Longan

Improving Yield and Quality

A report for the Rural Industries Research and Development Corporation

by Yan Diczbalis

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Foreword

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

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

This publication (Part one – Longan) highlights the outcomes of an industry based leaf and soil nutrient and irrigation monitoring survey in Queensland longan orchards located from the Atherton Tableland region in north Queensland (17^{o}S) to Nambour in SE Queensland (27^{o}S). The report discusses the concept of a nutrient budget and presents irrigation management guidelines to assist the longan industry in the management of fertiliser and water inputs.

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

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

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Executive Summary

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

The origin of longan is still disputed with some authors limiting the area of origin to the mountain chain from Burma to southern China while others extend it to south west India and Sri Lanka (Wong and Ketsa, 1991). It is commonly grown in Thailand, Cambodia, Laos, Vietnam and Taiwan where it is a major commercial crop with strong intra and inter country demand. Hong Kong and Singapore are major outlets for longans. Trees were imported into Florida in the early 1900’s (Morton, 1987) and from there into Hawaii where it is grown commercially for export to mainland USA.

Emigrants of Chinese origin, in the late 1800’s or early 1900’s, most likely brought longans into Australia. Commercial plantings commenced in the 1970’s (Menzel and McConchie 1998). Twenty varieties have been imported into Australia and have undergone preliminary evaluation in the Atherton Tablelands region, west of Cairns (Winston and O’Farrell 1989). The longan industry in Australia with 34,000 trees in 1997 is distributed from northern New South Wales to Cape Tribulation in north Queensland (Anon 1998). Current plantings are reported to be in the vicinity of 45,000 trees and the annual production of 300-500 tonnes is valued at $2.0M (Neil Sing pers. Com. 2002). The main commercial varieties in Australia include, Kohala and Homestead (USA selections) Biew Kiew, Chompoo, Dang and Haew (Thai selections) (Anon 1998).

The Australian longan and rambutan industries, together with DPI, NT DPIF and RIRDC and other bodies have, over the last few years engaged in detailed assessments of industry research and development needs. Industry strategic plans have been developed for the longan industry (Anon 1998) and a commitment to support research has been made by the relevant organizations. The longan industry has identified nutrition and irrigation research as a priority issue.

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

This report details the findings of three years of study from July 1998 to May 2001. Through this project longan 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. Its important to note that all commercial orchards surveyed had relatively high leaf nutrient status and no unfertilised trees were included in the study. This suggests that within the range of nutrient status observed other factors such as pruning practices and climate play a more important role in flowering and subsequent yield. Despite the lack of relationship between nutrient status and yield, the survey indicated that high leaf N levels (N 2.0%) during the period leading up to flowering should be avoided because it may be detrimental to flowering and hence subsequent cropping.

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 ground waters.

Longan irrigation requirements during fruit filling were monitored at three sites and the crop factor (tree water requirements relative to evaporation) estimated as 0.83. Hence irrigation requirements can be calculated using a simple evaporation based calculation;

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

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

As an outcome of the project longan 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 longan yields in conjunction with fertiliser management records to validate the nutrient budget approach over a minimum of 5 seasons, to reduce the effects of climate and other management issues (eg. pruning) on yield.

1. Introduction

1.1 Background

The longan (*Dimocarpus longan* Lour.) is a fruit and member of the Sapindaceae family closely related to the lychee and rambutan. The longan tree can grow to 10 m in height and up to 14 m in width. The bark is smooth to rough, depending on origin, with thick and long, spreading, slightly drooping, heavily foliaged branches. The evergreen, alternate, pinnate leaves have 4 to 10 opposite leaflets. Leaf shape is elliptic, ovate-oblong or lanceolate, with pointed or blunt-tip; 10-20 cm long and 3.5-5 cm wide; leathery, wavy, glossy-green on the upper surface, grayish-green on the underside. New growth is red wine to pink coloured and quickly develops into light green as the leaves become fully formed. The flowers, white to pale-yellow in colour with 5 petals, are either staminate, pistillate or hermaphrodite and are borne in upright terminal panicles which range in size from 150 to 400 mm in length. The fruits, in drooping clusters, are round to oblong, 24 to 30 mm in diameter, sometimes with distinctive shoulders. The rind (pericarp) is thin, brittle, yellow-brown to dark brown and slightly rough in texture. The flesh (aril) is whitish, translucent, sweet and musky and easily separates from the seed. The seed (8-10 mm diameter) is round, dark black, shiny, with a circular white spot at the base, giving it the look of an eye. Hence in South East Asia the fruit is often referred to as "Dragons Eye" (Menzel *et al*. 1989, Nakasone and Paull 1998).

The origin of longan is still disputed with some authors limiting the area of origin to the mountain chain from Burma to southern China while others extend it to south west India and Sri Lanka (Wong and Ketsa, 1991). It is commonly grown in Thailand, Cambodia, Laos, Vietnam and Taiwan where it is a major commercial crop with strong intra and inter country demand. Hong Kong and Singapore are major outlets for longans. Trees were imported into Florida in the early 1900's (Morton, 1987) and from there into Hawaii where it is grown commercially for export to mainland USA.

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The project aims are to;

monitor changes in longan leaf and soil nutrient status over three seasons

measure grower fertiliser inputs in relation to the above

assess the effect of nutrient status on productivity

monitor tree phenology in relation to climate and irrigation management

quantify longan water/irrigation requirements.

This report details the findings of three years of study from July 1998 to May 2001

1.2 Literature review

1.2.1 Plant nutrition - introduction

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

This review does not attempt to give a comprehensive history of fruit tree nutrition and how it impacts on yield, 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 species such as longan. The review also briefly covers other variables which impact on flowering and yield in longan.

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 root, tuber, leaf, 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 macro and micro nutrients as well as basic information on their chief role in plant growth.

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

Nutrient	Level required	Function
Nitrogen (N)	Macro	- accounts for 1.0 – 5.0 % of the dry weight of plants - controls growth and fruiting in plants - amino acid synthesis and protein formation - primary building block for all plant parts
Phosphorus (P)	Macro	- accounts for 0.1 – 0.5% of the dry weight of plants - involved in photosynthesis, respiration, root growth and flower and fruit development - energy storage and transfer - component of nucleic acid and phospholipids - stimulates seed development and root formation
Potassium (K)	Macro	- accounts for 1.0 – 6.0% of the dry weight of plants - regulates water relations of plants - involved in photosynthesis and respiration - promotes root growth
Sulphur (S)	Macro	- accounts for 0.1 – 0.5% of the dry weight of plants - involved in the synthesis of protein and function - electron transport in photosynthesis
Calcium (Ca)	Macro	- plant species differ greatly in their Ca needs. A Ca content of 0.5% dry weight is generally considered adequate - essential in cell wall and membrane construction - regulates nutrient uptake by roots and movement in plants - role in fruit ripening and quality
Magnesium (Mg)	Macro	- accounts for 0.1 – 0.5% of dry weight of plants - important component of chlorophyll (the green pigment in plants) - involved in CO_2 assimilation - involved in carbohydrate partitioning - activator of enzymes for growth
Chlorine (Cl)	Micro	- high amount required relative to other micro-nutrients, hence concentration often expressed as a percentage. Accepted range highly variable (0.05 – 0.7%) of dry weight. - important enzyme component in the production of Vitamin A - role in photosynthesis, protein and carbohydrate metabolism - maintenance of plant turgor
Sodium (Na) #	Micro	- important role in photosynthetic pathway in C_4 plants - can cause toxicity symptoms at relatively low levels

Nutrient	Level required	Function
Copper (Cu)	Micro	- compared to concentrations of iron, manganese and zinc, those of copper are very low and usually of the order of 5 to 15 mg/kg - stimulates lignification of cell walls - pollen formation and fertilisation - role in photosynthesis, protein and carbohydrate metabolism and respiration
Zinc (Zn)	Micro	- zinc levels between 20 to 100 mg/kg are considered normal - involved in nitrogen metabolism - influences development of auxins (plant hormone) - membrane integrity
Manganese (Mn)	Micro	- highly variable concentration in plants, often related to soil pH. Levels can range from 20 to 1500 mg/kg, however, sufficiency levels are in the range of 25 to 50 mg/kg. - enzyme activator - assimilates CO_2 in photosynthesis - assists iron in chlorophyll formation - 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 - required in the formation of chlorophyll activator in many biochemical processes (oxidation-reduction reactions)
Boron (B)	Micro	- range in plants 2.0 – 100.0 mg/kg - regulates metabolism of carbohydrates - involved in formation pollen tubes and feeder roots - aids in translocation of Ca, sugars and plant hormones
Nickel (Ni) #	Micro	- component of urease enzyme used to metabolise urea.
Molybdenum (Mo)	Micro	- 0.5 - 1.0 mg/kg is generally sufficient - involved in nitrogen fixation and nitrate reduction

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

In modern horticulture, plant nutrition management is a common feature with interested parties including; 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 while ensuring sustainability and economic viability. Plant analysis was and is still developing 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, 1998), lychee (Menzel *et al*. 1992), mango (Catchpoole and Bally, 1996), grapevines (Robinson and McCarthy, 1985), passion fruit (Menzel *et al*. (1993), persimmons (George *et al*. 2001) and form the basis of soil and leaf nutrient standards for these crops.

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 throughout 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, however, they are able to rapidly remobilise once leaf senescence begins. Young immature leaves are generally the most sensitive for nutrients that are immobile or variably mobile while older leaves are the most sensitive for those which are phloem mobile (Smith and Longeragan, 1997). In most cases the decision as to what plant part to collect for nutrient analysis is based on several important considerations; the best correlation between plant appearance or performance with elemental content; ease of identification of the plant part and its collection and the stability of the element across similar sampled material (Jones, 1985). In many cases the youngest fully expanded (YFE) leaf has been used successfully for many nutrients in many plant species. In a number of tree crops (lychee, mango, passionfruit) the suggested sampling regime is based on sampling the youngest mature leaf at a time when vegetative flushing activity is low. This often coincides with late autumn/early winter months when the trees or vines are vegetatively dormant and early flowering is commencing. Lim *et al*. (1997), found that in rambutan the middle leaflet pair of the latest mature green flush (third or fourth leaf from the shoot terminal) sampled in May/June just prior to flowering resulted in the lowest coefficient of variation of nutrients.

1.2.2 – Longan nutrition

Information for longan is limited to a few references from China, Taiwan and Thailand. Chen (1997) states that leaf position significantly affects the stability of the nutrient content and that leaves from below the flowering panicle were considered as appropriate for nutrient diagnosis. Their work aimed to investigate changes in nutrient content of leaves of flowering and non flowering trees of cv. Fen Kur from seven orchards in Kaohsiung county, Taiwan. Zhuang, *et al*. (1995) report that the range in leaf contents of 10 elements were assessed from 1992-93 in Longan, Fujian, China. Macro and micronutrients were affected by locality and year. The coefficient of variation (CV) was low for N and successively higher for K, Mg, P and Ca. The variation was greater for micronutrients than macro elements. Wang, *et al*. (1992) reported on nutrient levels of 30 to 50 year old productive trees grown on a red soil. Wong and Ketsa (1991) in their review of longan, report work from China on leaf macronutrient levels. Longan nutrient standards where reported and available are shown in Table 2.

Fertiliser recommendations for longans are rare and when presented are often presented without accompanying leaf nutrient standards and vary greatly. Tree recommendations from USA, Thailand and China are shown in Table 3.

Despite the availability of nutrient standards and fertiliser recommendations from a number of longan producing countries, there is a paucity of work that relates fertiliser inputs and leaf nutrient levels to tree productivity.

Table 2. Published Longan nutrient standards compared with current Australian lychee standards

Reference	N %	P %	K %	Ca %	Mg %	S %	Fe mg/kg	Mn mg/kg	Zn mg/kg	Cu mg/kg	B mg/kg	Comments
Wang *et al*. (1992)	1.21-1.73	0.17-0.25	0.52-1.02	0.59-1.33	0.09-0.23	na	na	na	na	na	na	Productive orchard - China. Red soil, 30 – 50 year old trees, cv. Shuizhang. Fertiliser mainly supplied by organic manures.
Chen (1997)	1.47-1.79	0.11-0.19	0.89-1.77	0.76-1.12	0.24-0.47	na	100-120	200-300	20-28	15-25	40-60	Investigation of changes in nutrient content - Taiwan, sampled leaf below panicle, cv. Fen Ker
Thai data (unpublished)	1.7	0.12-0.20	0.6-0.8	1.50-2.50	0.20-0.30	na	na	na	na	na	na	Work reported to be from Thailand (Rasananda, pers. com.)
Wong and Kesta (1991)	> 1.7	0.12-0.20	0.60-0.80	1.50-2.50	0.2-0.3	na	na	na	na	na	na	Work reported to be from China for high yielding crops (no reference given)
Menzel *et al*. (1992)	1.5-1.8	0.14-0.22	0.7-1.1	0.6-1.0	0.3-0.5	0.2	50-100	100-200	15-30	1.0-3.0	25-60	Productive lychee orchards in SE Queensland

Table 3. Overseas fertiliser schedules for longan

Location	Young trees	Mature bearing trees	Reference/ comment
Florida - USA	A month after planting spread 113 g/tree of a NPK (6:2.6:5) + minor elements. Note source of N should include 20-30 % organic material. Repeat every 6-8 weeks for the first year increasing the amount of fertiliser to 227g, 341g, 454 g etc as the tree grows. Six to 8 applications/year should be made up to the third year. A foliar mix (Mn, Zn, B, and Mo) plus Mg should be applied 4 to 6/year from April to September (fruiting months). For trees on acid to neutral soils apply $FeSO_4$ at 7 to 28 g/tree three to four times per year. In alkaline soils drench the soil with Fe chelate 2 to 3/year (Drench 14 – 21 g of Fe chelate to 15 – 20 litres, pour on soil adjacent to tree trunk).	Add 56-168 kg kg of N per hectare per year split into 2 to 3 applications. The fertiliser should be applied just prior to flowering, and again before harvest. The fertiliser mix should also include P and K and a NPK mix of 6:2.6:5 or 6:3.5:7.5 or similar. In addition 57 to 114 g of Fe chelate per tree per year should be applied for trees growing on alkaline soils. Four or more foliar micro nutrient sprays (Mn, Zn, B, and Mo) plus Mg should be made from early fruit set to harvest.	(Crane *et al.* 2000)
Chaing Mai - Thailand	Add manure or compost at planting. Once trees have settled add N:P:K such as 15:6.5:12.5 at a rate of 100 to 500 g/tree/year depending on year of age	Organic fertiliser (old manure, compost) should be spread under the tree after panicle emergence. Inorganic fertiliser (timing and type should vary with the stage of fruit development. More N and P are required in the early stages of development and increasing K is required in the later stages of fruit filling. The amount of fertiliser depends on tree age, size, crop yield and soil fertility. Prior to flowering; add fertiliser high in P and K eg (12:10.5:20 or 8:10.5:20) at 1-2 kg/tree Fruit set (match size); Add NPK (25:3:5.8) at 1-2 kg/tree Pea size fruit; Add NPK (16:7:13 or 15:6.5:12.5) at 1-2 kg/tree 1 month pre harvest; Add NPK high in potassium eg. (13:5.7:17 or 14:6.1:17 or 8:10.5:20) at 1-2 kg/tree Immediately after harvest; Add NPK high in nitrogen eg. (20:4.8:9.1 or 15:6.5:12.5) in conjunction with Urea at 1-2 kg/tree.	Ungasit. *et. al.* (1999).
Fujian Provence, China	na	Fertiliser applied to 30-50 year old productive trees 440 kg N, 145 kg P, 306 kg K per hectare (mainly supplied via organic matter.	Wang *et al.* (1992).

1.2.3 Longan tree phenology

An understanding of tree phenology is vital to the interpretation of leaf nutrient status and its relationship to tree productivity. The longan is a terminal flowering tree in which climatic and environment play an important role in flowering and fruit-set.

Wong and Ketsa (1991) describe longan as a subtropical tree that grows well in the tropics but requires a prominent change of seasons for satisfactory flowering. A short (2-3 months) but cool (mean temperature 15-22^{o}C) winter season induces flowering. Menzel *et al*. (1989) report that longans grow and crop best in areas with short, cool, frost-free winters and long, hot, humid and wet summers. Yaacob and Subhadrabandhu (1995) report that environmental factors are important to flowering and fruit setting. Long cool seasons help in flowering and fruit set while hot dry weather causes poor setting, and dropping of fruits is common. Nakasone and Paull (1998) have diagrammatically represented the longan fruiting cycle and the climatic and environmental clues that influence flowering (Figure 1).

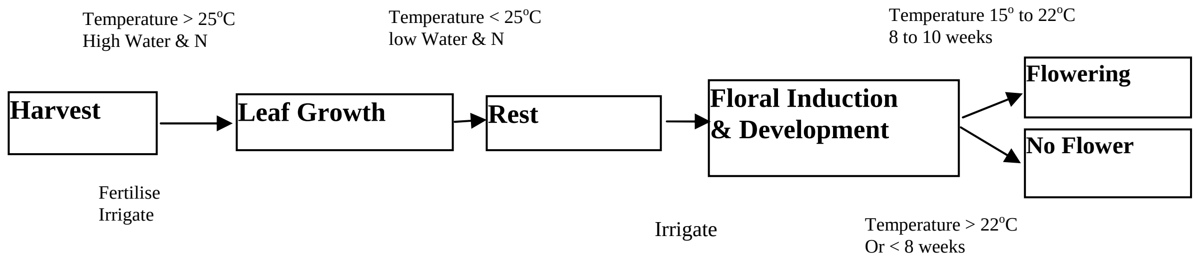


Figure 1. Fruiting cycle of longan (after Nakasone and Paull, 1998) as affected by temperature, nitrogen (N) fertilisation and soil water availability.

Nakasone and Paull (1998) suggest that in longan, low irrigation, nitrogen inputs and temperature (< 25^{o}C) are required in association with a "rest period" (a duration in which vegetative growth is negligible) as a precursor to floral induction and development.

The Longan is notorious for its irregular or biennial bearing (Menzel *et al*. 1989). Subhadrabandhu and Yapwattanaphun (2001) report that longan flowering is sensitive to environmental conditions and that irregular bearing is a common problem. A number of workers cited by Subhadrabandhu and Yapwattanaphun (2001) (Yupin 1986, Boonplod 1996, Chen *et al*. 1997, Huang 1999) have found high levels of cytokinin and low levels of gibberellin and abscisic acid during floral initiation. The antigibberellin (paclobutrazol) has however failed to induce flowering in longan. The variables which control flowering and subsequent fruit set and harvest are complex and climate, soil water and nutrition management appear to be interrelated. In Thailand research recommendations (Ungasit *et al.* 1999) are that;

- trees are pruned, fertilised (high N) and irrigated immediately after harvest to induce new leaf growth
- soil moisture and nitrogen fertiliser are withdrawn a month or two pre flowering to allow the mature flush to "Rest"
- pre flowering fertiliser application high in P and K
- following flowering apply fertiliser high in N and P
- in the month prior to harvest apply fertiliser high in K

1.2.4 Longan water requirements and irrigation management

Longan water requirements are scantly reported and perhaps by implication poorly understood. Most longan references (Menzel *et al*. 1989, Wong and Ketsa 1991, Nakasone and Paull 1998, Ungasit *et al.* 1999 and Crane *et al*. 2000) all refer to the fact that regular irrigation is required during the growth of young trees and in mature trees from flowering to harvest. Some writers suggest that irrigation should be reduced or withdrawn one to two weeks prior to harvest. The importance of irrigation is again emphasised following harvest and pruning to encourage vegetative bud burst and new leaf growth. Most authors report that irrigation should be limited or withdrawn completely in the "rest" period leading up to flowering. This reduction in soil moisture is said to reduce the possibility of late unwanted vegetative flushes occurring which would interfere with floral differentiation hence resulting in failure of flowering.

