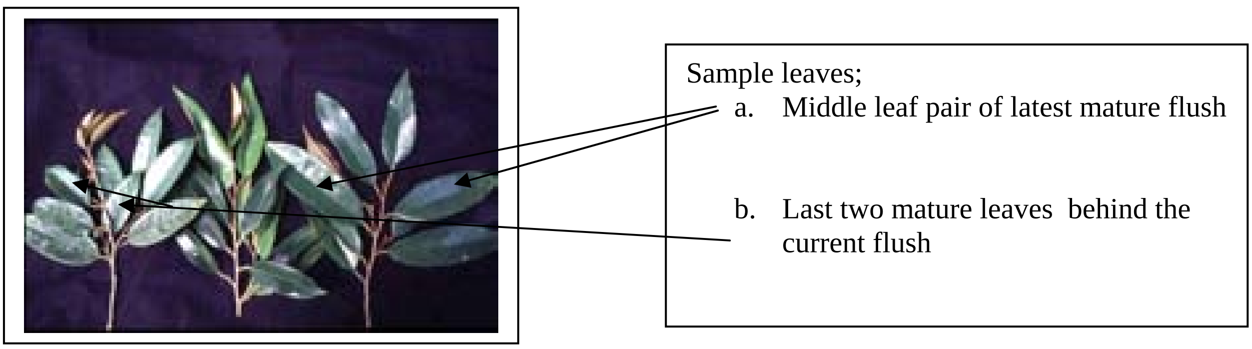
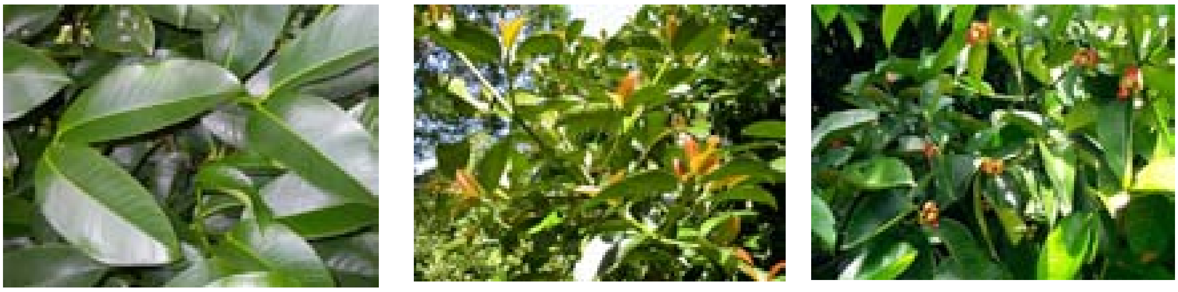



Plate 1. Durian Flush stages, from left to right (new flush, maturing flush and mature flush)

The fruit filling sampling (February and April) was the phenological stage at which six of thirteen elements showed the least variation (Table 9). A comparison of project nutrient standard with those from the NT and Southeast Asia suggest that standards for north Queensland are similar to those developed for other localities with some regional differences (Table 24).

Mangosteen

In mangosteen leaf flushing is less frequent and generally more synchronous within the tree and between trees within the same planting block. Leaf flush on any single branch occurs once or twice per year with a pair of leaves emerging simultaneously from the shoot apex. The mangosteen is relatively easy to leaf sample with clear dormant periods occurring. Sampling protocols are sparse. Ludders and Lim (1998) utilised the third expanded pair of leaves from the terminal bud, collecting from several branches around the tree. Poovarodom *et al.* (2002) reported that minimum variation in nutrient concentrations occurred over a wide range of sampling dates, however, with regard to a practical time of sampling they suggested leaves 8 to 10 months old should be sampled which usually occurs after fruit harvest. We chose the youngest mature green leaf, which is easily recognised (Plate 2). Four leaves were sampled per tree.



a. b. c

Plate 2. Mangosteen nutrient sampling leaf; a. youngest mature flush at terminal, b. youngest mature flush behind flush and c. youngest mature leaf behind flower or fruit.

The fruit sampling period (February and April) was the period when 11 of 13 elements showed the least variation (Table 10). A comparison of project nutrient standard with those from the NT and Southeast Asia suggest that standards for north Queensland are similar to those developed for other localities with some regional differences (Table 24).