The relationship between soil moisture, vegetative flush activity and climate is highlighted with an emphasis on the importance of promoting vegetative flush immediately post-harvest and a reduction in soil moisture pre-flowering to aid flowering and hence regular bearing.

1.2.4 Summary

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

2. Objectives

The objectives of this project were to;

monitor changes in longan leaf and soil nutrient status over three seasons

measure grower ertilizer inputs in relation to the above

assess the effect of nutrient status on productivity

monitor tree phenology in relation to climate, nutrition and irrigation management

quantify longan water/irrigation requirements.

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

3. Methodology

3.1 Site description

Nine longan growers collaborated in the project. The orchards were located along the south east coast of Queensland, Australia from Narangba (30 km north of Brisbane, approximately 27^{o}S) to the Atherton Tablelands (west of Cairns, approximately 17^{o}S). Five of the orchards were located on the Atherton Tablelands encompassing an area from Atherton in the south to Mareeba in the north and Mutchilba to the west. Of the remaining two sites one was located 30 km south of Mackay at Sarina Beach (21^{o}S) and the other north of Rockhampton at Byfield (approximately 23^{o}S). Climatically the trial sites were located from the subtropics (Narangba) through to the tropics (Sarina Beach) and onto the higher altitude tropics (Atherton Tablelands).

Nutrition sampling occurred on three longan varieties with seven sites representing cv. Kohala, two sites cv. Chompoo and one site cv. Biew Kew. The cv. Kohala (selected in Florida) is the earliest of the three varieties and is normally harvested from mid to late January in the Mackay/Rockhampton region and from late January to mid February in the Mareeba region. The cv. Chompoo and Biew Kiew, both of Thai origin, are later varieties and are harvested from mid to late February and from late February to mid March in the Mackay/Rockhampton and Mareeba areas respectively. In the cooler Atherton region the *cv*. Biew Kew is usually harvested in April.

3.2 Leaf and soil sampling

Leaf samples were collected four times per year and soil sampled twice per year The sampling schedule is as below.

Longan Leaf Sampling

- Early flowering (Sep)
- fruit filling (Nov)
- post harvest (Feb/Apr)
- hardened summer flush (May)

Longan Soil Sampling

- pre flowering (Jul/Aug)
- post harvest (Feb/Apr)

The four growers south of the Atherton Tablelands generally sampled and submitted their own samples on behalf of the project.

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

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

At each leaf sampling period the youngest fully mature leaf (petiole +leaflets) or during flowering and fruit set (the leaf under the panicle) was chosen for sampling. A composite sample of eight leaves from 10 monitoring trees was 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 respective grower. An electronic form of the data was emailed to the principal researcher generally within one to two months of sampling. Soil and leaf analysis results were compiled and presented by grower by sampling occasion, mean of all growers by sampling date ± standard error (se), mean grower over all sampling periods ± se and over all mean ± se. Mean leaf concentrations (all growers, all varieties, all regions) with associated 95% confidence intervals are presented as initial standards. These are compared to mean leaf concentrations with associated 95% confidence intervals for the sampling date which showed the least coefficient of variation among all sites sampled. Standards of this type are naturally tentative and it is normal for them to be refined with use (Cresswell, 1989).

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

3.3 Climate and irrigation monitoring

3.3.1 Weather station details

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

- Campbell CR10 data logger
- Air temperature sensor (CS500)
- Relative humidity sensor(CS500)
- Tipping Bucket Rain Gauge (Monitor Sensors , 0.5 mm/tip)

- Soil Temperature sensor @ 20 cm (CS107)
- WaterMark soil tension sensor (CS253). At two of the stations one sensor was placed at 30 cm depth whereas at the third station three WaterMark sensors were placed at 20, 40 and 80 cm.

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

The three units were placed on Tableland orchards and the locations were chosen to capture the extreme differences in climate across a relatively small geographic area.

Longan Unit 1. Marks Lane, Atherton (17^{o}16.5'S, 145^{o}31.4'E). This station represents the coolest and wettest of the five Tableland sites. Soils are of basaltic origin and are referred to as a ferrosols. The *cv*. Biew Kiew was monitored at this site.

Longan Unit 2. Springs Road, NW of Mareeba (16^{o}56.6'S, 145^{o}13.7'E). This station represents the hot/dry growing area on granitic sand around Mareeba. The *cv*. Kohala was monitored at this site.

Longan Unit 3. Piemonte Road, 10 km east of Dimbulah (17^{o}10.6'S, 145^{o}09.9'E). This station represents the more extreme end of the longan growing environment with cold dry winters and hot/dry summers. The *cv*. Kohala was monitored at this site.

A fourth weather station (Longan Unit 4) was installed in April 2000 on a Longan orchard at the Byfield site (Rockhampton area, 23^{o}01.5'S, 150^{o}41.2'E). This station represents the northern end of a sub-tropical environment with long cool winters and warm/hot summers. The *cv*. Chompoo was monitored at this site.

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

3.3.2 Replacement climate data procedures

During periods of sensor breakdown or weather station shut down missing data was replaced by using a relationship developed between the station data while operating and SILO data drill information. The Data Drill accesses grids of data derived by interpolating the Bureau of Meteorology's station records. Interpolations are calculated by splining and kriging techniques (Jeffrey *et al*. 2001). The data in the Data Drill are all synthetic, there are no original meteorological station data left in the calculated grid fields. However, the Data Drill does have the advantage of being available for any set of coordinates in Australia. Longitude and Latitude coordinates were measured using GPS recorder at each of the weather station sites. This data, along with periods in which data was missing, was provided to the SILO site (www.dnr.qld.gov.au/silo/datadril.html). The silo site calculated and returned synthetic data on daily max and min temperature, rainfall, evaporation, SWSR, vapour pressure, RH maxT, RH minT. Missing data was provided through a comparison of known weather station data (y-axis) and SILO data drill estimates (x-axis) for the appropriate latitude and longitude. The relationships utilised were unique to each site. For example the relationships utilised for latitude and longitude (17^{o} 15.8'S, 145^{o} 55.3'E) are as follows.

Variable	Relationship and r^2 value
Maximum temperature (C)	Y=0.9622x + 1.3533 (r^2 = 0.76)

Minimum temperature (C)	Y= 1.2009x – 5.7665 (r^2 = 0.94)
Rainfall (mm)	Y= 0.8235x (r^2 = 0.71)
Shortwave solar radiation (MJ/M2/day)	Y= 0.8579x – 1.1723 (r^2 = 0.44)

3.3.3 Irrigation monitoring

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

3.4 Phenology monitoring

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

At the remaining sites, grower observations were relied upon.

3.5 Compilation of fertiliser inputs and yield data

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

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

Fertiliser input data sheets were made available to all growers. The bulk of these were completed. 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.

Yield data (kg/tree) for each season was provided by all growers who provided detailed fertiliser input data.

3.6 Fruit analysis

Fruit from three locations on the Atherton Tablelands were sampled in the 2001 season so that an analysis of fruit nutrients could be undertaken. Seven samples of fruit, from two varieties Kohala and Biew Kiew, were sampled over the three orchards. The samples included fruit, panicle wood and approximately 20 to 30 cm of wood and leaf behind the panicle. On arrival in the laboratory, the total fresh weight was measured and the panicle divided into two parts; a). fruit with “minor” panicle wood as per industry packing standards and b). the remaining “heavy” panicle wood, stem and leaf material.

The fresh weight of these two parts was then recorded. The material was then dried at 40^o to 50^{o}C for approximately three weeks at which time it was determined that the material was oven dried. The dried material was weighed and then ground to < 1mm. The ground material was packed in polyethylene bags and dispatched to the Department of Natural Resources, Analysis Laboratory at the Centre for Dry Tropics Agriculture in Mareeba. Fruit with "minor" panicle wood and remaining "heavy" panicle wood, stem and leaf material were analysed for N, P, K, Ca, Mg, Na and S (%) and Cl, Mn, Fe, Cu, Zn, B and Al (mg/kg). The mean, maximum, minimum and standard error (se) data for each element are presented.

3.7 Nutrient budget calculations

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

4. Results

4.1 Climate

Weather station data and phenology recording allow a picture to develop of the climatic factors which effect flowering and fruit set. Because of the similar trends between Tableland sites only one example of climate recordings (Lagoma Orchards, Mareeba) is presented in this chapter. Detailed data for the other sites are presented in Appendix 1.

4.1.2: Maximum and minimum temperature

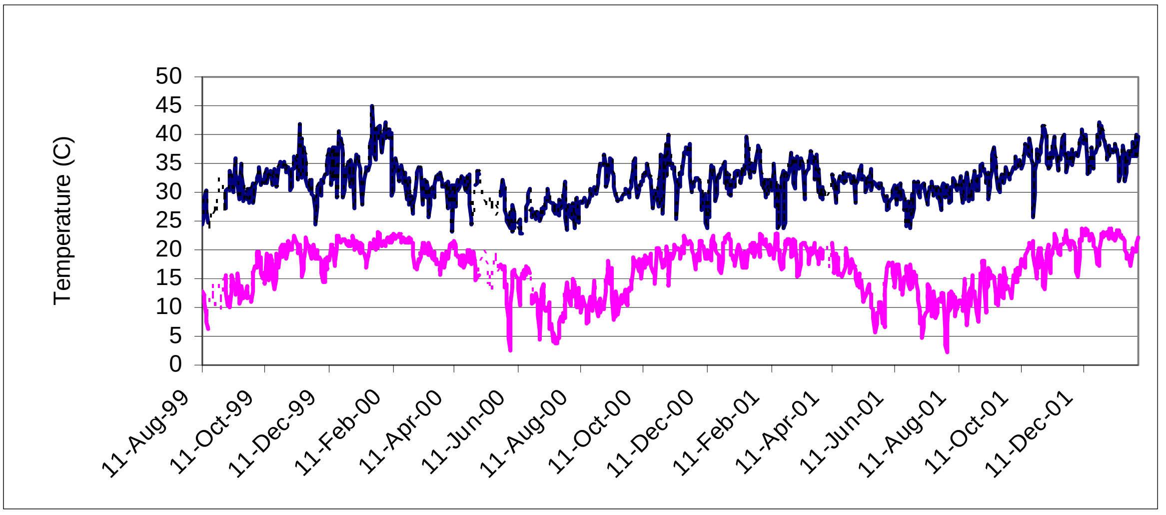


Fig 2. Daily maximum and minimum temperatures. Note dotted lines represent times in which SILO data was used to fill in missing weather station data.

The monitoring period, 11 August 99 to 31 January 2002, clearly shows the summer and winter temperature patterns (Fig 2). Extremes in temperature can occur throughout the year. To summarise the above daily data, Figure 3 below shows the average monthly temperature at the above location and includes data from Jan 1998 to July 1999 when on site temperature monitoring was not in place. This data was calculated using relationships between the known weather station data and SILO data.

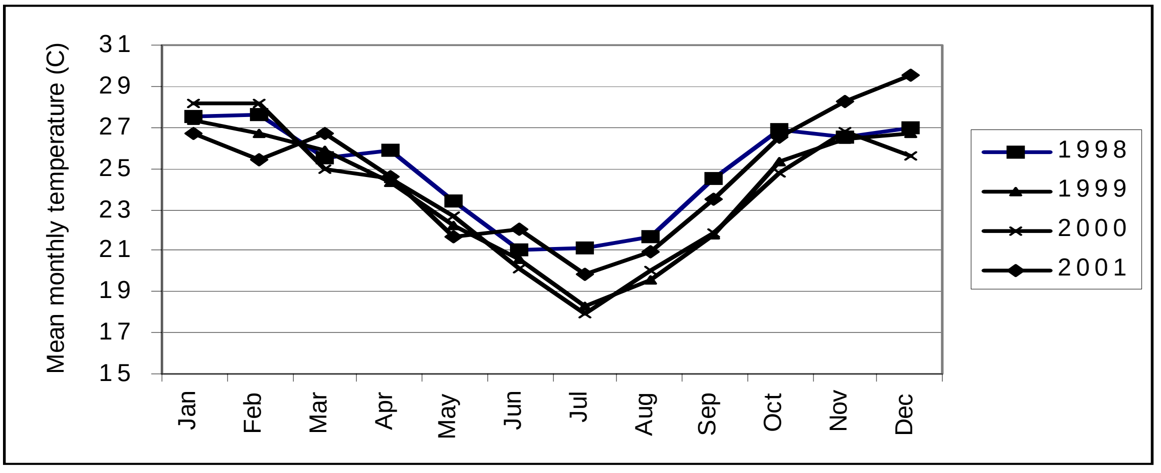


Figure 3. Average monthly temperatures from Jan 1998 to Dec 2000.

The 1999 and 2000 seasons were cooler than the 1998 and 2001 seasons, particularly during the months June to October. This pattern was similar for all tableland sites

4.1.2: Soil temperature

Another factor that may influence phenology, in particular flowering, is soil temperature. The relationship between root temperature and phenology in general is not well understood. In Figure 4, soil temperatures at 15 cm depth under the tree canopy (midway between the trunk and drip-line) are shown. Anecdotal observations suggest this is where the bulk of the trees feeder roots are active. As expected the fluctuations in soil temperature were not as great as that experienced by air temperatures as there was a damping effect. However, sudden decreases and increases in soil temperature appear to be closely linked to rapid movements in the minimum temperature ($r^2 = 0.85$) yet poorly related to maximum temperature ($r^2 = 0.28$).

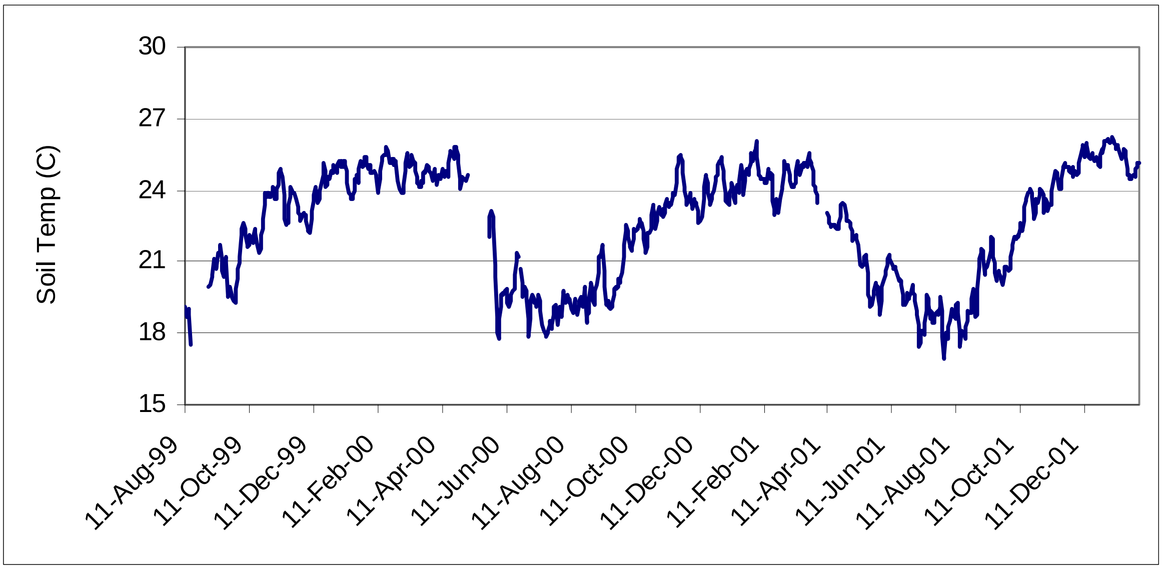


Figure 4. Soil temperature changes under the tree canopy (midway between the trunk and drip-line) from Aug 1998 to 31 Jan 2002.

Minimum soil temperatures (July –August) fluctuate around 18^{o}C, while maximum temperatures (December – April) fluctuate around 25^{o}C. The period from April to June is one in which there is a rapid fall in soil temperature while September to December is a period of rapid rise.

4.1.3: Minimum RH

Minimum relative humidity (RH) levels varied greatly from day to day and with the season. Minimum RH levels were generally higher during the summer months, particularly during rain periods. Lowest levels were recorded during the winter (dry months) with readings falling as low as 5.0% (Figure 5). Low or high RH levels can interfere with crop production. Dry conditions during flowering may be implicated in poor fruit set, whereas moist conditions during fruit filling may be associated with an increase in fungal contamination.

4.1.4: Short wave solar radiation (SWSR)

SWSR is a measure of the sun's energy inputs. Plant photosynthesis, assimilation rates and tree productivity are dependent on solar energy inputs. SWSR monitoring at each of the weather station sites began late in the project (Dec 2000) and hence does not allow for sufficient comparison over the period of the project. Data shown in Figure 6 is a comparison of the daily SILO data for sites near Mareeba (dry area) and Atherton (wet area). Over the monitoring period the average daily SWSR ($MJ/m^2/day$) for Mareeba and Atherton were 19.2 and 18.8 respectively.

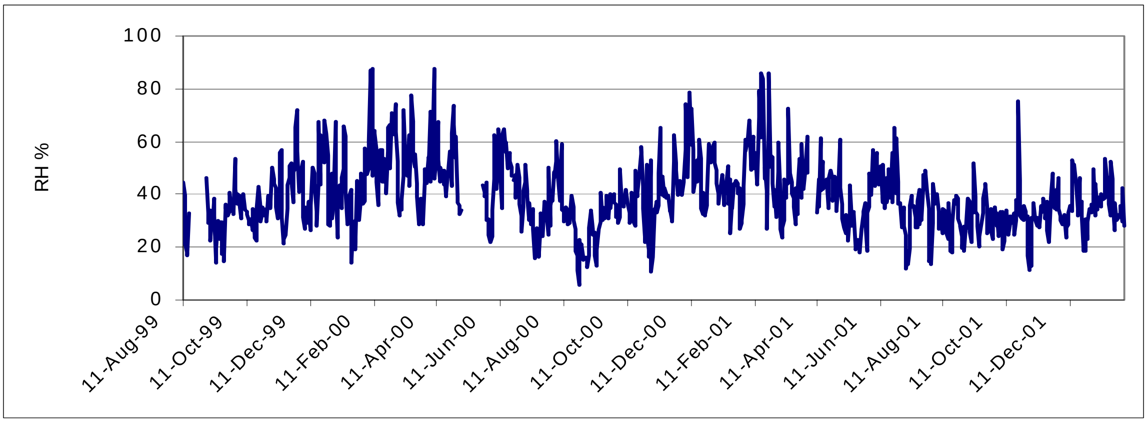


Figure 5. Daily minimum RH recorded at Lagoma orchards.

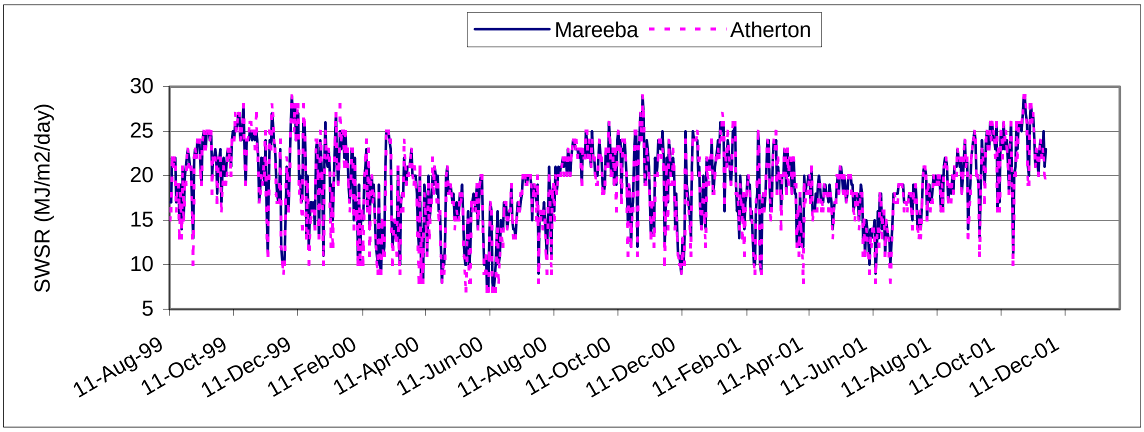


Figure 6. Shortwave solar radiation ($MJ/m^2/day$) for Mareeba and Atherton.

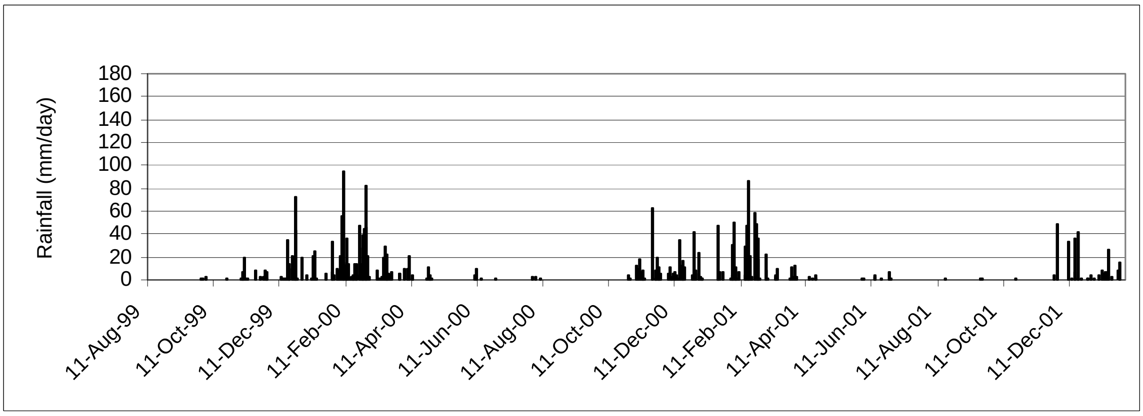


Figure 7. Daily rainfall at Lagoma orchards.

4.1.4: Daily rainfall

Daily rainfall patterns were seasonal with November to April being the wet season months (Fig 7). Peak falls occurred from December through to February. The pattern in the three Tableland farms was similar, although at the Atherton site rainfall was recorded in every month of the year during both full years of recording (Table 4). Yearly rainfall totals were highest for 2000, with the Atherton site obtaining 1,842 mm relative to a yearly total of 1,291 mm at the Dimbulah site where the measured yearly totals were the least over the period monitored. The month of February was the wettest for all sites for both 2000 and 2001 whereas the month of July was the driest.

Table 4. Rainfall summary from Aug 1999 to Dec 2001, for the three Tableland sites. * indicates measured totals from August 11 to December 31 1999.

	1999			2000			2001		
	Amerio	Craigie	Sing	Amerio	Craigie	Sing	Amerio	Craigie	Sing
Jan	-	-	-	103.0	196.0	177.5	99.5	93.5	162.0
Feb	-	-	-	636.5	525.5	783.0	483.0	425.0	567.0
Mar	-	-	-	137.0	31.0	201.0	63.5	112.0	170.5
Apr	-	-	-	67.5	6.0	153.0	24.0	16.5	67.0
May	-	-	-	0.0	1.0	40.0	1.0	0.0	3.0
Jun	-	-	-	19.5	29.5	55.0	21.0	9.0	73.0
Jul	-	-	-	3.0	0.0	4.5	0.0	0.0	7.0
Aug	0.5	0.0	13.0	4.5	1.0	21.0	2.0	0.0	5.5
Sep	3.5	3.5	41.0	0.5	0.0	3.0	2.0	0.5	24.5
Oct	4.5	13.5	18.0	7.5	0.0	39.0	1.5	7.5	26.0
Nov	66.5	56.5	138.0	177.0	246.5	158.0	54.0	70.0	98.0
Dec	231.0	72.5	187.0	187.0	255.0	207.0	133.0	76.5	99.0
TOTAL	306.0*	146.0*	397.0*	1343.0	1291.5	1842.0	884.5	810.5	1302.5

4.2 Tree phenology

Table 5. Phenological patterns over four seasons (1998 to 2002) for *cv*. Kohala grown at two sites and *cv*. Biew Kiew grown at Atherton. N.B. Tree phenology stages advance over the calendar years related to the season indicated, starting from panicle emergence.

	Tree Phenology stages						
Season	Farm	Panicle emergence	Fruit set	Fruit half size	Harvest	New flush	Dormant Period
1998/1999	Amerio *Kohala*	No emergence	na	na	No crop	1 Feb 99 & 1 Apr 99	15 May 99 – 28 Jul 99
	Craigie *Kohala*	No emergence	na	na	No crop	na	na
	Sing *Biew Kiew*	No emergence	na	na	No crop	na	na
1999/2000	Amerio *Kohala*	11 Aug 99	12 Oct 99	21 Dec 99	8 Feb 00	17 Apr 00	25 May 00 – 28 Jul 00
	Craigie *Kohala*	19 Sep 99	20 Oct 99	7 Jan 00	8 Feb 00	8 Apr 00	23 Jun 00 – 28 Jul 00
	Sing *Biew Kiew*	18 Jul 99	18 Oct 99	7 Jan 00	1 Apr 00	17 Apr 00 on non fruiting wood	5 May 00 – 23 Jun 00
2000/2001	Amerio *Kohala*	10 Sep 00	18 Oct 00	12 Dec 00	1 Feb 01	3 Apr 01	25 May 01 - 24 Jul 01
	Craigie *Kohala*	19 Sep 00	18 Oct 00	12 Dec 00	1 Feb 01	3 Apr 01	1 May 01 – 25 Jun 01
	Sing *Biew Kiew*	28 Jul 00	18 Oct 00	12 Jan 01	10 Apr 01	22 Aug 01 #	1 May 01 – 15 Aug 01
2001/2002	Amerio *Kohala*	15 Aug 01	20 Oct 01	14 Dec 01	4 Feb 02	na	na
	Craigie *Kohala*	24 Jul 01	1 Oct 01	30 Nov 01	15 Jan 02	na	na
	Sing *Biew Kiew*	27 Jul 01 minor from pruned wood	20 Oct 01	Early Jan 02	10 Apr 02	na	na

- 1st flush did not commence until four months after harvest.

In the 1998/99 season flowering was poor to non existent across longan growing areas and was generally considered an "off year". Flowering occurred in the 1999/2000 and 2000/2001 seasons for Kohala, and. Biew Kiew. The *cv.* Kohala behaved similarly, in terms of flowering, fruit development and harvest dates, whereas the *cv.* Biew Kiew, grown at the cooler site (Marks Lane – Atherton) flowered earlier, set fruit later and was the last crop to be harvest on the Tablelands. In the *cv*. Kohala there was generally sufficient time following harvest for two flushes to occur following the onset of cooler weather when the trees became dormant. The last flush occurred in early to mid April, but was not necessarily uniform across all trees monitored. Grower pruning activities, which occurred in September of the previous season and leaf minor attack (in March/April following harvest) on new and hardening flush sometimes masked activity levels.

In the 1999/2000 season fruit development was monitored, without replicate measurements, from fruit set (fruit approximately 1.0 mm in diameter) until harvest. Growth curves are shown in Figure 8. Fruit development in *cv.* Kohala was slower at the Dimbulah site relative to the Mareeba site, while the *cv.* Biew Kiew, a later maturing cultivar, took substantially longer to reach harvest size (28-30 mm diameter) in the cooler Atherton environment.

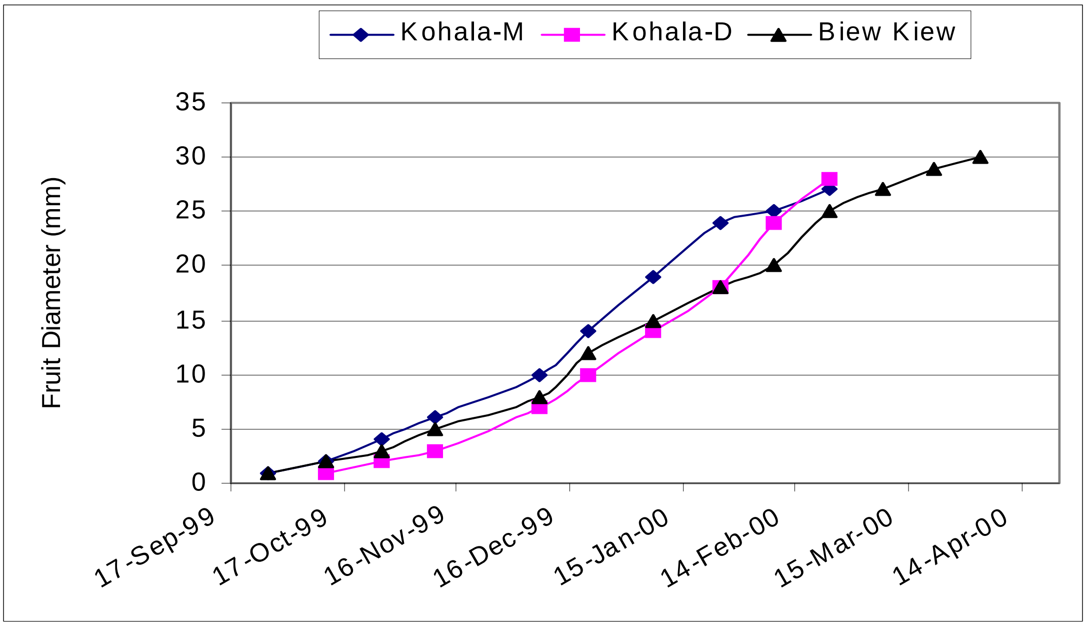


Figure 8. Fruit development (as measured by change in diameter) for *cv.* Kohala (grown at Mareeba 'M' and Dimbulah 'D' sites) and for *cv.* Biew Kiew grown near Atherton.

4.3 Tree yield

Growers provided yield data, in most cases, based on their total orchard performance (Table 6). Although not a direct reflection of what occurred on the trees that were monitored for leaf nutrient levels, this data allows an examination of variability in tree yield over season and across growers.

Yield (kg/tree) varied from 0 to 179 kg/tree (0 to 37.5 tonnes/ha) while tree density varied from 125 to 833 trees/ha with the bulk of orchards having a density of 125 – 250 trees/ha. There was no trend in yield performance across seasons. In most cases high yields (in excess of 10 t/ha) were either preceded or followed by low yield seasons. Yields were generally low to non existent for most orchards during the 1998-1999 season, although one orchard produced 12.5 tonnes/ha in a year which was considered an "off year".

Table 6. Yield data for commercial longan orchards

	1998-1999		1999-2000		2000-2001		
Grower Code	Yield kg/tree	Yield t/ha	Yield kg/tree	Yield T/ha	Yield kg/tree	Yield t/ha	Tree Density
A	100	12.5	40	5.0	4	0.5	125 trees/ha
B	26	3.3	36	4.5	179	22.4	125 trees/ha
C	na	-	low	-	na	-	-
D	0	0	215	26.9	0	0	125 trees/ha
E	na	-	na	-	na	-	-
F	na	-	3.4	2.8	na	-	833 trees/ha
G1	20	5.0	35	8.8	35	8.8	250 trees/ha
G2	0	0	150	37.5	150	37.5	250 trees/ha
H	0	0	6	1.2	8	1.6	208 trees/ha
I	0	0	90	14.9	28	4.6	166 trees/ha

4.4 Irrigation monitoring

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

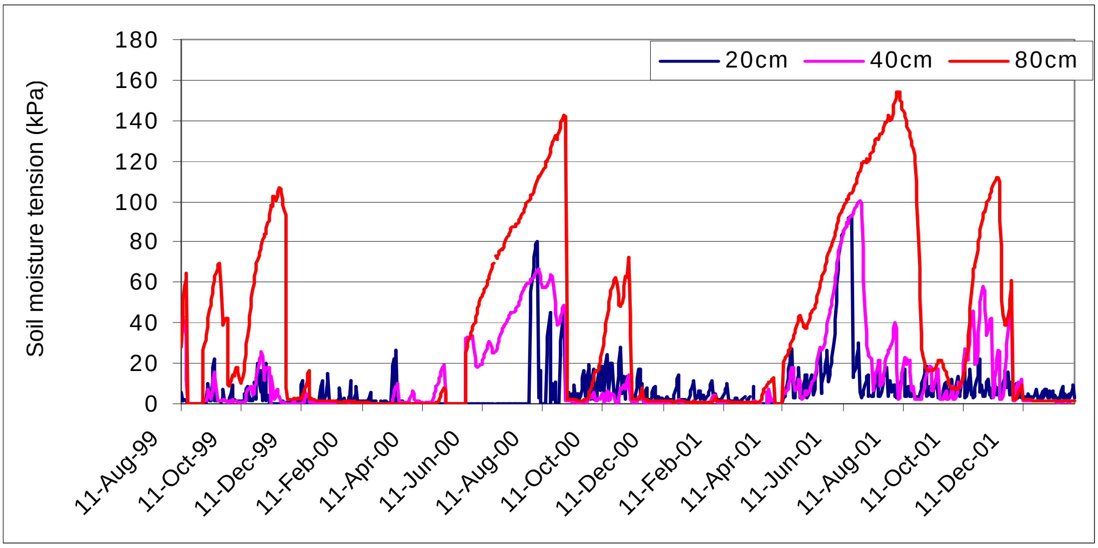
A 'crop factor' (tree water requirements/potential evapo-transpiration) was estimated using data collected from three Tableland sites from 1st August to 30 November over three monitoring seasons, 1999 – 2001, (Table 7).

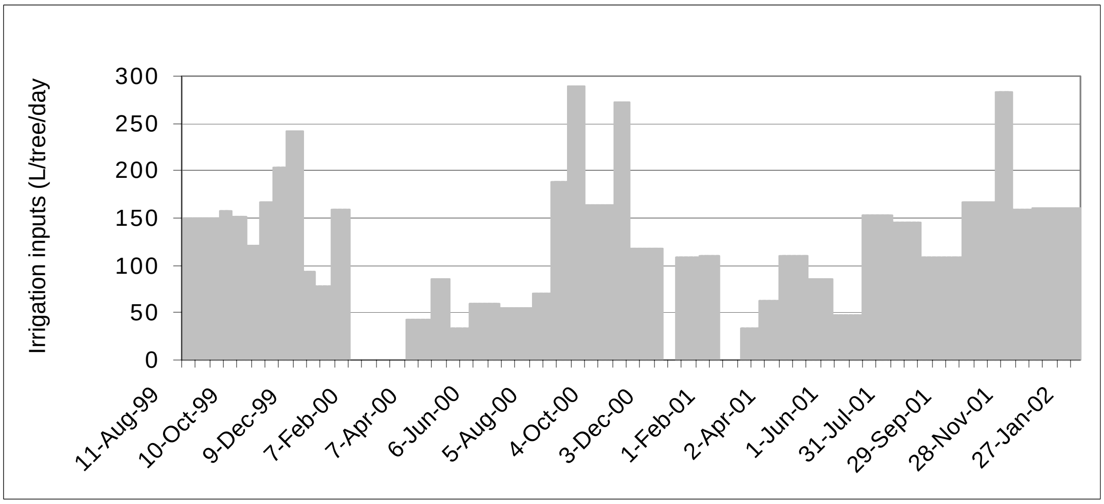
Table 7. 'Crop factor' estimates based on three orchards from 1 August to 30 November over three seasons (1999-2001).

Grower Code	Av. irrigation input (L/tree/day)	Av. canopy area (m^2)	Av. daily evaporation (mm/day)	Potential evapo-transpiration (L/tree/day)	"Crop Factor" Ratio Irrigation inputs/potential ET
I	164	36.0	5.0	180	0.91
H	84	18.0	5.0	90	0.93
B	97	30.0	5.0	150	0.64
Mean					**0.83**

The average "crop factor" for the three sites during a relatively rain free period and during fruit filling is estimated to be 0.83. Hence for every 10 mm of evaporation, the tree requires 8.3 mm. This data can be used to estimate irrigation requirements for longan orchards with differing spacings, tree age and canopy areas. These estimates should be checked with soil moisture monitoring equipment (eg. Tensiometers, Enviroscan, TDR) to ensure that the amount and frequency of irrigation are suited to the tree/soil environment.

Data sets for the three monitoring sites are shown and include; soil tension (kPa), rainfall and irrigation inputs expressed as L/tree/day, which represented the mean input between recording periods (Fig. 9, 10 and 11).





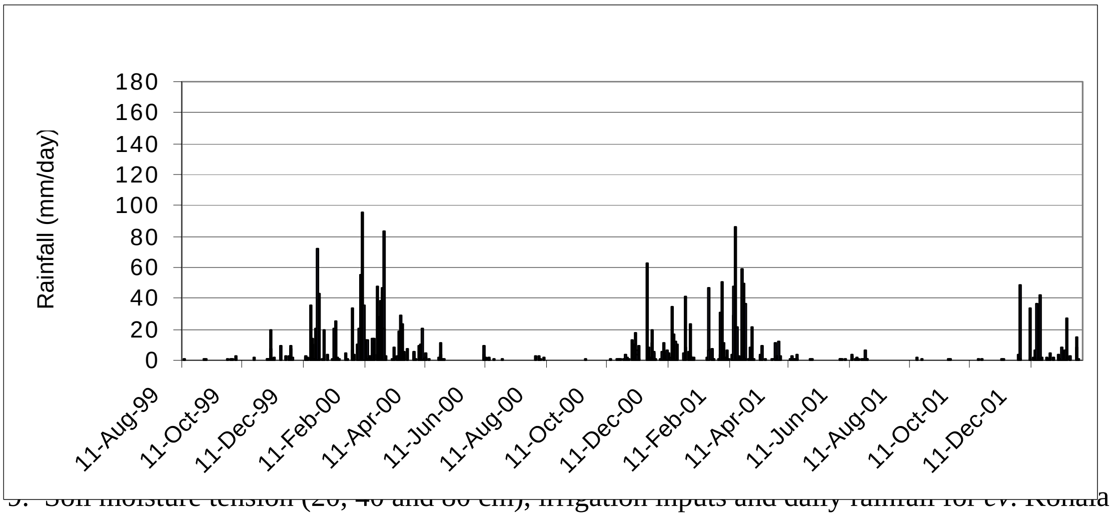


Fig. 9. Soil moisture tension (20, 40 and 80 cm), irrigation inputs and daily rainfall for *cv.* Kohala grown in the Mareeba area.