Table 24. Published durian and mangosteen nutrient standards compared with project standards for north Queensland

| Comments | N % | P % | K % | Ca %a | Mg % | S % | Fe mg/kg | Mn mg/kg | Zn mg/kg | Cu mg/kg | B mg/kg | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Durian** | | | | | | | | | | | | |
| Thailand cv. Monthong | 2.0-2.4 | 0.15-0.25 | 1.5-2.5 | 1.7-2.5 | 0.25-0.50 | na | 40-150 | 50-120 | 10-30 | 10-25 | na | Poovarodom, S et al (2001) |
| Tahiland, cv. Monthong | 2.06-2.18 | 0.14-0.21 | 1.55-1.71 | 1.58-1.94 | 0.21-0.30 | na | na | na | 9.84-24.54 | na | na | Poovarodom and Chatupote (2002) |
| Malaysia | 1.8-2.3 | 0.12-0.25 | 1.6-2.2 | 0.9-1.8 | 0.25-0.50 | na | 50-150 | 25-50 | 15-40 | 6-10 | 15-80 | Zakarai, 1994 |
| Australia, NT | 1.58-1.98 | 0.18-0.22 | 1.48-1.96 | 1.11-1.88 | 0.83-1.13 | na | 15.02-30.86 | 6.25-27.65 | 11.92-14.64 | 5.82-12.47 | 33.29-38.52 | Lim et al. (1999) |
| **Australia, north Queensland. Fruit set and filling** | **1.95-2.13** | **0.23-0.25** | **1.56-1.76** | **1.40-1.59** | **0.61-0.69** | **0.23-0.25** | **53-69** | **46-62** | **12-14** | **22-84** | **37-47** | **Diczbalis and Westerhuis (2005)** |
| **Mangosteen** | | | | | | | | | | | | |
| Australia, Northern Territory | 1.14 | 0.06 | 0.76 | 1.20 | 0.26 | 0.32 | 95.2 | 166.3 | 42.24 | 11.17 | 86.99 | Luders and Lim (1998) |
| Cote d'Ivoire | 1.40 | 0.08 | 1.10 | 0.88 | 0.15 | na | 32.00 | 283.00 | 20.00 | 9.00 | na | Marchal (1972) |
| Thailand | 1.34 | 0.07 | 0.83 | 1.19 | 0.17 | na | 127.6 | 189.9 | 27.5 | 15.7 | na | Poovarodom et al (2002) |
| **Australia, north Queensland. Fruit set and filling** | **1.36-1.43** | **0.10-0.12** | **1.18-1.29** | **1.07-1.16** | **0.17-0.19** | **0.34-0.36** | **27-32** | **155-253** | **20-27** | **11-30** | **41-48** | **Diczbalis and Westerhuis (2005)** |

### Objective 2

*Develop recommendations for a desired nutrient range for durian and mangosteen trees grown in the wet tropics of north Queensland.*

Leaf Sampling

Tables 9 and 10 clearly set out the leaf nutrient sampling range for three major phenological periods (flowering, fruit set and filling, postharvest) for durian and mangosteen. Our preferred sampling time and hence leaf nutrient standard is between fruit set and filling because of the low CVs recorded while sampling during this period. However, this does not rule out sampling in other periods, but the nutrient ranges will differ and generally be wider than those chosen for the ideal sampling time.

Soil Sampling

Soil sample mean and ranges and comparison with optimum ranges in sub-tropical climates are clearly identified in Tables 11 and 12 for durian and mangosteen respectively. A summary range for both crops is shown below in Table 25.

Table 25. Recommended appropriate soil nutrient ranges for durian and mangosteen grown in far north Queensland.

| **Nutrient** | **Optimum Range** |
|---|---|
| pH (1:5 water) | 5.5-6.5 |
| Organic carbon (Walkley-Black) | 1.5-4% |
| Electrical conductivity (1:5 aqueous extract) | < 1 dS/m |
| Chloride (1:5 aqueous extract) | < 200 mg/kg |
| Sodium (exchangeable) | < 0.5 meq/100 g |
| Nitrate nitrogen | 5-50 mg/kg |
| Phosphorus (Colwell) | 50-200 mg/kg |
| Potassium (exchangeable) | 0.2-1.0 meq/100 g |
| Calcium (exchangeable) | 2.8–3.5 meq/100 g |
| Magnesium (exchangeable) | 0.8–2.0 meq/100 g |
| Copper (DPTA) | 1-4 mg/kg |
| Zinc (DPTA) | 2-15 mg/kg |
| Manganese (DPTA) | 10-50 mg/kg |
| Boron (hot calcium chloride) | 0.5-1 mg/kg |
| Typical CEC and Cation Balance | |
| CEC | 5-7 (meq/100g) |
| Ca | 60-70% |
| Mg | 18-20% |
| K | 5-7% |
| Na | 1-1.5% |
| Al | 3-12% |

### Objective 3

*Test for a relationship between tree nutrient status and productivity*

Yields in both durian and mangosteen were erratic and differed widely over two seasons despite the similarity in leaf nutrient status of orchards. For durian there was no relationship between tree nutritional status and productivity. Durian yields in this survey ranged fro 0 to 10,000 kg/ha with the average yield over two seasons being a low 1,500 kg/ha or approximately 12 kg/tree. In mangosteen yields ranged from 0 to 6,383 kg/ha over the two seasons with the average yields being a low 814 kg/ha or approximately 4.4 kg/tree.