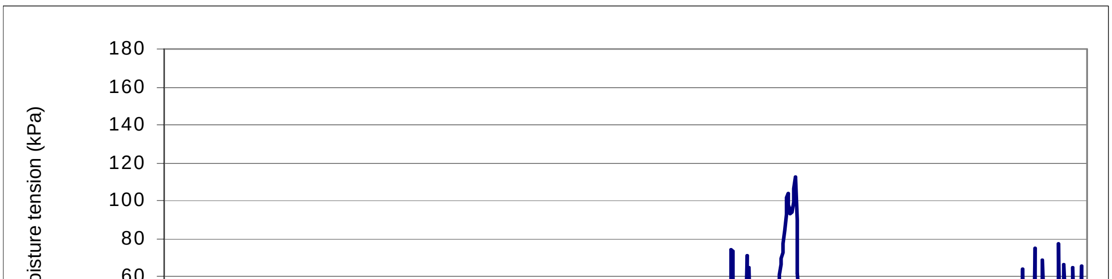


Figure 10. Soil moisture tension at 30 cm (kPa), irrigation inputs (L/tree/day) and daily rainfall(mm) for *cv*. Kohala grown in the Dimbulah area.

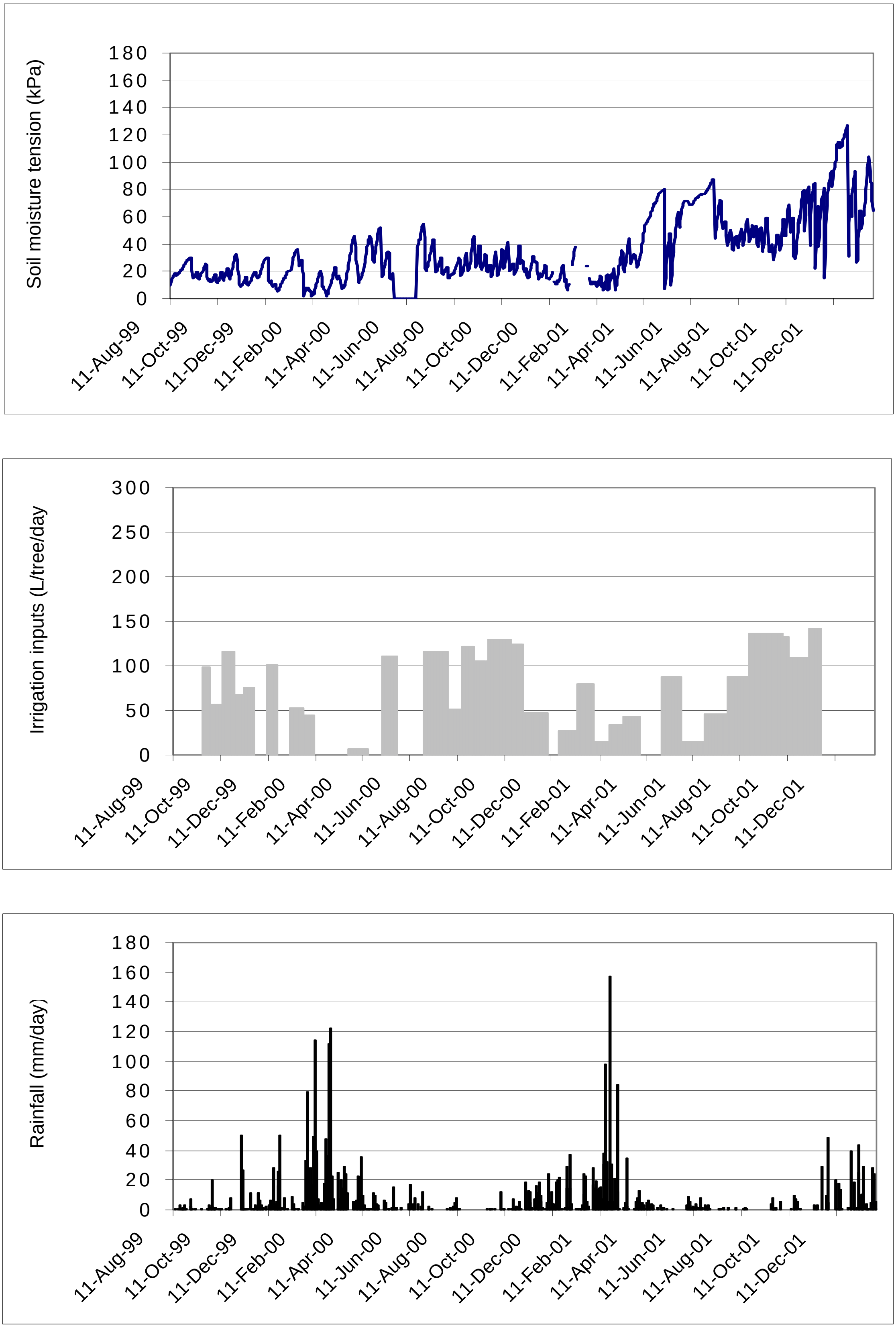


Figure 11. Soil moisture tension at 30 cm (kPa), irrigation inputs (L/tree/day) and daily rainfall (mm) for *cv*. Biew Kiew grown in the Atherton area.

Irrigation inputs vary between sites, dependent on tree size, rainfall, season, soil type and management. The highest irrigation inputs (>250 L/t/day) occurred for short periods of time at site I to reduce soil tension at 80 cm depth. The lowest irrigation inputs coincided with the wet season while the highest inputs coincided with fruit filling. Soil tensions rise during periods when rainfall was less than 30 mm/week and irrigation inputs were less than 50 L/tree/day (or 350 L/week). Irrigation frequency varied between sites depending on soil type and season. Generally irrigation occurred up to three times per week during fruit filling when hot/dry conditions were experienced. Only one of the three orchards monitored, actively used soil moisture monitoring equipment to determine irrigation schedules. Most growers use a combination of techniques to determine irrigation frequency. These techniques rely on a range of factors including; perception of weather conditions, stage of growth, short term use of tensiometers and observation of tree health.

4.5 Leaf nutrient monitoring

4.5.1 Mean leaf nutrient levels
Mean leaf nutrient levels, across all varieties and sampling locations over the 30 month sampling period revealed that longan nutrient composition varied with season and year. The seasonal cycle of leaf nutrients varied with the nutrient. Seasonal trends for the macronutrients (N, P, K, Mg, Ca and S) are shown in Figure 12.

Leaf N, P and K: Concentrations of these nutrients changed greatly throughout the year with significant differences occurring between sampling months. Leaf N, P and K followed similar trends, with small exceptions, in starting at relatively high levels at the beginning of sampling (Oct 98) then declining until August 1999, remaining relatively stable until March 2000 then peaking in June to September 2000 before declining to March 2000 levels by March 2001.

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

Leaf micronutrients: The concentrations of leaf micronutrients Fe, Zn, Mn, Cu and B all had different seasonal patterns through out the monitoring period. The standard errors at sampling intervals were the least for Fe and B, with concentrations of B showing the least change over the monitoring period. The concentration of elements Cu and Zn fluctuated greatly between sampling intervals and the standard error at individual sampling intervals was large in some cases. Concentration of leaf Mn varied greatly over the first three sampling intervals and then stabilised at 80 mg/kg over the remainder of the monitoring period (Figure 13).

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 8. The variability in concentration was least for the macro-nutrients with CV ranging from 10.6% for S at the early flowering sample to 43.5% for Ca at the fruit filling sampling. Variability was much greater for the micro nutrients were CV's ranged from 28% for B at the pre-flowering sample to 234% for Cu at the early flowering sampling. This variability is within the range experienced in other nutrient research projects (Menzel et al. 1993, George *et al*. 1995). The post summer flush sampling was the phenological stage at which the greatest number of elements (6 of 13 elements) showed the least variation (CV).

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

Table 8. Mean leaf nutrient concentrations (with 95% confidence intervals in parenthesis) and coefficient of variation (CV%) for orchards sampled from 1998 – 2001 from 11 sites on nine orchards with a history of good production, management and the absence of nutrient deficiency or toxicity symptoms.

Nutrient	Overall	Post-harvest	Mature Summer flush	Early panicle emergence	Fruit filling
N (%)	1.75 (1.68-1.82) 17.0%	1.69 (1.57-1.81) 15.7%	1.89 (1.57-2.21) 20.3%	**1.70 (1.60-1.81) 15.7%**	1.80 (1.67-1.94) 17.1%
P (%)	0.17 (0.16-0.18) 20.9%	0.17 (0.15-0.18) 21.4%	**0.19 (0.17-0.21) 14.6%**	0.16 (0.15-0.17) 16.9%	0.17 (0.15-0.19) 24.1%
K (%)	0.83 (0.77-0.89) 29 %	0.77 (0.69-0.86) 24.6%	**0.84 (0.68-1.00) 22.7%**	0.82 (0.71-0.92) 32.4%	0.89 (0.78-1.00) 28.4%
Ca (%)	2.66 (2.41-2.91) 39.6%	2.67 (2.25-3.09) 35.4%	2.50 (1.62-3.38) 42.0%	**2.77 (2.40-3.14) 34.1%**	2.63 (2.16-3.14) 43.5%
Mg (%)	0.36 (0.34-0.39) 28.1%	**0.38 (0.35-0.42) 21.3%**	0.31 (0.23-0.39) 30.9%	0.35 (0.31-0.39) 28.5%	0.37 (0.32-0.43) 30.2%
S (%)	0.16 (0.15-0.17) 22.7%	0.16 (0.15-0.18) 24.6%	0.16 (0.14-0.18) 15.0%	**0.15 (0.15-0.16) 10.6%**	0.17 (0.15-0.19) 29.5%
Mn (mg/kg)	83 (70-96) 67%	74 (56-92) 55%	**76 (58-94) 28%**	86 (58-113) 81%	95 (65-125) 72%
Fe (mg/kg)	115 (88-141) 97%	148 (76-220) 110%	95 (35-156) 76%	120 (86-154) 72%	**69 (52-86) 56%**
Cu (mg/kg)	84 (36-132) 242%	81 (19- 144) 174%	**43 (15-71) 78%**	107 (8-206) 234%	35 (5-61) 195%
Zn (mg/kg)	48 (30-65) 157%	**27 (20-34) 56%**	46 (10-82) 95%	58 (18-97) 175%	59 (16-101) 164%
B (mg/kg)	56 (48-63) 58%	68 (47-89) 70%	**51 (39-63) 28%**	51 (43-58) 39%	50 (40-61) 47%
Na (%)	0.03 (0.02-0.03) 71.5%	**0.02 (0.01-0.03) 63%**	0.02 (0.02-0.03) 71%	0.03 (0.02-0.04) 71%	0.03 (0.02-0.04) 78%
Cl (%)	0.04 (0.04-0.05) 43%	0.04 (0.03-0.05) 45%	**0.04 (0.03-0.06) 32%**	0.05 (0.04-0.06) 56%	0.04 (0.04-0.05) 33%

Data in bold: Represents the leaf nutrient concentrations with the least CV between seasons.

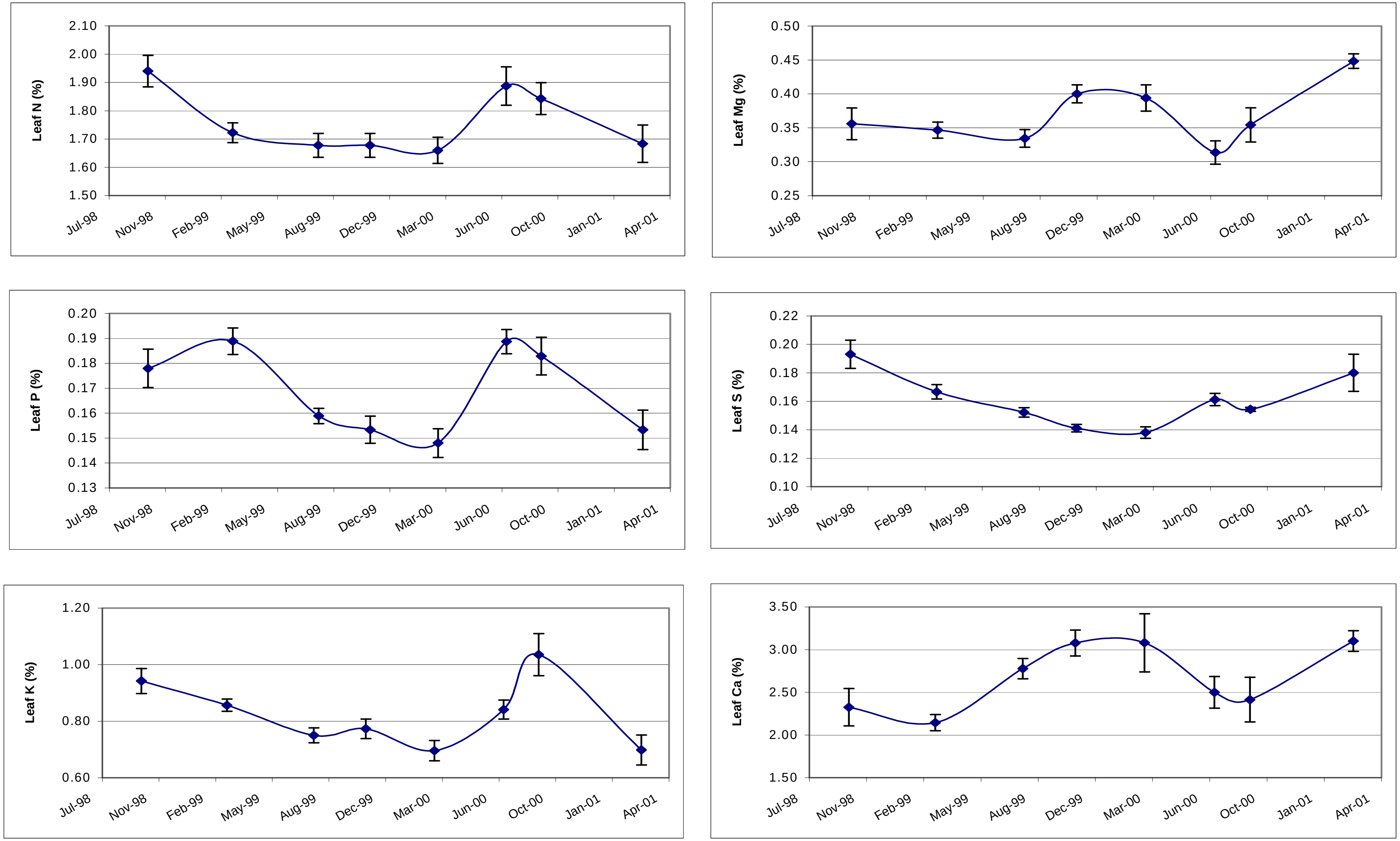


Figure 12. Mean seasonal macronutrient levels over 30 months, for all varieties, all locations. Bars denote standard error at each sampling occasion .

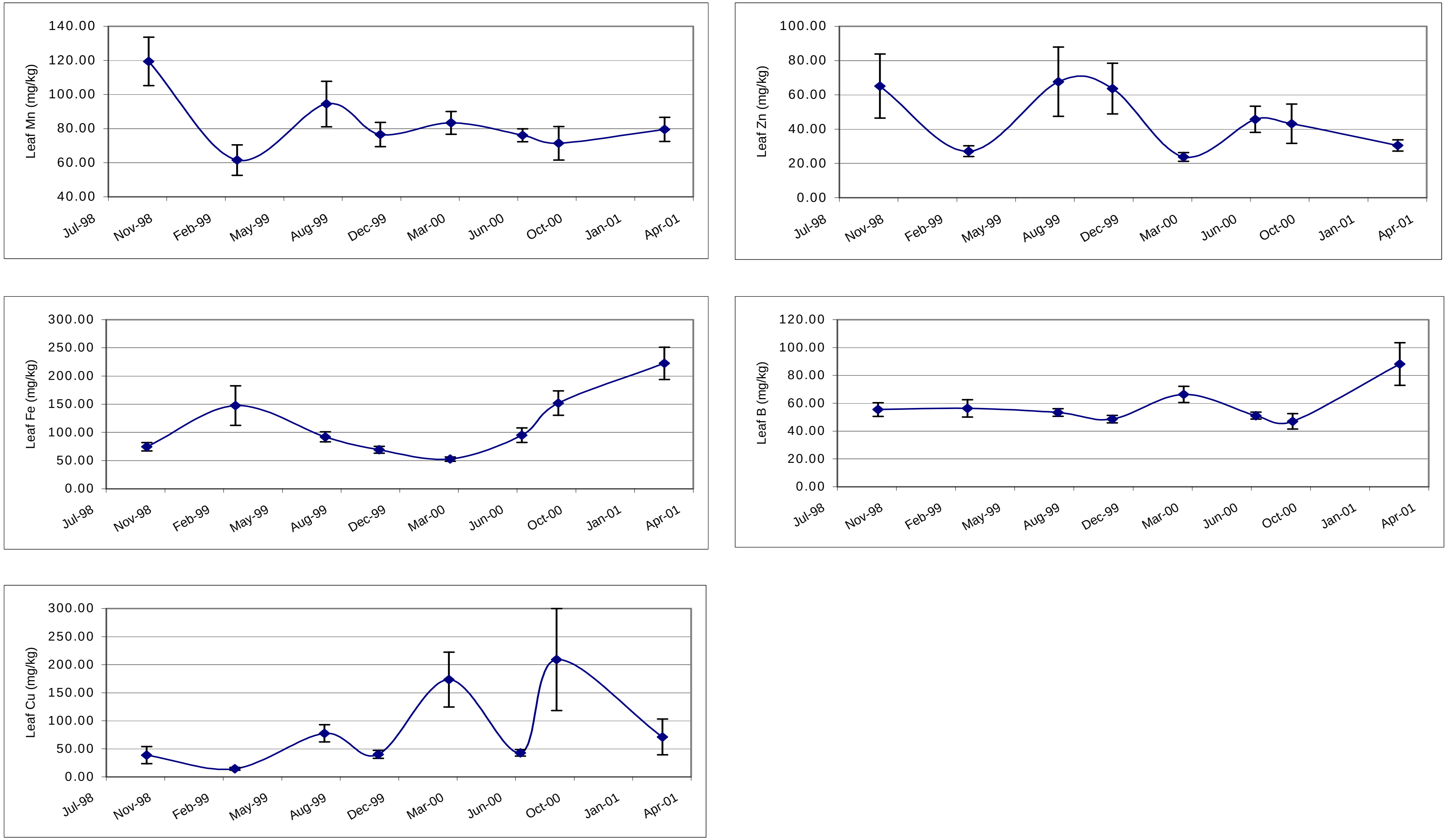


Figure 13. Mean seasonal micronutrient levels over 30 months, for all varieties, all locations. Bars denote standard error at each sampling occasion.

4.5.2 Comparison of mean nutrient levels between growers

From a commercial perspective growers are interested in seeing how their orchards compare with their competitors. Mean macronutrient levels by grower code are shown in Figure 14. For elements such as N, P, Mg and S mean nutrient concentrations were relatively similar among growers, whereas for Ca and K there were 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 was a tendency to have a lower mean leaf K concentration. These differences may be due to interactions with soil type and the ratio of soil cations (K, Ca and Mg).

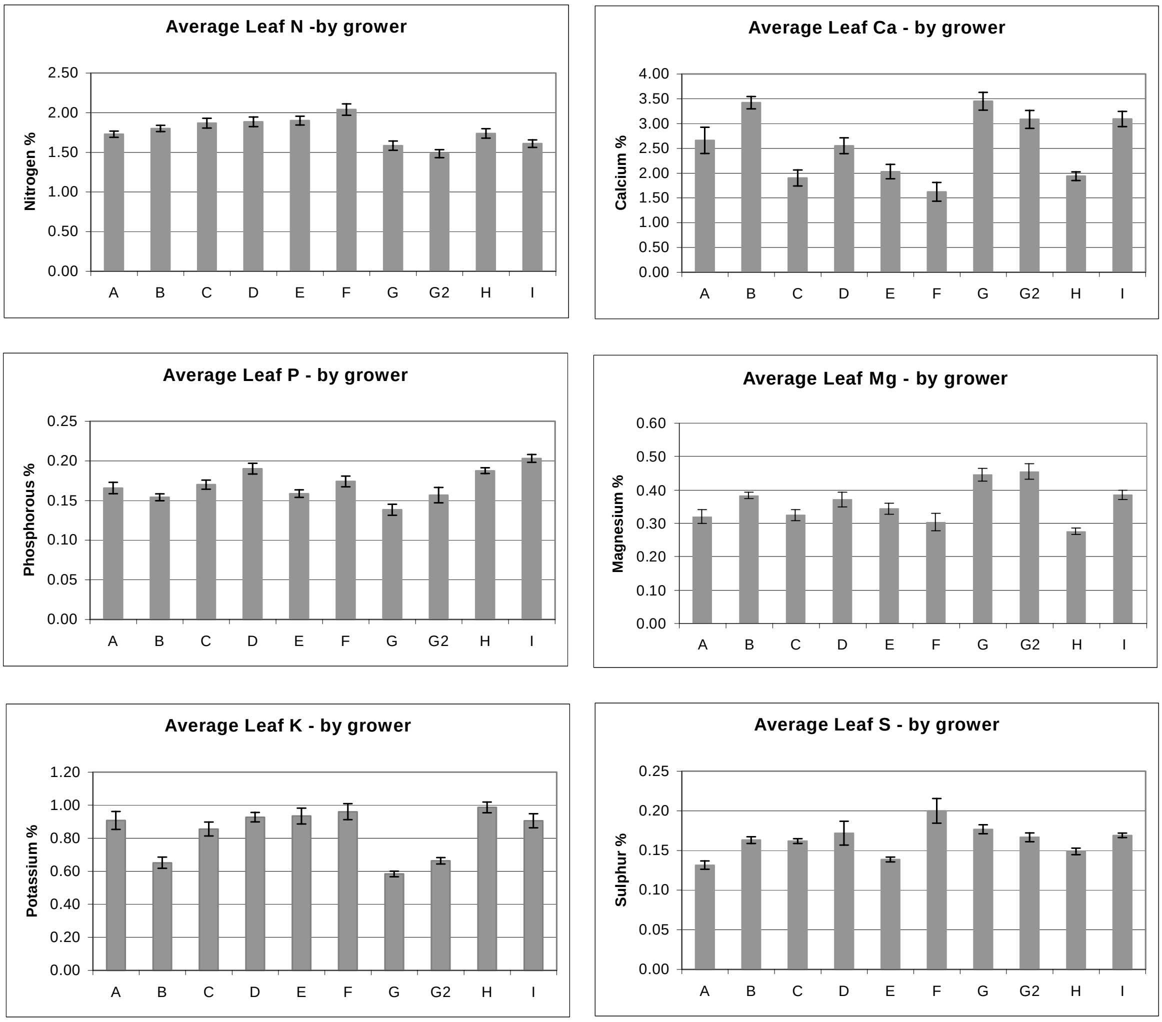


Figure 14. Mean leaf macronutrient levels by grower. Vertical bars represent the standard errors.

For micronutrients the variability in mean leaf concentrations between growers was much larger, particularly for Cu and Zn. The high concentrations of these elements in a few orchards were directly due to the high foliar inputs either as a elemental spray or the use of copper based fungicides. This variability, reinforces the need to interpret leaf micronutrient concentrations with caution, because management practices other than nutrient application can markedly affect the concentration of micronutrients in leaves. It also suggests that growers need to wash their leaf samples in deionised water prior to dispatch to the laboratory or notify the laboratory of any recent foliar nutrient or pesticide applications.

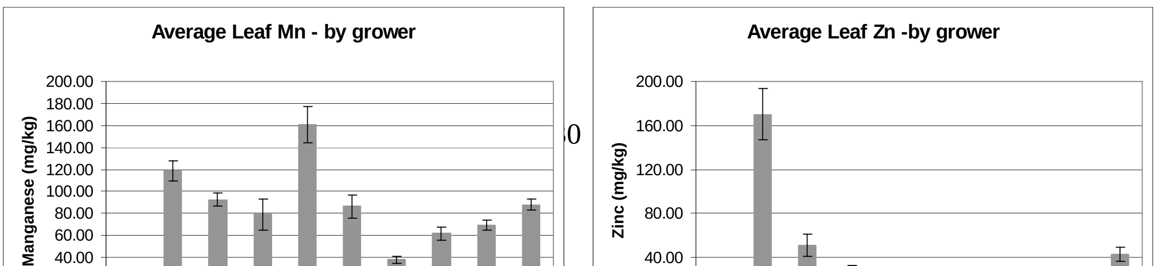


Figure 15. Mean leaf micronutrient levels by grower. Vertical bars represent the standard errors.

4.6 Soil chemical characteristics and nutrient monitoring

4.6.1 Soil pH, EC and Organic Matter
Average Soil pH, EC and Organic Matter are shown in Table 9 and variations over time in Figure 16. Soil pH varied over time from 5.9 to 6.4, but differences were small and in most cases were not significant. The range measured was well within optimum soil specifications. Likewise soil EC also varied over time, (0.04 – 0.08 dS/m) with seasonal differences apparent, but was always very low. Organic matter percentage measured ranged from 0.97 – 3.00 % and also varied with season. Soil OM levels of 1.0% are low relative to observations in other horticulture soils (Baldock and Sjemstad, 1999). These low levels are likely to be a reflection of the soil type and climate with three of the five tableland orchards being located on soils with sand profiles.

4.6.2 Mean soil chemical and nutrient values
Soil nutrient levels (0-20 cm), their range and the variation are shown in Table 9.

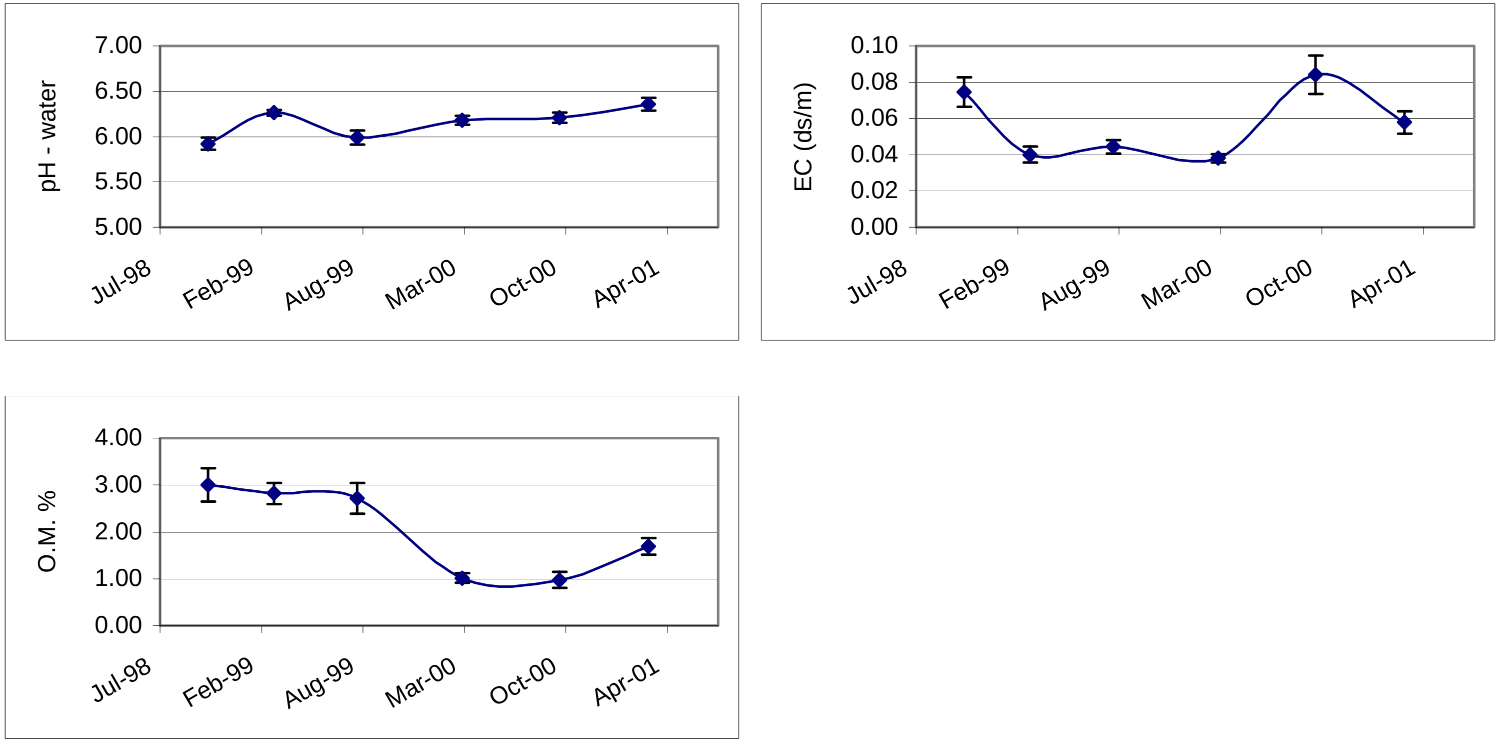


Figure 16. Average soil pH, EC and Organic Matter (0-20 cm) in longan orchards monitored from October 1998 to March 2001. Vertical bars are standard errors at each sampling period.

Table 9. Mean soil nutrient levels/ chemical characteristic and ranges encountered in longan orchards.

Nutrient/Chemical characteristic	Mean ± se	Median (range)	Generalised optimum values[#]
pH (1:5 water)	6.15 ± 0.05	6.20 (4.90-7.10)	5.5-6.5
pH (1:5 $CaCl_2$)	5.34 ± 0.06	5.35 (4.00-6.30)	
EC (1:5 aqueous)	0.06 ± 0.01	0.05 (0.02-0.16)	<0.4
Organic Matter	2.21 ± 0.22 (%)	2.00 (0.42-7.22)	3.4-6.9
Nitrate nitrogen	6.61 ± 1.26 (mg/kg)	2.70 (1.00-32.00)	10-60
Phosphorus (Colwell)	79.7 ± 9.9 (mg/kg)	67.0 (5.0-300.0)	20-120
Sulphur (KCl)	11.8 ± 2.1 (mg/kg)	5.4 (2.4-87.0)	
Potassium (exchangeable)	0.48 ± 0.06 (meq/100g)	0.29 (0.09-1.69)	>0.4
Calcium (exchangeable)	5.54 ± 0.59 (meq/100g)	5.55 (0.10-19.00)	>5.0
Magnesium (exchangeable)	2.53 ± 0.30 (meq/100g)	1.96 (0.25-8.20)	>1.6
Sodium (exchangeable)	0.16 ± 0.05 (meq/100g)	0.09 (0.01-2.75)	<0.5
Aluminium (exchangeable)	0.36 ± 0.24 (meq/100g)	0.10 (0.01-11.68)	<0.5
Chloride (1:5 aqueous)	14.5 ± 1.28 (mg/kg)	13.5 (5.0-46.0)	<300
Manganese (DTPA)	33.4 ± 6.3 (mg/kg)	22.0 (2.6-260.0)	4-45*
Iron (DTPA)	66.5 ± 10.9 (mg/kg)	48.5 (12.0-240.0)	Meaningless test (McFarlane 1999)
Copper (DTPA)	3.0 ± 0.4 (mg/kg)	1.65 (0.09-11.0)	0.3-10.0
Zinc (DTPA)	4.0 ± 1.4 (mg/kg)	1.39 (0.10-69.00)	2.0-10.0
Boron (calcium chloride)	0.96 ± 0.10 (mg/kg)	0.77 (0.13-2.79)	1.0-2.0
Cation balance			
Ca:Mg ratio	2.71 ± 0.14	2.33 (1.34-4.89)	3.0-5.1
Calcium	62.7 ± 1.5 (%)	64.0 (52.0-77.0)	65-80
Magnesium	26.6 ± 1.2 (%)	27.0 (14.0-39.0)	10-15
Potassium	6.6 ± 0.5 (%)	6.0 (1.0-14.0)	1-5
Sodium	1.91 ± 0.5 (%)	1.0 (0.0-4.0)	< 1.0
Aluminium	2.38 ± 0.39 (%)	1.0 (0.0-11.0)	< 1.0
C.E.C.	8.8 ± 0.9	8.6 (1.7-27.3)	> 7.0

[#] - range of publications; (Menzel *et al*. 1992, Menzel *et al*. 1993, George *et al*. 2001)
*- Analysis results are rarely useful for correctly diagnosing either Mn toxicity or deficiency (Uren, 1999).

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

4.6.3 Seasonal variations in soil nutrient concentrations

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

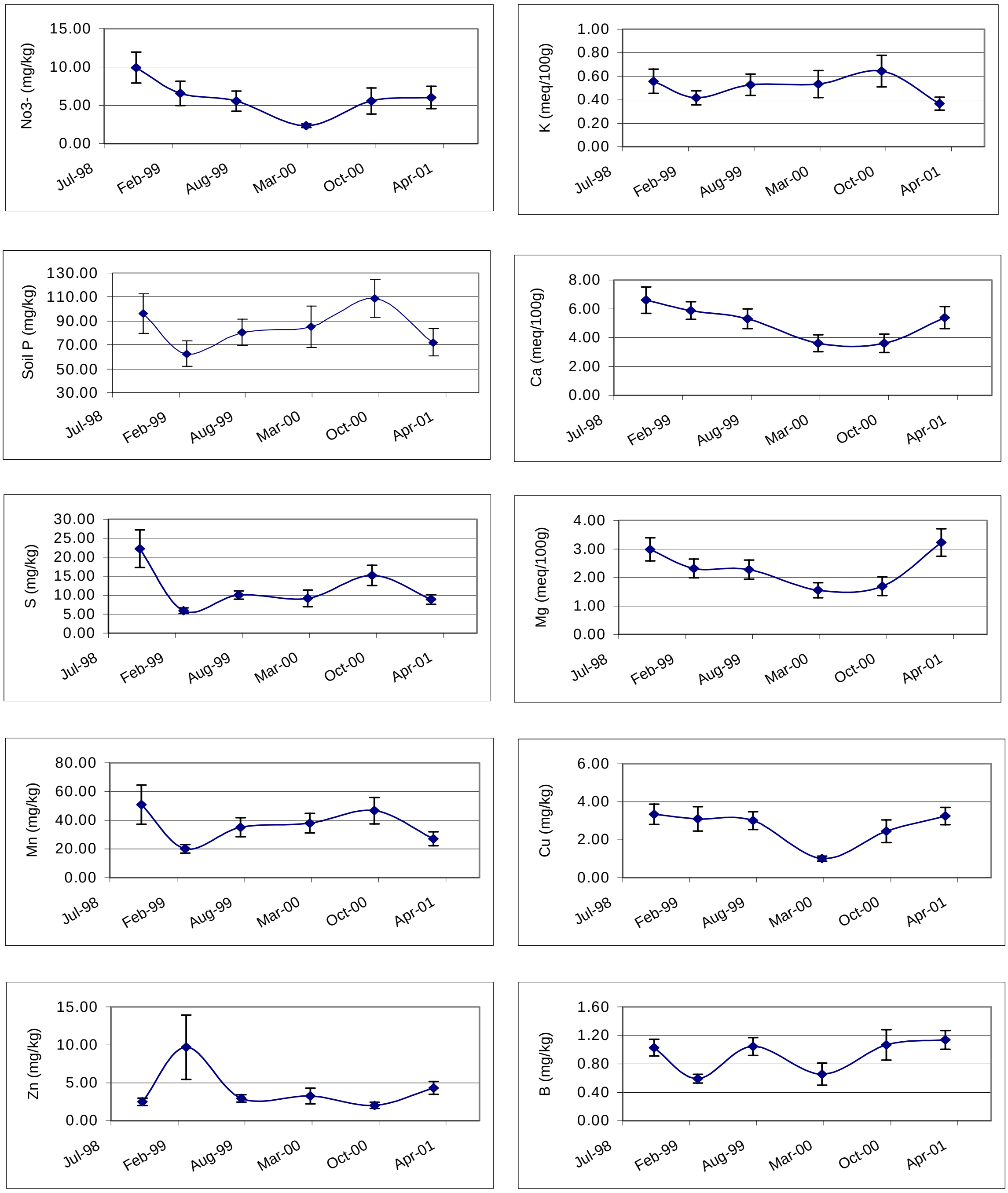


Figure 17. Seasonal variation in mean soil nutrient concentrations (NO_3-, P, S, K, Ca, Mg, Mn, Cu, Zn and B) in nine commercial longan orchards. Bars represent standard errors at each sampling. Iron levels are not shown due to the unreliability of the test and its interpretation.

4.7 Fertiliser inputs

Details on fertiliser inputs were collected over the monitoring period. Fertiliser inputs were converted to grams of element at each application and the total elemental input was then calculated (Table 10).

Table 10. Longan orchard fertiliser (foliar, granular, fertigated) inputs (g/tree) over three seasons. Maximum inputs of elements for each season are highlighted in bold. Median fertiliser inputs are shown in ***bold italics***.