Poor or non existing relationships between yield and leaf nutrient levels are not unusual; Poovarodom *et al.* (2002) stated that there was no relationship between leaf nutrient concentration and yield in 15

Thai durian orchards despite tree yields ranging from 0 to 350 kg/tree. Poovarodoom *et al*. (2002b) carried out similar work in mangosteen but only on 4 orchards. Although yields were not reported the authors comment that orchard 3 was the highest yielding orchard despite low leaf K levels relative to the three other orchards. In longan and rambutan (Diczbalis and Alvero, 2005) were unable to identify any direct links between tree nutritional status, fertiliser inputs and yield. This suggests that within the range of nutrient status observed other factors such as management practices and climate play a more important role in flowering and subsequent yield.

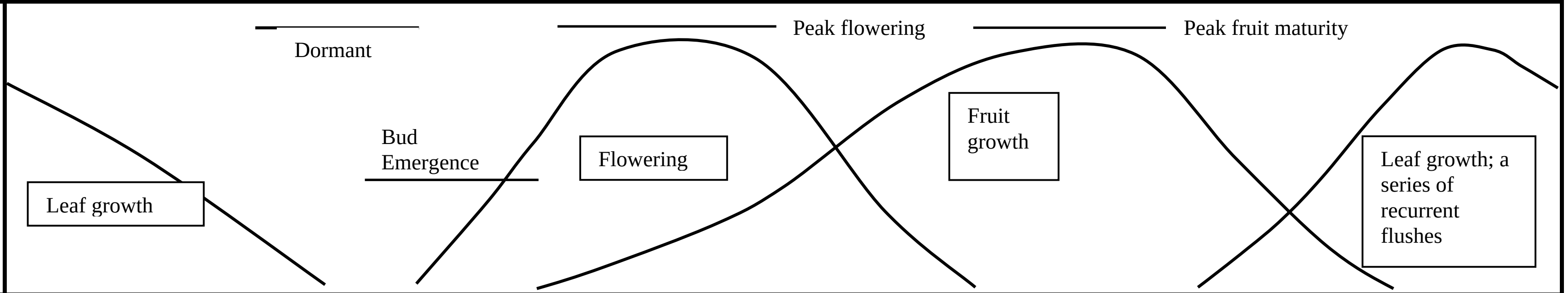
## Objective 4

*Improve understanding of the effect of micro-climate within north Queensland on tree phenology.*

Climate has an overriding affect on flowering in both durian and mangosteen. Seasonal drought and tree vegetative dormancy are believed to be important precursors to flowering. Nakasone and Paull (1998) have diagrammatically shown the sequence of phenological and climatic events required to maximise flowering. Our phenology surveys show that a similar sequence of events are required in north Queensland with flowering generally occurring from early to late spring following a period with less rainfall, increasing temperatures and higher solar radiation levels. What is not known is whether drought is responsible for flower induction or whether leaf dormancy linked to low winter temperatures and low soil moisture is the main flowering trigger. Flowering failure or poor flowering is commonly reported in north Queensland and may be linked to continuous wet conditions which occur in some years which promote additional vegetative growth. We have developed draft management calendars for both durian and mangosteen (Figures 19 and 20) which are linked to natural phenological patterns. Targeted irrigation and nutrition management although not inducing flowering in themselves may assist flowering to occur even in “off’ years.