Season	Grower Code	N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Mo	Fe
98/99	I	420.60	**508.00**	528.00	1280.00	**718.40**	**1005.35**	0.30	2.86	0.01	0.00	0.02	4.50
98/99	H	360.00	156.00	423.00	397.50	186.00	120.00	0.30	0.60	**4.56**	0.00	0.02	4.50
98/99	G	0.08	0.04	0.05	0.00	0.00	0.00	0.00	1.03	0.00	0.00	0.00	0.00
98/99	D	6.62	5.92	8.12	**2194.50**	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.14
98/99	B	378.67	431.60	**1537.13**	150.00	531.76	917.12	**27.44**	**14.86**	1.13	**0.81**	0.01	**6.62**
98/99	A	**721.38**	434.50	856.50	373.50	30.00	596.94	1.13	0.50	0.01	0.00	0.01	3.75
98/99	*Mean*	*314.56*	*256.01*	*558.80*	*732.58*	*244.36*	*439.90*	*4.86*	*3.31*	*0.95*	*0.13*	*0.01*	*3.25*
98/99	***Median***	***369.33***	***293.80***	***475.50***	***385.50***	***108.00***	***358.47***	***0.30***	***0.81***	***0.01***	***0.00***	***0.01***	***4.13***
98/99	*min*	*0.08*	*0.04*	*0.05*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
98/99	*max*	*721.38*	*508.00*	*1537.13*	*2194.50*	*718.40*	*1005.35*	*27.44*	*14.86*	*4.56*	*0.81*	*0.02*	*6.62*
		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Mo	Fe
99/00	I	250.10	66.12	772.42	425.00	209.52	864.86	22.53	4.04	0.00	0.00	0.00	4.95
99/00	H	236.00	140.10	469.30	944.60	427.41	1036.15	**63.09**	4.49	0.05	0.02	1.16	1.58
99/00	G	5.00	0.00	30.00	7.00	4.50	3.00	0.00	1.03	0.00	0.00	0.00	0.00
99/00	D	**1040.53**	**2120.51**	501.46	**3776.79**	350.83	**1625.13**	44.91	8.67	**30.43**	**249.54**	**3.40**	**750.18**
99/00	B	285.60	39.71	**1070.41**	0.00	**428.81**	503.20	26.38	**10.86**	0.00	0.00	0.00	2.79
99/00	A	165.88	81.00	166.00	137.50	38.40	140.60	0.50	0.28	0.00	0.00	0.11	1.50
99/00	*Mean*	*330.52*	*407.91*	*501.60*	*881.81*	*243.25*	*695.49*	*26.23*	*4.89*	*5.08*	*41.59*	*0.78*	*126.83*
99/00	***Median***	***243.05***	***73.56***	***485.38***	***281.25***	***280.18***	***684.03***	***24.45***	***4.26***	***0.00***	***0.00***	***0.06***	***2.19***
99/00	*min*	*5.00*	*0.00*	*30.00*	*0.00*	*4.50*	*3.00*	*0.00*	*0.28*	*0.00*	*0.00*	*0.00*	*0.00*
99/00	*max*	*1040.53*	*2120.51*	*1070.41*	*3776.79*	*428.81*	*1625.13*	*63.09*	*10.86*	*30.43*	*249.54*	*3.40*	*750.18*
		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Mo	Fe
00/01	I	412.90	228.00	637.50	790.00	126.00	**1092.30**	0.10	0.20	0.00	0.00	**0.51**	1.50
00/01	H	98.79	107.60	216.55	722.50	**228.60**	665.25	**58.09**	0.66	0.00	0.00	0.19	1.59
00/01	G	54.60	44.10	126.90	21.00	13.50	13.50	0.00	0.55	0.00	0.00	0.00	0.00
00/01	D	602.86	262.86	707.86	250.00	60.00	200.00	0.50	1.00	0.02	0.00	0.03	8.15
00/01	B	628.42	27.85	**988.26**	**7700.00**	138.14	412.98	17.53	**10.81**	**0.08**	**0.05**	0.00	4.36
00/01	A	**773.00**	**546.00**	896.00	2368.00	88.80	615.25	2.34	1.29	0.02	0.00	0.03	**9.00**
00/01	*Mean*	*428.43*	*202.74*	*595.51*	*1975.25*	*109.17*	*499.88*	*13.09*	*2.42*	*0.02*	*0.01*	*0.13*	*4.10*
00/01	***Median***	***507.88***	***167.80***	***672.68***	***756.25***	***107.40***	***514.12***	***1.42***	***0.83***	***0.01***	***0.00***	***0.03***	***2.97***
00/01	*min*	*54.60*	*27.85*	*126.90*	*21.00*	*13.50*	*13.50*	*0.00*	*0.20*	*0.00*	*0.00*	*0.00*	*0.00*
00/01	*max*	*773.00*	*546.00*	*988.26*	*7700.00*	*228.60*	*1092.30*	*58.09*	*10.81*	*0.08*	*0.05*	*0.51*	*9.00*

Seasonal inputs were calculated by summing all inputs from early post harvest to the following harvest. Fertiliser inputs varied considerably among orchards and season. For macro elements such as N, P and K minimum inputs were 0.8, 0.04, 0.05 g/tree respectively where as maximum inputs were 1040, 2120, 1537 g/tree respectively. Similarly for Ca, Mg and S inputs varied from 0 g/tree to 7700 g/tree for Ca. Micro nutrient inputs were also variable; however the range in inputs was smaller (0-750 g/tree/season). Maximum orchard/seasonal inputs for Zn, B, Cu, Mn, Mo and Fe were 63.09, 14.86, 30.43, 249.54, 3.40 and 750.18 g/tree respectively.

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

4.8 Fruit nutrient content

Fruit panicles from three orchards, including two cultivars (Kohala and Biew Kiew) were analysed for nutrient concentrations in the 2000/2001 season. Panicles were harvested at maturity, approximately a fortnight after commercial harvest had commenced. As described in the materials and methods, fruit plus minor stem as per commercial packaging was analysed separately from the remaining heavy panicle stem and stem plus leaf behind the panicle (Table 11).

Table 11. Nutrient concentration (dry weight basis) of fruit (skin, aril, seed plus minor panicle wood) and remaining panicle wood (stem plus leaf) and whole panicle. Data is presented as mean ± se and maximum and minimum values.

		%	%	%	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
vr.	Tissue	N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
Kohala	fruit	0.87	0.17	1.14	0.58	0.11	0.08	14.70	21.60	22.60	22.00	38.00
Kohala	fruit	1.18	0.20	1.35	0.49	0.12	0.10	16.90	17.10	8.80	29.00	40.00
Biew Kiew	fruit	1.31	0.20	1.22	0.79	0.15	0.12	26.90	21.20	55.10	22.00	51.00
Biew Kiew	fruit	1.50	0.22	1.20	0.54	0.13	0.12	40.00	22.60	91.60	17.00	57.00
Biew Kiew	fruit	1.55	0.22	1.45	0.70	0.16	0.15	35.50	22.80	80.70	42.00	68.00
Mean		***1.28****	***0.20***	***1.27***	***0.62***	***0.13***	***0.11***	***26.80***	***21.06***	***51.76***	***26.40***	***50.80***
SE		***0.12***	***0.01***	***0.06***	***0.06***	***0.01***	***0.01***	***4.97***	***1.03***	***16.02***	***4.34***	***5.54***
Max		***1.55***	***0.22***	***1.45***	***0.79***	***0.16***	***0.15***	***40.00***	***22.80***	***91.60***	***42.00***	***68.00***
Min		***0.87***	***0.17***	***1.14***	***0.49***	***0.11***	***0.08***	***14.70***	***17.10***	***8.80***	***17.00***	***38.00***
		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
Kohala	leaf+stem	0.97	0.16	0.96	2.82	0.31	0.12	19.60	38.90	88.60	86.00	53.00
Kohala	leaf+stem	0.94	0.15	0.76	2.85	0.31	0.09	13.10	31.20	5.70	71.00	49.00
Biew Kiew	leaf+stem	1.08	0.12	0.52	3.79	0.35	0.11	70.90	41.90	376.10	88.00	130.00
Biew Kiew	leaf+stem	1.18	0.20	0.67	3.49	0.31	0.14	198.70	54.80	883.70	120.00	160.00
Biew Kiew	leaf+stem	1.20	0.18	0.88	1.40	0.10	0.08	79.20	26.40	524.10	38.00	120.00
Mean		***1.07***	***0.16***	***0.76***	***2.87***	***0.28***	***0.11***	***76.30***	***38.64***	***375.64***	***80.60***	***102.40***
SE		***0.05***	***0.01***	***0.08***	***0.41***	***0.04***	***0.01***	***33.34***	***4.88***	***158.02***	***13.31***	***22.00***
Max		***1.20***	***0.20***	***0.96***	***3.79***	***0.35***	***0.14***	***198.70***	***54.80***	***883.70***	***120.00***	***160.00***
Min		***0.94***	***0.12***	***0.52***	***1.40***	***0.10***	***0.08***	***13.10***	***26.40***	***5.70***	***38.00***	***49.00***
Mean	***Panicle***	***1.18***	***0.18***	***1.02***	***1.74***	***0.20***	***0.11***	***51.55***	***29.85***	***213.70***	***53.50***	***76.60***
SE	***Panicle***	***0.10***	***0.01***	***0.14***	***0.60***	***0.05***	***0.01***	***25.32***	***5.31***	***130.54***	***15.82***	***19.41***
Max	***Panicle***	***1.55***	***0.22***	***1.45***	***3.79***	***0.35***	***0.15***	***198.70***	***54.80***	***883.70***	***120.00***	***160.00***
Min	***panicle***	***0.87***	***0.12***	***0.52***	***0.49***	***0.10***	***0.08***	***13.10***	***17.10***	***5.70***	***17.00***	***38.00***

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

Fruit plus minor stem contained higher concentrations of N, P and K than the remaining panicle stem plus leaf. Levels of S are the same in both samples, whereas the macronutrients Ca and Mg and all micronutrient levels were at a higher concentration in the remaining panicle stem and attached leaf than in the fruit. Fruit nutrient concentrations are generally less than those in leaf samples, except for potassium which is at a higher level in fruit (1.27%) than in leaf at any stage of sampling (0.89%).

4.9 Nutrient Budget

The tree productivity, fruit nutrient analysis and fertiliser input survey carried out as part of this project has allowed crop nutrient removal to be calculated. Mean fruit analysis concentrations (dry weight basis) were used to calculate nutrient removal based on an average fresh to dry weight ratio of 3.8 for fresh fruit plus minor panicle wood (Table 12). Nutrient budget in its simplest form is the difference between nutrient inputs and crop removal, in this case expressed as the difference.

Table 12. Mean longan fruit (minor panicle wood, skin, aril and seed) nutrient concentrations (dry weight basis) used for nutrient removal calculations.

Fruit Analysis	% N	% P	% K	% Ca	% Mg	% S	mg/kg Zn	mg/kg B	mg/kg Cu	mg/kg Mn	mg/kg Fe
Average	1.28	0.2	1.27	0.617	0.133	0.11	26.8	21.06	51.76	26.4	50.8

Nutrients budgets were calculated for participating growers who provided full details of their nutrient inputs and crop yields.

Table 13. Nutrient budget (g/tree) for Grower I based on fertiliser input and tree yields provided.

Inputs												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99		420.60	508.00	528.00	1280.00	718.40	1005.35	0.30	2.86	0.01	0.00	4.50
99/00		250.1	66.1	772.4	425.0	209.5	864.9	22.5	4.0	0.0	0.0	5.0
00/01		412.90	228.00	637.50	790.00	126.00	1092.30	0.10	0.20	0.00	0.00	1.50
Removal												
Season	Yield/tree (kg)	N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99	0	0	0	0	0	0	0	0	0	0	0	0
99/00	90	303.16	47.37	300.79	146.13	31.50	26.05	0.63	0.50	1.23	0.63	1.20
00/01	28	94.32	14.74	93.58	45.46	9.80	8.11	0.20	0.16	0.38	0.19	0.37
Difference												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99		420.60	508.00	528.00	1280.00	718.40	1005.35	0.30	2.86	0.01	0.00	4.50
99/00		-53.06*	18.75	471.63	278.87	178.02	838.81	21.90	3.54	-1.22	-0.63	3.75
00/01		318.58	213.26	543.92	744.54	116.20	1084.19	-0.10	0.04	-0.38	-0.19	1.13

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

For grower I nutrient inputs generally exceed those removed by the crop, except in the 1999/2000 season where crop removal of N, Cu and Mn exceeded that of fertiliser inputs. This site yield well in the 99/00 season and had an average crop in the 00/01 season despite high macro nutrient inputs.

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

Inputs												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99	Total	360.00	156.00	423.00	397.50	186.00	120.00	0.30	0.60	4.56	0.00	4.50
99/00	Total	236.00	140.10	469.30	944.60	427.41	1036.15	63.09	4.49	0.05	0.02	1.58
00/01	Total	98.79	107.60	216.55	722.50	228.60	665.25	58.09	0.66	0.00	0.00	1.59
Removal												
	Yield/tree											
Season	(kg)	N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99	0	0	0	0	0	0	0	0	0	0	0	0
99/00	6	20.21	3.16	20.08	9.74	2.10	1.74	0.04	0.03	0.08	0.04	0.08
00/01	8	26.95	4.21	26.78	12.99	2.80	2.32	0.06	0.04	0.11	0.06	0.11
Difference												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99		360.00	156.00	423.00	397.50	186.00	120.00	0.30	0.60	4.56	0.00	4.50
99/00		215.79	136.94	449.22	934.86	425.31	1034.41	63.05	4.45	-0.03	-0.02	1.50
00/01		71.84	103.39	189.77	709.51	225.80	662.93	58.03	0.61	-0.11	-0.06	1.48

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

For grower H nutrient inputs exceed those removed by the crop, except in the 1999/2000 and 2000/2001seasons where crop removal of Cu and Mn slightly exceeded that of fertiliser inputs. Over the duration of monitoring this site has been relatively low yielding, yet fertiliser inputs were relatively high.

Table 15. Nutrient budget (g/tree) for Grower G (*cv*. Kohala) based on fertiliser input and tree yields provided.

Inputs												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99	Total	0.08	0.04	0.05	0.00	0.00	0.00	0.00	1.03	0.00	0.00	0.00
99/00	Total	5.0	0.0	30.0	7.0	4.5	3.0	0.0	1.0	0.0	0.0	0.0
00/01	Total	54.60	44.10	126.90	21.00	13.50	13.50	0.00	0.55	0.00	0.00	0.00
Removal												
	Yield/tree											
Season	(kg)	N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99	20	67.37	10.53	66.95	32.47	7.00	5.79	0.14	0.11	0.27	0.14	0.27
99/00	35	117.89	18.42	117.16	56.83	12.25	10.13	0.25	0.19	0.48	0.24	0.47
00/01	35	117.89	18.42	117.16	56.83	12.25	10.13	0.25	0.19	0.48	0.24	0.47
Difference												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99		-67.29	-10.48	-66.89	-32.47	-7.00	-5.79	-0.14	0.91	-0.27	-0.14	-0.27
99/00		-112.89	-18.42	-87.16	-49.83	-7.75	-7.13	-0.25	0.83	-0.48	-0.24	-0.47
00/01		-63.29	25.68	9.74	-35.83	1.25	3.37	-0.25	0.36	-0.48	-0.24	-0.47

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

For grower G (*cv*. Kohala) nutrient removal exceeded inputs to the crop, for almost all elements, except B, in the first two seasons. In the last season (2000/2001) inputs of P, K, Mg, S and B exceeded removal. Over the duration of monitoring this site has yielded an average crop, yet fertiliser inputs were relatively low.

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

Inputs												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99	Total	0.08	0.04	0.05	0.00	0.00	0.00	0.00	1.03	0.00	0.00	0.00
99/00	Total	5.0	0.0	30.0	7.0	4.5	3.0	0.0	1.0	0.0	0.0	0.0
00/01	Total	54.60	44.10	126.90	21.00	13.50	13.50	0.00	0.55	0.00	0.00	0.00
Removal												
	Yield/tree											
Season	(kg)	N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
99/00	150	505.26	78.95	502.11	243.55	52.50	43.42	1.06	0.83	2.04	1.04	2.01
00/01	150	505.26	78.95	502.11	243.55	52.50	43.42	1.06	0.83	2.04	1.04	2.01
Difference												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99		0.08	0.04	0.05	0.00	0.00	0.00	0.00	1.03	0.00	0.00	0.00
99/00		-500.26	-78.95	-472.11	-236.55	-48.00	-40.42	-1.06	0.19	-2.04	-1.04	-2.01
00/01		-450.66	-34.85	-375.21	-222.55	-39.00	-29.92	-1.06	-0.28	-2.04	-1.04	-2.01

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

For grower G (*cv*. Chompoo) nutrient removal exceeded inputs to the crop, for almost all elements, except B, in all three seasons. Over the duration of monitoring, this site has yielded an above average crop in two of three seasons, yet fertiliser inputs were low.

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

Inputs												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99	Total	6.62	5.92	8.12	2194.50	0.00	0.00	0.01	0.00	0.00	0.00	0.14
99/00	Total	1040.5	2120.5	501.5	3776.8	350.8	1625.1	44.9	8.7	30.4	249.5	750.2
00/01	Total	602.86	262.86	707.86	250.00	60.00	200.00	0.50	1.00	0.02	0.00	8.15
Removal								g/tree				
	Yield/tree											
Season	(kg)	N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
99/00	215	724.21	113.16	719.68	349.09	75.25	62.24	1.52	1.19	2.93	1.49	2.87
00/01	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Difference												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99		6.62	5.92	8.12	2194.50	0.00	0.00	0.01	0.00	0.00	0.00	0.14
99/00		316.32	2007.35	-218.22	3427.69	275.58	1562.89	43.39	7.48	27.50	248.05	747.31
00/01		602.86	262.86	707.86	250.00	60.00	200.00	0.50	1.00	0.02	0.00	8.15

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

For grower D nutrient inputs exceed those removed by the crop, except for K in the high yielding 1999/2000 season where crop removal of K exceeded that of fertiliser inputs. Nil yields were recorded in the two of three seasons.

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

Inputs												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99	Total	378.67	431.60	1537.13	150.00	531.76	917.12	27.44	14.86	1.13	0.81	6.62
99/00	Total	285.6	39.7	1070.4	0.0	428.8	503.2	26.4	10.9	0.0	0.0	2.8
00/01	Total	628.42	27.85	988.26	7700.00	138.14	412.98	17.53	10.81	0.08	0.05	4.36
Removal												
	Yield/tree											
Season	(kg)	N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99	26.4	100.97	14.82	89.62	46.78	10.05	9.03	0.24	0.15	0.53	0.19	0.41
99/00	36.4	139.21	20.44	123.57	64.50	13.86	12.45	0.33	0.21	0.73	0.26	0.56
00/01	178.5	682.68	100.21	605.96	316.29	67.96	61.07	1.60	1.04	3.56	1.27	2.76
Difference												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99		277.70	416.78	1447.51	103.22	521.71	908.09	27.20	14.70	0.61	0.62	6.21
99/00		146.39	19.27	946.85	-64.50	414.95	490.75	26.05	10.65	-0.73	-0.26	2.23
00/01		-54.27	-72.36	382.30	7383.71	70.19	351.91	15.93	9.77	-3.48	-1.21	1.60

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

For grower B nutrient inputs generally exceed those removed by the crop, except in the 1999/2000 where Ca, Cu and Mn inputs were deficient and 2000/2001seasons where crop removal of N, P, Cu and Mn exceeded that of fertiliser inputs. Over the duration of monitoring this site has been low to high yielding, yet fertiliser inputs were relatively high.

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

Inputs												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99	Total	721.38	434.50	856.50	373.50	30.00	596.94	1.13	0.50	0.01	0.00	3.75
99/00	Total	**165.9**	**81.0**	**166.0**	**137.5**	**38.4**	**140.6**	**0.5**	**0.3**	**0.0**	**0.0**	**1.5**
00/01	Total	773.00	546.00	896.00	2368.00	88.80	615.25	2.34	1.29	0.02	0.00	9.00
Removal												
	Yield/tree											
Season	(kg)	N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99	100	336.84	52.63	334.74	162.37	35.00	28.95	0.71	0.55	1.36	0.69	1.34
99/00	40	134.74	21.05	133.89	64.95	14.00	11.58	0.28	0.22	0.54	0.28	0.53
00/01	4	13.47	2.11	13.39	6.49	1.40	1.16	0.03	0.02	0.05	0.03	0.05
Difference												
Season		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
98/99		384.53	381.87	521.76	211.13	-5.00	567.99	0.42	-0.05	-1.35	-0.69	2.41
99/00		31.14	59.95	32.11	72.55	24.40	129.02	0.21	0.06	-0.54	-0.28	0.97
00/01		759.53	543.89	882.61	2361.51	87.40	614.09	2.31	1.27	-0.03	-0.03	8.95

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

For grower A nutrient inputs generally exceed those removed by the crop, except for Cu and Mn in all seasons where crop removal exceeded that of fertiliser inputs. Over the duration of monitoring this site has been low to high yielding, yet fertiliser inputs were relatively high.