## Draft Durian Management Calender – Wet Tropics

Crop Phenology

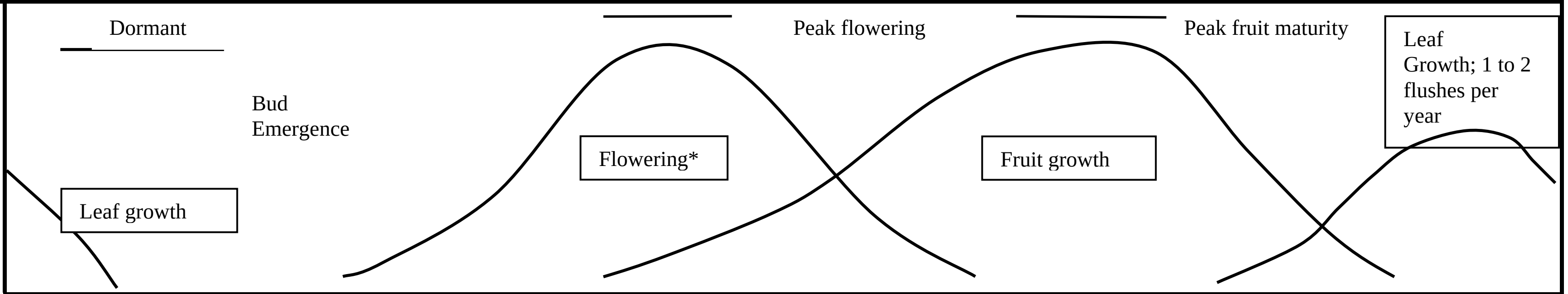



| | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fertiliser | | | | | | | | | | | | | |
| N | | | | | | Majority of N to be applied during fruit filling and immediately post harvest | | | | | | | |
| P | | | | | | | | | | | | | |
| 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 | | | Optional | | | | Early to mid fruit set | | | | | | |
| Soil Analysis | | | Optional | | | | Early to mid fruit set | | | | | | |
| Irrigation | | Withdraw if possible | | Critical time to maintain soil moisture. 30 mm/wk during winter, 50 mm/wk during summer | | | | | | | | | |
| Pruning | | | | | | | | | | | | Internal pruning | |
| | Major branch removal, if necessary and internal pruning is best done in winter to minimise regrowth. | | | | | | | | | | | | |

Figure 19. Durian management calendar in the wet tropics region of north Queensland (Daintree to Murray Upper)

Draft Mangosteen 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 | | | | Optional | | | | Early fruit filing | | | | | |
| Soil Analysis | | | | Optional | | | | Early fruit filling | | | | | |
| Irrigation | | Withdraw if possible | | Critical time to maintain soil moisture. 30 mm/wk during winter, 50 mm/wk during summer | | | | | | | | | |
| Pruning | | Major branch removal | | | | | | | | | | Internal leaf and branch removal | |
| | Major branch removal, if necessary, is best done in winter to minimise regrowth | | | | | | | | | | | | |

* - Note, the flowering flush can be the main vegetative flush for the season, particularly in non fruiting trees and trees which have failed to flower.

Figure 20. Mangosteen management calendar in the wet tropics region of north Queensland (Daintree to Murray Upper)

## Objective 5

*Develop industry awareness of the relationship between fertiliser inputs, tree nutrient status, tree phenology and yield.*

Fertiliser management alone does not influence the productivity of durian and mangosteen particularly when trees are already at a high nutritional plain. Leaf nutrient concentrations in north Queensland orchards although differing slightly from nutrient standards set in South east Asia are comparable. This suggests that our durian and mangosteen orchards benefit from higher management inputs, in particular fertiliser and irrigation, and hence are comparable to the best managed overseas orchards.

In well managed orchards fertiliser inputs need to be based on a nutrition budget because flowering and subsequent productivity of nutrionally well managed durian and mangosteen are more dependent on climate then on nutrient levels. A nutrition budget will ensure that fertiliser inputs are rational and not based on the philosophy that “more is better”.

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 25, Table 26). Fruit harvest and removal is prime source of nutrient loss, as shown in the above formula. Fortunately it is easily calculated.

Table 25. Mean durian fruit nutrient analysis and amount of element removed (kg/tree) for various tree yields. Note FW/DW (fresh weight/dry weight ratio) = 4.69.

| Fruit nutrient | % | % | % | % | % | % | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg |
|---|---|---|---|---|---|---|---|---|---|---|---|
| concentration | N | P | K | Ca | Mg | S | Zn | Fe | Cu | Mn | B |
| Dry weight basis | 0.92 | 0.18 | 2.07 | 0.11 | 0.24 | 0.1 | 19.8 | 58.6 | 10.1 | 15.2 | 20.6 |
| Yield | | | | | | kg/tree | | | | | |
| kg/tree | N | P | K | Ca | Mg | S | Zn | Fe | Cu | Mn | B |
| 10 | 19.6 | 3.8 | 44.1 | 2.3 | 5.1 | 2.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| 20 | 39.2 | 7.7 | 88.3 | 4.7 | 10.2 | 4.3 | 0.1 | 0.2 | 0.0 | 0.1 | 0.1 |
| 50 | 98.1 | 19.2 | 220.7 | 11.7 | 25.6 | 10.7 | 0.2 | 0.6 | 0.1 | 0.2 | 0.2 |
| 100 | 196.2 | 38.4 | 441.4 | 23.5 | 51.2 | 21.3 | 0.4 | 1.2 | 0.2 | 0.3 | 0.4 |
| 200 | 392.3 | 76.8 | 882.7 | 46.9 | 102.3 | 42.6 | 0.8 | 2.5 | 0.4 | 0.6 | 0.9 |
| 1000 | 1961.6 | 383.8 | 4413.6 | 234.5 | 511.7 | 213.2 | 4.2 | 12.5 | 2.2 | 3.2 | 4.4 |

Table 26. Mean mangosteen fruit nutrient analysis and amount of element removed (kg/tree) for various tree yields. Note FW/DW (fresh weight/dry weight ratio) = 4.03.