5. Discussion

The project objectives were to;

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

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

5.1 Changes in longan leaf and soil nutrient status

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

5.1.1 Soil nutrient status

Soil nutrients were presented as mean ± se as well as the median value with associated range (Table 8). In most cases soil nutrient and chemical characteristics (pH, EC) were within optimum range for horticulture crops. Mean soil nutrient data generated from all farms over all sampling dates suggest that the soil cation balance, in particular the Ca:Mg ratio was biased toward magnesium. Ideal Ca:Mg ratios are reported to be in the range of 3.0-5.0 whereas the median Ca:Mg ratio reported in longans orchards was 2.33 with a range of 1.34-4.89. The importance of cation balance and in particular Ca:Mg ratio is now commonly raised as an important issue in horticulture industry publications, in particular *via* advertising literature supplied by some fertiliser companies. Conyers (1999) reports that although the ideal soil was considered to contain exchangeable cations in the proportions 65-85% Ca, 6-12% Mg and 2-5% K when expressed relative to CEC, it was noted that for Ca, Mg and K substantial departures from these ideal proportions could occur without detriment to yield, particularly for crops other than lucerne. Hence, Conyers (1999) suggests that it is best to regard these much quoted 'ideal' ratios as no more than a general guide and therefore do not form the basis for making fertiliser recommendations.

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

5.1.2 Leaf nutrient status

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

sampling a wide range of commercial orchards with yield being documented
identification of leaf standards based on orchard yields and tree health
determination of the ideal sampling time (nutrient concentrations are most stable)
selection of an easily recognizable leaf for sampling purposes.

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

Leaf nutrient concentrations are presented as overall and seasonal means with associated se, range data at 95% confidence interval and coefficient of variation (Table 8). The leaf nutrient concentrations of N, P, K, found in this study are generally similar to that presented by overseas researchers for producing orchards (Table 20). For the macronutrients N, P and K nutrient concentrations are generally similar to overseas data. Leaf nutrient concentrations of Ca and Mg are higher in Australian orchards than their overseas counterparts. This may be simply a reflection of higher Ca and Mg fertiliser inputs. Direct comparison cannot be made because of the lack of fertiliser input data presented in the overseas literature. Overseas data for S is not available to comment on.

Table 20. Longan leaf macronutrient range (95% confidence interval of the mean) from this study compared to data presented by overseas researchers.

Reference	N %	P %	K %	Ca %	Mg %	S %
This Study	**1.68-1.82**	**0.16-0.18**	**0.77-0.89**	**2.41-2.91**	**0.34-0.39**	**0.15-0.17**
Wang et al. (1992)	1.21-1.73	0.17-0.25	0.52-1.02	0.59-1.33	0.09-0.23	na
Chen (1997)	1.47-1.79	0.11-0.19	0.89-1.77	0.76-1.12	0.24-0.47	na
Thai data (unpublished)	1.7	0.12-0.20	0.6-0.8	1.50-2.50	0.20-0.30	na
Wong and Ketsa (1991)	> 1.7	0.12-0.20	0.60-0.80	1.50-2.50	0.2-0.3	na

Leaf micronutrient concentrations found in this study are compared to overseas data in Table 21. Data is scarce for leaf micronutrients, with the only overseas data available being presented by Chen (1997).

Table 21. Longan leaf micronutrient range (95% confidence interval of the mean) from this study compared to data presented by overseas researchers.

Reference	Fe mg/kg	Mn mg/kg	Zn mg/kg	Cu mg/kg	B mg/kg
This Study	88 - 141	70 -96	30 - 65	36 - 132	48 - 63
Wang et al. (1992)	na	na	na	na	na
Chen (1997)	100 -120	200-300	20-28	15-25	40-60
Thai data (unpublished)	na	na	na	na	na
Wong and Kesta (1991)	na	na	na	na	na

Australian orchard standard ranges are lower for Mn (70-96 mg/kg) relative to 200-300 mg/kg presented by Chen (1997). This may be a reflection of soil type, soil water status rather than an absolute requirement for Mn in overseas grown longan. The Australian standard range for Fe, Zn, Cu and B are similar or higher than that presented by Chen (1997). The higher end of the range in Australian orchards is most likely a reflection of the frequent use of foliar micronutrient sprays which is a regular feature of Australian orchard management.

The mean seasonal leaf nutrient concentrations with associated coefficient of variation are presented in Table 7; indicate that sampling the mature summer flush resulted in 6 of thirteen nutrients with the lowest coefficient of variation, relative to 3 of thirteen for the postharvest and early panicle emergence samples and 1 of thirteen for the fruit filling sample. The sampling period in which the largest numbers of nutrients have the lowest CV is generally accepted as the best sampling period for analytical and fertiliser recommendation purposes (lychee - Menzel *et al.* 1992, mango - Catchpoole and Bally, 1996 and persimmons - George *et al*. 2001).

Although this may suggest that the mature summer flush is the ideal sampling time, mean leaf nitrogen levels of 1.89 % with a CV of 20% relative to the lower (1.7 %) and more stable mean (CV = 15.7%) which exists at early panicle emergence could adversely affect flowering and yield. The leaf and nutrient survey data suggests that flowering and hence subsequent fruit set and yield may be adversely affected when leaf N levels exceeds 2.0%, pre-flowering, despite the fact that the season may be ideal for flowering, often described by industry as an “on year”.

Based on the above observations, the ideal sampling time for the leaf standards are considered to be at early panicle emergence. This is a common time for a number of crops. Another advantage of this sampling period is the ease of which sample leaves can be collected. The mature leaf below the emerging panicle is easily identifiable unlike the mature summer flush. Sampling only at early panicle emergence, however, does not assist with the management of nitrogen inputs, from post harvest to flowering because the potentially deleterious effects of high leaf N levels may have already occurred at that sampling time. Leaf sampling of the summer flush would allow growers to manage their nitrogen inputs to avoid excessive levels pre-flowering. Increased frequency of sampling will enable growers to fine tune their fertiliser management program.

5.2 Fertiliser inputs

Full fertiliser inputs were provided by six of the nine cooperative growers. These data clearly showed that fertiliser inputs varied widely between orchards and between years on the same orchard. For example elemental N inputs varied from a low of 0.08 to a high of 1040.5 g/tree/season. Similarly inputs of elemental P varied from 0.0 to 2120.5 g/tree/season while elemental K inputs varied from 0.05 to 1537.13 g/tree/season. Likewise, micronutrient inputs were also highly variable with large differences occurring between orchards and seasons.

The variability in fertiliser input is less dramatic but still highly variable, when tree density is taken into account. Fertiliser inputs in kg/ha are shown in Table 22. In terms of the three major macro nutrients nitrogen inputs ranged from 0 to 130 kg/ha while P inputs ranged from 0 to 265 kg/ha and K inputs ranged from 0 to 192 kg/ha. Similarly inputs for Ca, Mg and S were also highly variable.

Elemental micronutrient inputs also varied widely and ranged from 0 kg/ha to highs of 31.2 and 93.7 kg/ha for Mn and Fe in orchard D during the 99/00 season. In most cases micronutrient inputs were generally less than 10 kg/ha. Its clear from the fertiliser input data that the key micronutrient inputs were considered to be Fe, Zn and B, whereas very few growers actively added Cu and Mn.

Fertiliser inputs in Australian orchards are in the same range as inputs reported overseas. Wang *et al*. (1992) reports that 30 to 50 year old productive trees receive the equivalent of 440kg/ha N, 145 kg/ha P and 306 kg/ha K, mainly in the form of organic matter. In Thailand Ungasit *et al*. (1999) reports a fertiliser management strategy where total inputs of inorganic fertiliser are equivalent to 287 kg/ha N, 104 kg/ha P and 214 kg/ha K for 10 year old trees. The fertiliser schedule is growth stage dependent with 63 % of N, 51 % of K and 55 % of K being added from flowering to harvest in three applications. Conversely 37 % of N, 49 % P and 45 % K is added at two stages, immediately post harvest and pre-flowering.

The bulk of fertiliser inputs occurred from flowering through to harvest with smaller, although still substantial amounts applied immediately after harvest and pruning. Little to no fertiliser was added in the month prior to flowering, with the exception of a few growers who apply a range of micronutrients (Zn, B, Fe) as foliar sprays during this period. This suggests that orchard managers are applying fertilisers when they are most needed, during fruit filling and immediately post harvest and pruning. Many fertilisers, in particular N, K, Mg and micronutrients are applied via the irrigation system further improving the efficiency of fertiliser uptake.

Table 22. Seasonal nutrient inputs (kg/ha) occurring on six longan orchards over three seasons.

Grower Code	Season	Tree per ha	N	P	K	Ca	Mg	S	Zn (kg/ha)	B	Cu	Mn	Fe
A	98/99	125	90.2	54.3	107.1	46.7	3.8	74.6	0.14	0.06	0.00	0.00	0.47
A	99/00		20.7	10.1	20.8	17.2	4.8	17.6	0.06	0.04	0.00	0.00	0.19
A	00/01		96.6	68.3	112.0	296.0	11.1	76.9	0.29	0.16	0.00	0.00	1.13
B	98/99	125	47.3	54.0	192.1	18.8	66.5	114.6	3.43	1.86	0.14	0.10	0.83
B	99/00		35.7	5.0	133.8	0.0	53.6	62.9	3.30	1.36	0.00	0.00	0.35
B	00/01		78.6	3.5	123.5	962.5	17.3	51.6	2.19	1.35	0.01	0.01	0.54
D	98/99	125	0.8	0.7	1.0	274.3	0.0	0.0	0.00	0.00	0.00	0.00	0.02
D	99/00		130.1	265.1	62.7	472.1	43.9	203.1	5.61	1.08	3.80	31.19	93.77
D	00/01		75.4	32.9	88.5	31.3	7.5	25.0	0.06	0.13	0.00	0.00	1.02
G	98/99	250	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.26	0.00	0.00	0.00
G	99/00		1.3	0.0	7.5	1.8	1.1	0.8	0.00	0.26	0.00	0.00	0.00
G	00/01		13.7	11.0	31.7	5.3	3.4	3.4	0.00	0.14	0.00	0.00	0.00
H	98/99	208	74.9	32.4	88.0	82.7	38.7	25.0	0.06	0.12	0.95	0.00	0.94
H	99/00		49.1	29.1	97.6	196.5	88.9	215.5	13.12	0.93	0.01	0.00	0.33
H	00/01		20.5	22.4	45.0	150.3	47.5	138.4	12.08	0.14	0.00	0.00	0.33
I	98/99	166	69.8	84.3	87.6	212.5	119.3	166.9	0.05	0.47	0.00	0.00	0.75
I	99/00		41.5	11.0	128.2	70.6	34.8	143.6	3.74	0.67	0.00	0.00	0.82
I	00/01		68.5	37.8	105.8	131.1	20.9	181.3	0.02	0.03	0.00	0.00	0.25

5.3 Effect of nutrient status on productivity

Tree productivity varied widely between orchards and within orchards across seasons (Table 6). This is not unexpected given that flowering in longan is usually associated with cool dry conditions (Batten 1986, Menzel 1989, Subhadrabandhu and Yapwattanaphun, 2001) and the climatic variability between seasons at any one survey location and the variability between locations over the three monitoring seasons.

Average yields over the three seasons of monitoring are compared with average macro and micro nutrient concentrations (Table 23).

Table 23. Average macro and micro leaf nutrient concentrations for seven longan orchards with corresponding average yields over three seasons of monitoring.

Code	N %	P %	K %	Ca %	Mg %	S %	Mn mg/kg	Fe mg/kg	Cu mg/kg	Zn mg/kg	B mg/kg	Av. Yield kg/ha
G2	1.48	0.16	0.66	3.08	0.46	0.17	61.67	207.50	28.35	24.33	49.17	25000
G1	1.58	0.14	0.58	3.45	0.45	0.18	38.00	144.33	63.10	18.67	54.33	7500
I	1.61	0.20	0.91	3.09	0.39	0.17	88.00	62.90	55.88	43.30	61.50	6529
A	1.73	0.17	0.91	2.66	0.32	0.13	29.86	51.29	10.69	17.86	36.00	6000
H	1.74	0.19	0.99	1.94	0.28	0.15	69.50	47.38	61.01	27.00	58.25	971
B	1.80	0.15	0.65	3.42	0.38	0.16	118.80	152.20	330.02	170.30	59.10	10050
D	1.88	0.19	0.93	2.55	0.37	0.17	79.17	70.50	45.60	31.00	50.17	8959

There is no clear association between mean nutrient status and fruit yield over the three seasons. This is a reflection of the other key factors that control yield potential, such as pruning management and climate. For the sake of this discussion it is presumed that water inputs (rain or irrigation) were sufficient and no yield decline occurred due to water deficits. In four of six orchards this was confirmed via irrigation monitoring. Observations during the conduct of the project suggest that flowering was poor or non existent in orchards where leaf N exceeded 1.8 % and in particular where leaf N was near or over 2.0% despite climatically favorable conditions. Li *et al.* (1999) have also questioned the effect of leaf nitrogen level and flowering success in a range of terminal flowering tropical crops in Florida. Observations from this project in relation to leaf N and flowering further confirm the observations reported by Nakasone and Paull (1998) where they suggest that low leaf N is required as trees enter a “rest period” prior to floral induction. Further work is required to define the relationship between pre-flowering leaf N concentrations and flowering.

Soil nutrient status and fertiliser inputs are all critical to maintaining tree nutrient status. The CEC of orchard ‘G’ soils were high (15.8 meq/100g) and average yields of the two monitored plots over the three seasons were high despite relatively low macro and micro nutrient inputs (Table 24). In the other sites where yield data is available soil CEC ranged from 2.3 to 13.4. Although high CEC soils offer advantages in terms of improved nutrient storage there is no evidence to suggest that long term yields are directly related to soil CEC. Likewise yield is not directly related to total nutrient inputs.

Table 24. Longan yield (average and total) over three seasons compared to total macro and micro nutrient inputs.

Grower	Average Yield (kg/tree)	Average Yield (kg/ha)	Total Yield (kg/ha)	Total Macro Nutrients (kg/ha)	Total Micro Nutrients (kg/ha)	Average CEC (meq/100g)
H	4.67	971	2800	1443	29	2.3
A	48	6000	18000	1129	2.5	11.4
I	39.33	6529	19500	1716	6.8	4.0
D	71.67	8959	26900	1714	136.7	7.9
G1	30	7500	22600	80.8	0.65	15.8
B	80.4	10050	30200	2021	15.4	13.4
G2	100	25000	75000	80.8	0.65	15.8

5.4 Tree phenology, climate and irrigation

Tree phenology was monitored and presented in Table 5 and yield data is presented in Table 6. The relationship between phenology, yield and climate was best observed on Tableland Farms where climate monitoring and yield data was available without the influence of heavy pruning and or flowering manipulation practices. Mean monthly temperature data (1998 – 2001) for orchard I, representative of Tableland sites, is shown in Figure 3 and clearly shows that the winter months (June – August) in 1998 and 2001 had higher average mean temperatures than occurred in 1999 and 2000.

The mean yields of the four Tableland farms that provided data for the three seasons 98/99, 99/00 and 00/01 were 3.9 t/ha, 6.4 t/ha and 7.3 t/ha. Over that period individual orchards performed best in different seasons (Table 25).

Table 25. Tableland orchard yield (t/ha)over three seasons.

Grower Code	1998/1999	1999/2000	2000/2001
A	12.5	5.0	0.5
B	3.3	4.5	22.4
H	0.0	1.2	1.6
I	0.0	14.9	4.6
Average Yield (t/ha)	3.9	6.4	7.3

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

Irrigation inputs varied between sites, dependent on tree size, rainfall, season, soil type and management. The lowest irrigation inputs coincided with the wet season while the highest inputs coincided with fruit filling. Soil tensions increased during periods when rainfall was less than 30 mm/week and irrigation inputs were less than 50 L/tree/day (or 350 L/week).

In general irrigation inputs were more than sufficient to maintain tree growth. It is highly unlikely that trees were stressed at any occasion during the monitoring period. In most cases over irrigation, which potentially promotes leaching of fertiliser, is more of an issue than under irrigation.

5.5 Fertiliser management strategy

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

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

Table 26. Mean longan fruit nutrient analysis and amount of element removed (g/tree) for various tree yields.

		%	%	%	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Fruit		N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
nutrient status		1.28	0.2	1.272	0.617	0.133	0.11	26.8	21.06	51.76	26.4	50.8
Yield		Nutrient Removal (g/tree)										
(kg/tree)	Fw/Dw	N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
1	3.8	3.37	0.53	3.35	1.62	0.35	0.29	0.007	0.006	0.014	0.007	0.013
10	3.8	33.68	5.26	33.47	16.24	3.50	2.89	0.07	0.06	0.14	0.07	0.13
20	3.8	67.37	10.53	66.95	32.47	7.00	5.79	0.14	0.11	0.27	0.14	0.27
30	3.8	101.05	15.79	100.42	48.71	10.50	8.68	0.21	0.17	0.41	0.21	0.40
40	3.8	134.74	21.05	133.89	64.95	14.00	11.58	0.28	0.22	0.54	0.28	0.53
50	3.8	168.42	26.32	167.37	81.18	17.50	14.47	0.35	0.28	0.68	0.35	0.67
80	3.8	269.47	42.11	267.79	129.89	28.00	23.16	0.56	0.44	1.09	0.56	1.07
100	3.8	336.84	52.63	334.74	162.37	35.00	28.95	0.71	0.55	1.36	0.69	1.34
140	3.8	471.58	73.68	468.63	227.32	49.00	40.53	0.99	0.78	1.91	0.97	1.87
180	3.8	606.32	94.74	602.53	292.26	63.00	52.11	1.27	1.00	2.45	1.25	2.41
210	3.8	707.37	110.53	702.95	340.97	73.50	60.79	1.48	1.16	2.86	1.46	2.81

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 26). Fruit harvest and removal is prime source of nutrient loss, as shown in the above formula. Fortunately it is easily calculated. The more difficult issue is accounting for other forms of nutrient loss via leaching, runoff and volatilisation.

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

Further nutrient requirements are needed due to nutrient loss or 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 and 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 longan 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. Longan fruit nutrient loss (g/kg) and nutrient replacement based on generalised 'other loss' factors.

	N	P	K	Ca	Mg	S	Zn	B	Cu	Mn	Fe
Fruit loss (g/kg)	3.37	0.53	3.35	1.62	0.35	0.29	0.01	0.01	0.01	0.01	0.01
Other loss %	40	100	30	10	25	0	0	0	0	0	0
Total Replacement (g/kg)	4.72	1.05	4.35	1.79	0.44	0.29	0.01	0.01	0.01	0.01	0.01

Hence for a high yielding longan crop (25 tonne/ha) the macronutrient inputs per hectare required to replace total nutrient loss are 118 kg N, 109 K, 45 kg Ca, 26 kg P, 11 kg Mg, 7.2 kg S. For micronutrients where no 'other loss' factors are available estimates of loss based on fruit nutrient content only are 0.3 kg for Cu and Fe, 0.2 kg for Zn and Mn and 0.1 kg for B. In most longan orchards monitored macro and micronutrient inputs exceeded outputs by 100%.

6. Implications

6.1 Longan fertiliser management

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

High leaf N levels (2.0%) during the period leading up to flowering should be avoided as there are indications that this may be detrimental to flowering and hence subsequent cropping. Over the duration of the project the data collected as part of the nutrient survey was unable to identify any direct links between tree nutritional status, fertiliser inputs and yield. This suggests that other factors such as pruning practices and climate play an 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.