| Fruit nutrient concentration Dry weight basis | % N | % P | % K | % Ca | % Mg | % S | mg/kg Zn | mg/kg Fe | mg/kg Cu | mg/kg Mn | mg/kg B |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.42 | 0.07 | 1.02 | 0.12 | 0.15 | 0.13 | 27.67 | 115.89 | 3.24 | 23.62 | 15.31 |
| Yield | | | | | | g/tree | | | | | |
| kg/tree | N | P | K | Ca | Mg | S | Zn | Fe | Cu | Mn | B |
| 10 | 10.4 | 1.7 | 25.3 | 3.0 | 3.7 | 3.2 | 0.1 | 0.3 | 0.0 | 0.1 | 0.0 |
| 20 | 20.8 | 3.5 | 50.6 | 6.0 | 7.4 | 6.5 | 0.1 | 0.6 | 0.0 | 0.1 | 0.1 |
| 50 | 52.1 | 8.7 | 126.6 | 14.9 | 18.6 | 16.1 | 0.3 | 1.4 | 0.0 | 0.3 | 0.2 |
| 100 | 104.2 | 17.4 | 253.1 | 29.8 | 37.2 | 32.3 | 0.7 | 2.9 | 0.1 | 0.6 | 0.4 |
| 200 | 208.4 | 34.7 | 506.2 | 59.6 | 74.4 | 64.5 | 1.4 | 5.8 | 0.2 | 1.2 | 0.8 |
| 1000 | 1042.2 | 173.7 | 2531.0 | 297.8 | 372.2 | 322.6 | 6.9 | 28.8 | 0.8 | 5.9 | 3.8 |

The order of nutrient removal for;

- durian fruit is N ≥ K > Ca > P > Mg > S > Mn > Fe > Zn > Cu >B.
- mangosteen fruit is K>N>Mg>S>Ca>P>Fe>Zn>Mn>B>Cu.

The more difficult issue is accounting for other forms of nutrient loss via leaching, runoff and volatilisation. 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 durian and mangosteen based on fruit nutrient concentrations and the above ‘other loss’ factors are shown in Table 27. No additional loss factors have been used for S and the micronutrients.

Table 27. Fruit nutrient loss (kg/tonne) and nutrient replacement based on generalised 'other loss' factors.

| | N | P | K | Ca | Mg | S | Zn | Fe | Cu | Mn | B |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Durian** | | | | | | | | | | | |
| Fruit loss (kg/tonne) | 2.0 | 0.4 | 4.4 | 0.2 | 0.5 | 0.2 | 0.004 | 0.012 | 0.002 | 0.003 | 0.004 |
| Other loss % | 40 | 80 | 30 | 10 | 25 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total replacement (kg/tonne) | 2.7 | 0.7 | 5.7 | 0.3 | 0.6 | 0.2 | 0.004 | 0.012 | 0.002 | 0.003 | 0.004 |
| **Mangosteen** | | | | | | | | | | | |
| Fruit loss (kg/tonne) | 1.0 | 0.2 | 2.5 | 0.3 | 0.4 | 0.3 | 0.007 | 0.029 | 0.001 | 0.006 | 0.004 |
| Other loss % | 40 | 80 | 30 | 10 | 25 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total replacement (kg/tonne) | 1.5 | 0.3 | 3.3 | 0.3 | 0.5 | 0.3 | 0.007 | 0.029 | 0.001 | 0.006 | 0.004 |

Hence for a high yielding durian crop crop (10 tonne/ha) the macronutrient inputs per hectare required to replace total nutrient loss are 27 kg N, 57 K, 7 kg P, 3 kg Ca, 6 kg Mg, 2 kg S. For micronutrients where no 'other loss' factors are available estimates of loss based on fruit nutrient content only are 0.12 kg Fe, 0.04 kg Zn and B, 0.03 kg Mn and 0.02 kg Cu.

Whereas for a high yielding mangosteen crop (8 tonne/ha) the macronutrient inputs per hectare required to replace total nutrient loss are 26.3 kg K, 11.7 kg N, 2.5 kg P, 2.6 kg Ca, 3.7 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 0.23 kg Fe, 0.06 Kg Zn, 0.05 kg Mn, 0.03 kg B and 0.01 kg Cu.

# Implications

Through this project durian and mangosteen researchers, extension officers, growers and associated industry organisations are now able to access an improved understanding of the effect of nutrition on yield and 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 management 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.

# Recommendations

Durian and Mangosteen 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.
- Further refine fertiliser input using the adjustment technique.

### ***The* adjustment *technique***

To make leaf and soil analysis information really useful, you must maintain and record your fertiliser program for several years. The program should have known rates of fertiliser and a set system of application times, because this technique is one of adjustment, up or down, based on long-term trends.

Changing the rate or timing constantly leaves no base line from which to adjust. The leaf and soil analysis indicates if the amount of fertiliser applied on a given block should be increased or decreased compared with the previous year. Without several years of records, the leaf and soil levels do not indicate the level of fertiliser to apply.

Recommendations based on one analysis are a good starting point but are only an educated guess based on local experience. They are not as good as the adjustment technique based on annual soil and leaf analysis and good records of fertiliser products, rates and timing.

Here is an example of the adjustment technique:

- In the past year you used 1.5 kg of potassium sulphate per tree and potassium leaf levels were 1.10%. You know you haven't used enough because the desired potassium leaf level in Mangosteen is between 1.18 and 1.29%. How much more potassium do you need?
- Until you have more experience with your soil types and climate, no exact amount can be recommended. The best approach is to increase the application rate in the coming year by 20% to 1.8 kg of potassium sulphate per tree.
- If in the next year the leaf sample analysis is 1.20% potassium, you will know you are near the right level. You could then increase the rate by say a further 10% to 2 kg per tree in that year. If the leaf potassium level exceeds 1.30%, drop the application rate by 5%.

Monitoring the nutrient status of the orchard is a valuable decision aid for fertiliser management. The adjustment technique is most useful in helping to decide whether to change a fertiliser program and by how much. It is the only method of gaining a customised fertiliser management system for each durian and mangosteen orchard.

Despite the cost of the analysis, the potential savings in costs and gains in yield and fruit quality are great. The analyses provide valuable feedback to remedy nutrient deficiencies and imbalances before they become obvious. The adjustment technique should be used in conjunction with the nutrient budget information. Primary fertiliser inputs should be based on crop load, further fertiliser inputs should be based on the adjustment technique.

# References

Almeyda N. and Martin, F.W. (1976). Cultivation of Neglected Tropical Fruits with Promise. Part 1. The Mangosteen. Agriculture research Service, USDA.

Annon. (1999). Durian. www.da.gov.ph/tips/durian.html

Baldock, J.A. and Skjemstad, J.O. (1999). Soil organic carbon/soil organic matter. In '*Soil Analysis an interpretation manual'* (Eds. K.I. Peverill, L.A. Sparrow and D.J. Reuter) CSIRO, Australia.

Bergmann, W. (1992). *Nutritional Disorders of Plants – developmental, visual and analytical diagnosis*. Gustav Fischer Verlag Jena, Stuttgart.

Boberg, J. and Dyberg, A. (2002). The effect of fertiliser regimes on mycorrhizal colonisation of mangosteen growing on an acid sulphate soils in southern Vietnam. Minor Field Studies – International Office. Swedish University of Agricultural Sciences, 194:44.

Brown, M.J. (1997). Durio – A Bibliographic Review. International Plant Genetic Resource Institute, New Delhi, India.

Catchpoole, D. and Bally, I. (1995). Mango Nutritional Investigations. Final Report FR/0034, Horticulture Research and Development Corporation.

Chaikiattiyos, S. (1992). Floral induction in tropical trees. PhD Thesis. Department of Botany. University of Queensland, Australia.

Chandraparnik, S., H. Hiranpradit, U. Punnachit and S. Salakpetch. 1992. Paclobutrazol influences flower induction in durian, *Durio zibethinus* Murr. Frontier in Tropical Fruit Research, Volume I. Acta Horticulturae No. 321, 282-290.

Chen et al. (2000). Silicon the Estranged Medium Element. Bulletin 341, University of Florida Extension Service.

Coronel, R.I. (1983). *Mangosteen*. In Promising Fruits of the Philippines. University of the Phillipines, Laguna.

Cresswell, G.C. (1989). Development of a leaf sampling technique and leaf standards for kiwifruit in New South Wales. *Australian Journal of Experimental Agriculture*, 29:411-417.

Diczbalis, Y. and Alvero, G. (2005). Nutrition Management of Australian Longan and Rambutan Orchards. Acta Horticulturae. 665:301-310.

Diczbalis, Y. et al. (2004). Durian tree phenology and the control of Phytophthora diseases using phosphonate trunk injection. In. Diversity and management of Phytophthora in Southeast Asia. Ed. A. Drenth and D.I. Guest, ACIAR. Pp. 206-216.

Downton, J., and Chacko, E. (1997). *Mangosteen*. In The New Rural Industries – A handbook for farmers and investors. RIRDC.

George, A.P., Nissen, R.J. and Broadley, R. (2001). Persimmon nutrition – A practical guide to improving fruit quality and production. Department of Primary Industries, Queensland.

Goenaga, R. and Rivera-Amador, E. (in print). Growth and nutrient uptake of mangosteen grown under shade. Journal of Agriculture of the University of Puerto Rico.

Grundon, N.J., Robson, A.D., Lambert, M.J. and Snowball, K.A. (1997). Nutrient deficiency and toxcicity symptoms. In '*Plant Analysis an interpretation manual'* (Eds. D.J. Reuter and J.B. Robinson) CSIRO, Australia.

Hassan, S. (19xx). Durian cultivation. Malaysian Agricultural Research and Development Institute. Fruit Research Branch, Mardi, Serdang.

Huett, D.O. and Dirou, J.F. (2000). An evaluation of the rationale for fertiliser management of tropical fruit crops. *Australian Journal of Experimental Agriculture*, 40:1137-1143.

Kanapathy, K. 1976. Guide to fertilizer use in peninsular Malaysia. Ministry of Agriculture and Rural Development Bulletin No. 143. Pages 88-90.

Khoi, B.X. and Tri, M.V. (2003). Fertilizer recommendations for sustainable production of orchard fruit in the South of Vietnam. Food and Fertiliser Technology Centre. www.fftc.agnet.org/library/article/eb535.html

Kostermans, A.J.G.H. (1958). The genus Durio Adans (Bombac,). *Reinwardtia* 4(3):357-460.

Loquias, Virgilio L., Pascua, Orlando C. and Cantila, Myrna S. (1996). Effect of Different Foliar Fertilizers and Quality of Durian Fruits.. Bureau of Plant Industry – Davao National Crop Research and Development Center (BPI-DNCRDC), Bago Oshiro, Davao **City,**

Lim, T.K. (1997). Boosting Durian Productivity. RIRDC Final Project Report, DNT-13A. Rural Industries Research and Development Corporation.

Lim,T.K., Luders, L. and Poffley, M. (1999). Seasonal changes in durian leaf and soil mineral nutrient element content.. *Journal of Plant Nutrition*. 22:657-667.

Macmillan, H.F (1991). Tropical planting and Gardening. 6$^{th}$ Edition ed. (H.S. Barlow, I. Enoch and R.A. Russel). United Selangor Press, K.L., Malaysia.

Mansfield, J. (1995). Control of production Patterns in Tropical Fruits – Part 4. Durian. Project Report DAQ116A, Rural Industries Research and Development Corporation.

Mansfield, J. (1995). Control of production Patterns in Tropical Fruits – Part 5. Mangosteen. Project Report DAQ116A, Rural Industries Research and Development Corporation.

Marchal, J. (1972). Premiers analyses foliaires du mangoustanier. Fruits 27:361-362.

Menzel, C.M., Barry, G.A. and Simpson, D.R. (1992). Observations on the concentrations of soil nutrients in lychee orchards in subtriopical Australia. *Journal of the South African Society of Horticultural Science*, 2:36-40.

Menzel, C.M., Carseldine, M.L., Haydon, G.F. and Simpson, D.R. (1992). A review of existing and proposed new leaf nutrient standards for lychee. *Scientia Horticulturae*, 49:33-53.

Menzel, C.M., Haydon, G.F., Doogan, V.J. and Simpson, D.R. (1993). New standard leaf nutrient concentrations for passionfruit based on seasonal phenology and leaf composition. *Journal of Horticultural Science*, 68:215-229.

Moody, P.W. and Aitken, R.L. (1996). Fertiliser management in tropical horticulture: Is it sustainable? In '*Proceedings of the third Australian Society of Horticultural Science and the first Australian Macadamia Society Research Conference*'. Broadbeach, Qld. (Eds. R.A. Stephenson and C.W. Winks) pp.109-115. ASHS Brisbane.

Moody, P.W., Reghenzani, J.R., Armour, J.D., Prove, B.G. and McShane, T.J. (1996). Nutrient balances and transport at farm scale – Johnstone River Catchment. In '*Proceedings of the Conference on Downstream Effects of Land Use*'. Rockhampton, 1995. (Eds. Ag Eyles, HM Hunter, GE Rayment) Department of Natural Resources Queensland.

Nakanone, H.Y. and Paull, R.E. (1998). *Mangosteen*. In Tropical Fruits, CABI International, NY, USA,

Nanthachai, S. (1994). *Introduction in* Durian: Fruit development, Postharvest Physiology, Handling and Marketing in ASEAN. Ed. (Sonthat Nanthachai). ASEAN Food Handling Bureau, KL, Malaysia

Ng, K.S. and Thamboo, S. (1967). Nutrient removal studies on Malayan fruits. Durian and rambutan. Malaysian Agricultural Journal, 46:164-182.

Nuntagij, I., Waijaroen, S., Lerdrat, P. (2002). The effect of fertigation rates on durian (durio zibethinus Murr.) yield in eastern Thailand. Paper 1909. In Proceedings of the 17th World Congress of Soil Sciences, 14-21 August 2002, Bangkok, Thailand.

Poovarodom, S. and Chatopte, W. (2002). Boundary line approach in specifying durian nutrient standards. Paper 2319. In Proceedings of the 17th World Congress of Soil Sciences, 14-21 August 2002, Bangkok, Thailand.

O' Farrell, P., Armour, J. and Reid, D. (1999). The effect of nitrogen on cashew in north Queensland. Rural Industries Research and Development Corporation. Project No. 00/24 – DAQ145A.

Poerwanto, R. (2002). Nurse stock Plant – A new technique to enhance mangosteen (*Garcinia mangostana*) growth. *Acta Horticulturae*. 575:751–756

Poovarodom, S., Kanyawangha, P., Lertrat, P. and Boonplang, N. (2002). Leaf age and position on mineral composition of mangosteen leaves. Paper 2272. In Proceedings of the 17th World Congress of Soil Sciences, 14-21 August 2002, Bangkok, Thailand.

Punnachit, U., Kwangthong, C. and Chandraparnik, S. (1992). Effect of plant growth regulators and fertiliser on leaf flushing and quality of durian. Acta Horticulturae 321:343-347.

Ramage, C.M., Sando, L., Peace, C.P., Carroll, B.J. and Drew, R.A. (2004). Genetic diversity revealed in the apomictic fruit species Garcinia mangostana L. (mangosteen). *Euphytica*, 136:1-10.

Rasiah, V. and Armour, J.D. (2001). Nitrate accumulation under cropping in the Ferrosols of Far North Queensalnd wet tropics. *Australian Journal of Soil Research*, 39:329-341.

Robinson, J.B. and McCarthy, M.G. (1985). Use of petiole analysis for assessment of vineyard nutrient status in the Barossa district of South Australia. *Australian Journal of Experimental Agriculture*, 25:231-240.

Rukayah, A. and Zabedah, M. (1992). Studies on the early growth of mangosteen (*Garcinia mangostana* L.). *Acta Horticulturae* 292:93-100.

Salafsky, N. 1994a. Drought in the rain forest: Effects of the 1991 El Nino-Southern oscillation event on a rural economy in West Kalimantan, Indonesia. Climatic Change 27: 373-396.

Salakpetch, S. (2000). Durian Production in Thailand. In Proceedings Tenth Annual International Tropical Fruit Conference, Hawaii tropical Fruit Growers, 20-22 October, Hilo, Hawaii.

Salakpetch, S. (2000). Mangosteen Production in Thailand. In Proceedings Tenth Annual International Tropical Fruit Conference, Hawaii tropical Fruit Growers, 20-22 October, Hilo, Hawaii.

Salisbury, F.B. and Ross C. (1969). Chapter 10. Mineral Nutrition in Plants. In '*Plant Physiology*'. Wadsworth Publishing Co.

Sdoodee, S. and Limpun-Udom, S. (2002). Effect of excess water on the incidence of translucent flesh disorder in mangosteen (*Garcinia mangostana* L.). In Proceedings of Tropical and subtropical fruit conference ed. R. Drew. *Acta Horticulturae* 575:813-820.

Sing, S., Krishnamurthi, S. and Katyal, S.L. (1963). Fruit culture n India. Indian Council of Agricultural Research, New Delhi.

Slack, J., Huett, D. and George, A. (1996). Fertilising low-chill stonefruit. NSW Agriculture; Alstonville.

Smith, F.W. and Loneragan, J.F. (1997). Interpretation of Plant Analysis: Concepts and Principles. In '*Plant Analysis an Interpretation Manual'* (Eds. D.J. Reuter and J.B. Robinson) CSIRO, Australia.

Subhadrabandhu,S., Schneeman, J.M.P., and Verheij, E.W.M. (1991). Durio zibethinus Murray. In Plant Resources of South-East Asia (PROSEA) Number 2. Edible Fruits and Nuts. Ed. E.W.M. Verheij and R.E. Coronel. Purdoc, Wageningen. Pp. 157-161.

Subhadrabandhu, S. and Ketsa, S. (2001). Durian – King of Tropical Fruit. Daphne Brassell Associates Ltd., Wellington.

Stephens, S.E. (1935). Some Tropical Fruits. 1. The Mangosteen. *Queensland Agricultural Journal*. Sep:346-348.

Tatt, O.H. (1976). Climatic changes in water balance and their effects on tropical flowering. *Planter, Kuala Lumpur* 52:174-179.

Uren, N.C. (1999). Manganese. In '*Soil Analysis an interpretation manual'* (Eds. K.I. Peverill, L.A. Sparrow and D.J. Reuter) CSIRO, Australia.

Watson, B.J. (1983). Durian. Fact Sheet No. 6. Rare Fruits Council of Australia.

Wong, W.W. (1993). The major fruits – an overview, in Fruits, Nuts and Spices, (ed.) W.W. Wong and A. Lamb. Department of Agriculture, Sabah.

Wong, W. (1993). The major Fruits – An Overview. In Fruits, Nuts and Spices. Ed. W.W. Wong and A. Lamb. Proceedings of In House workshop on Fruits, 24-26 October, 190, ARS, Tenom. Department of Agriculture, Sabah, Malaysia.

Yaacob, O. and Tindall, H.D. (1995). Mangosteen Cultivation. FAO Plant production and protection paper – 129. FAO, Rome. pp. 100.

Zappala, G., Zappala, A. and Diczbalis, Y. (2002). Durian Germplasm Evaluation for tropical Australia, Phase 1. Rural Industries Research and Development Corporation. Publication No. 02/091.