6.2 Longan irrigation requirements

Longan irrigation requirements during fruit filling were monitored at three sites and the crop factor (tree water requirements relative to evaporation) estimated as 0.83. Hence irrigation requirements can be calculated using a simple evaporation based calculation;

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

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

6.3 Longan Phenology based management calendar

The recommendations arising from the data collected during this survey has been summerised in a management calendar (Figure 18). The calendar is for *cv*. Kohala grown in the elevated tropical environment of the Atherton Tablelands.

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

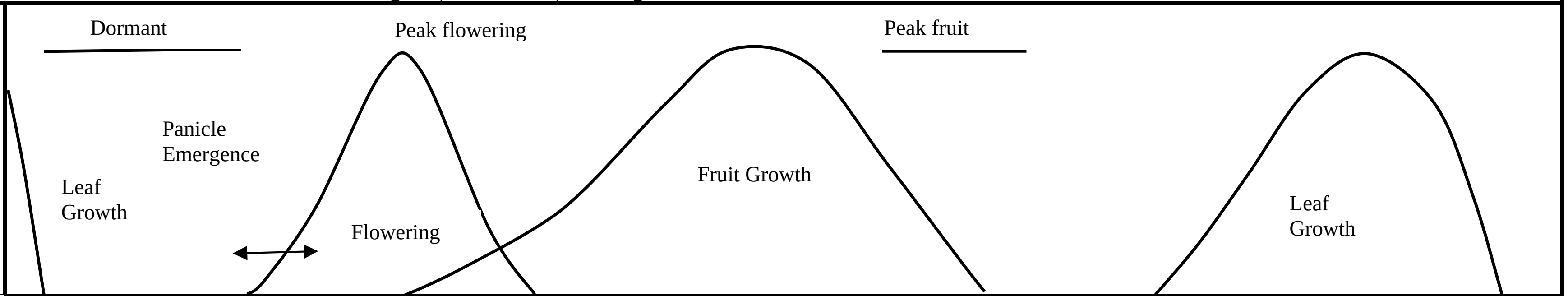
Longan (*cv.* Kohala) Management Calender – Atherton Tablelands													
Crop Phenology													
Month	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Fertiliser													
N					Majority of N to be applied during fruit filling and immediately post harvest								
P													
K					Majority of K to be applied during fruit filling and immediately post harvest								
pH/Ca/Mg													
Trace elements						Add as foliar or *via* fertigation as required (leaf test)							
Leaf Analysis		Pre or early panicle emergence				Optional						Optional	
Soil Analysis		Pre or early panicle emergence											
Irrigation	Reduce or withdraw irrigation.		Increase irrigation as temperatures and fruit size increase. Monitor soil moisture and ensure adequate soil moisture available from 0 – 60 cm where the bulk of feeder roots present.							Ensure sufficient soil moisture is available for active leaf growth			
Pruning		Major branch removal			Panicle pruning to ensure development of full fruit size.				Immediately after harvest				
	Major branch removal is best done in winter to minimise regrowth								Prune at or immediately harvest to maintain tree shape and size				

Figure 18. Proposed longan management calendar for cv. Kohala grown in the elevated tropics of the Atherton Tablelands.

7. Recommendations

1. Longan 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.

Use the nutrient budget to develop a fertiliser program for the season, based on yield projections.

Encourage the use of ‘fertigation” as a more efficient method of fertiliser application.

Monitor longan yields in conjunction with fertiliser management records to validate the nutrient budget approach over a minimum of 5 seasons, to reduce the effects of climate and other management issues (pruning) on yield.

2. Further work should be considered to better define the relationship between pre-flowering leaf N concentrations and the ability of longan to flower. This work should take into account cultivars and growing region.

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9. Appendix – Climate Measurements

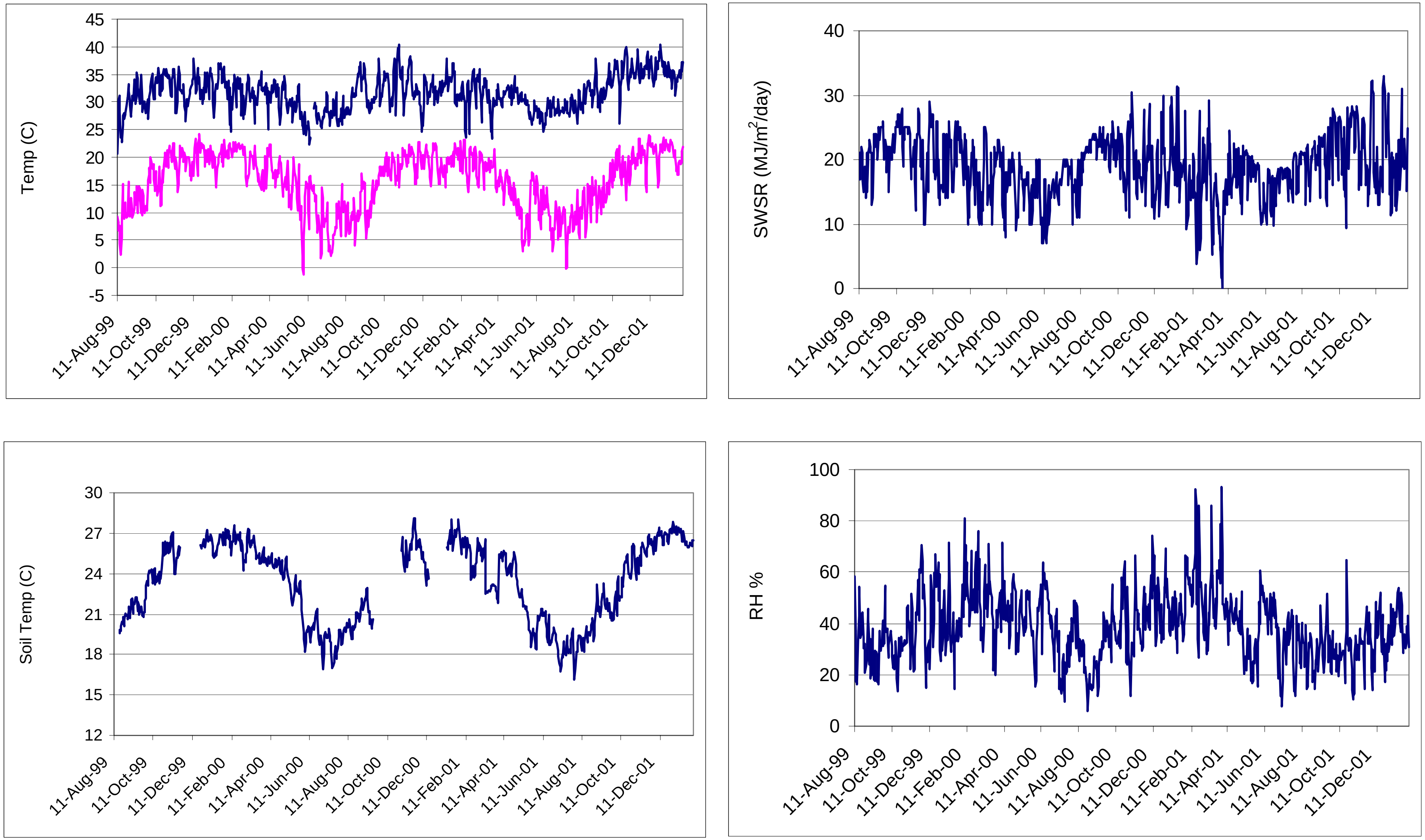

Figure 19. Daily Maximum and Minimum Temperature, Soil Temperature, Short wave solar radiation and minimum RH recorded at Piemonte Road site.

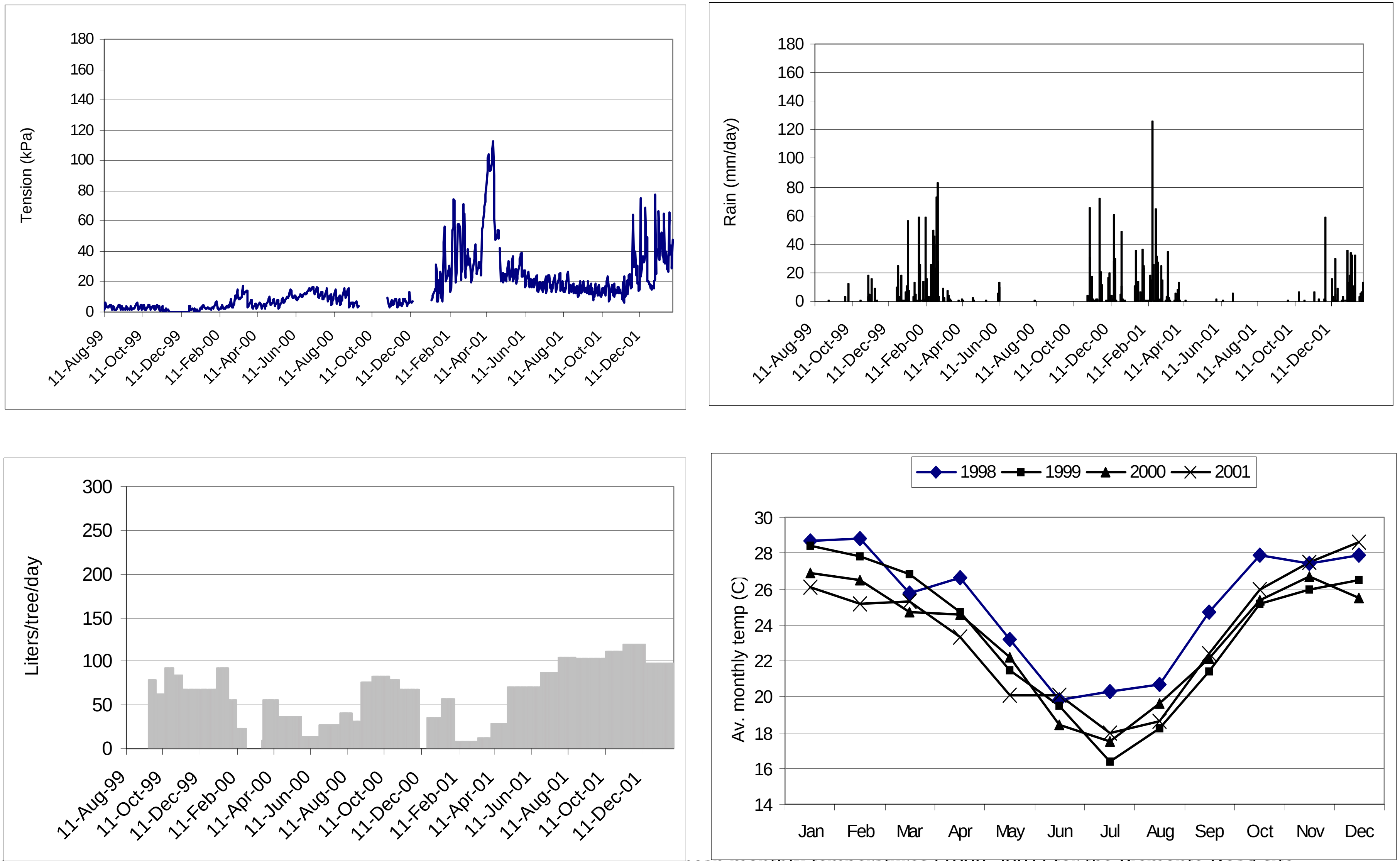

Figure 20. Daily rainfall, soil moisture tension at 30 cm, irrigation input and mean monthly temperatures (1998-2001) for the Piemonte Road site.

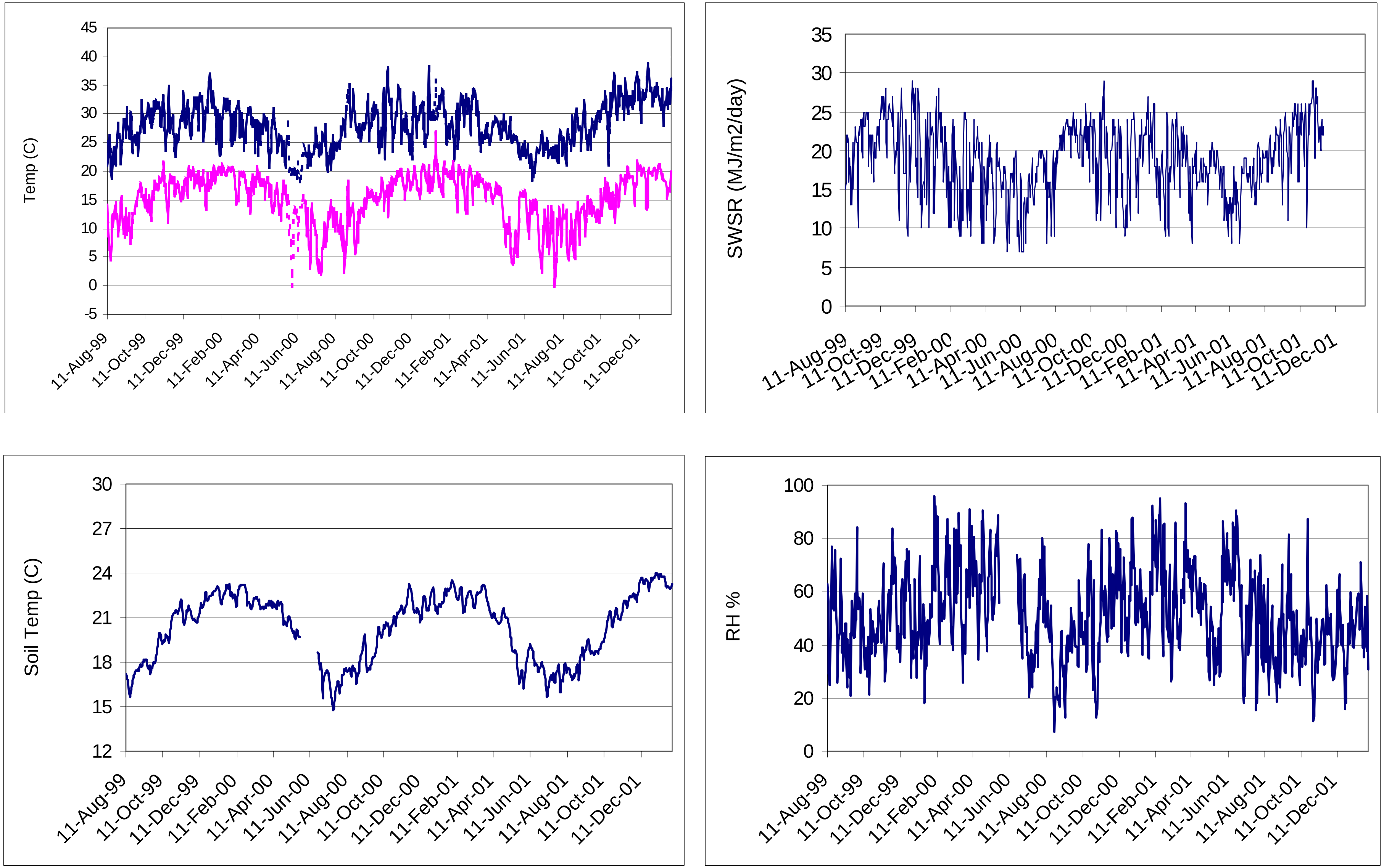

Figure 21. Daily Maximum and Minimum Temperature, Soil Temperature, Short wave solar radiation and minimum RH recorded at the Marks Lane site.

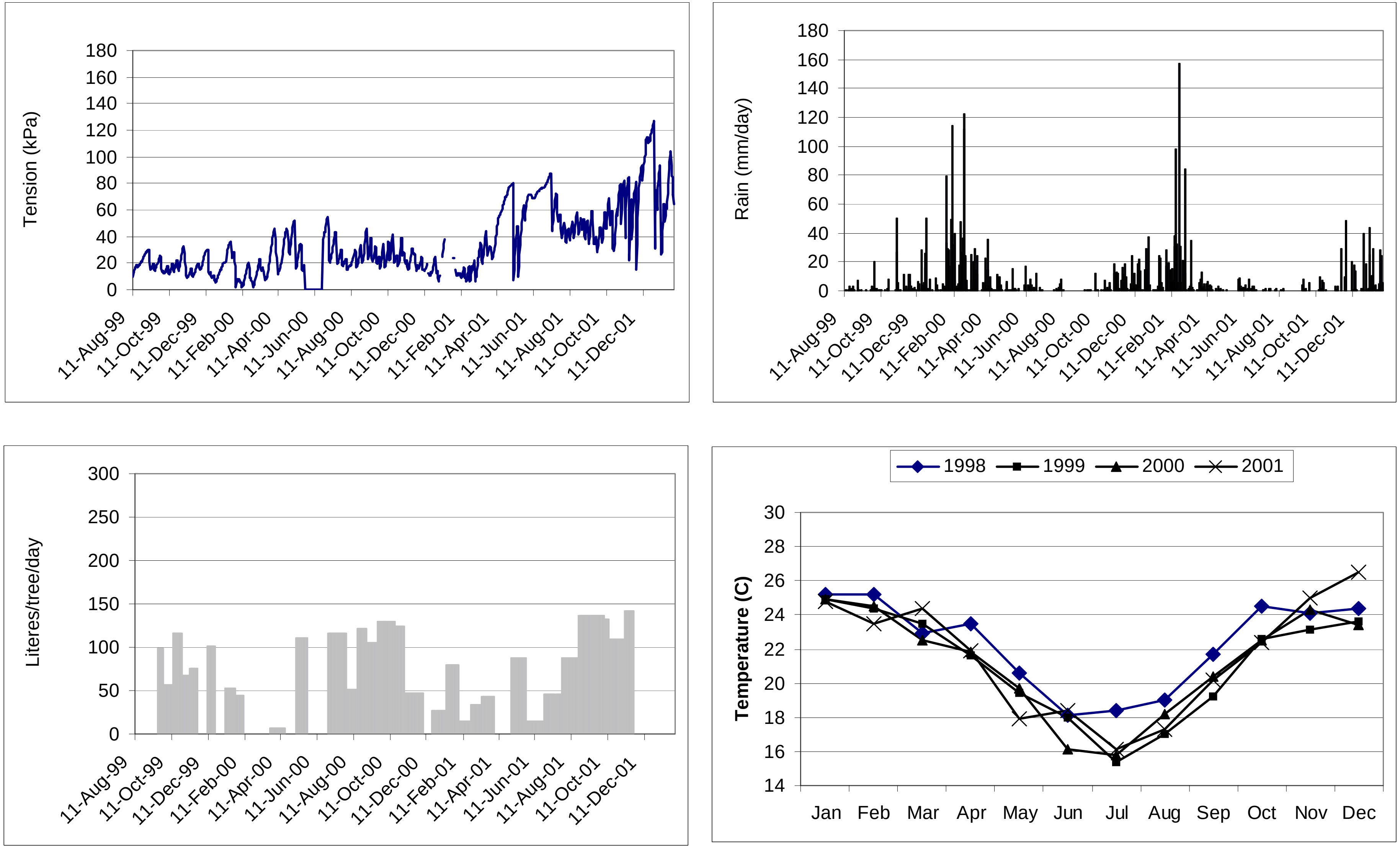

Figure 22. Daily rainfall, soil moisture tension at 30 cm, irrigation input and mean monthly temperatures (1998-2001) for the Marks Lane site.

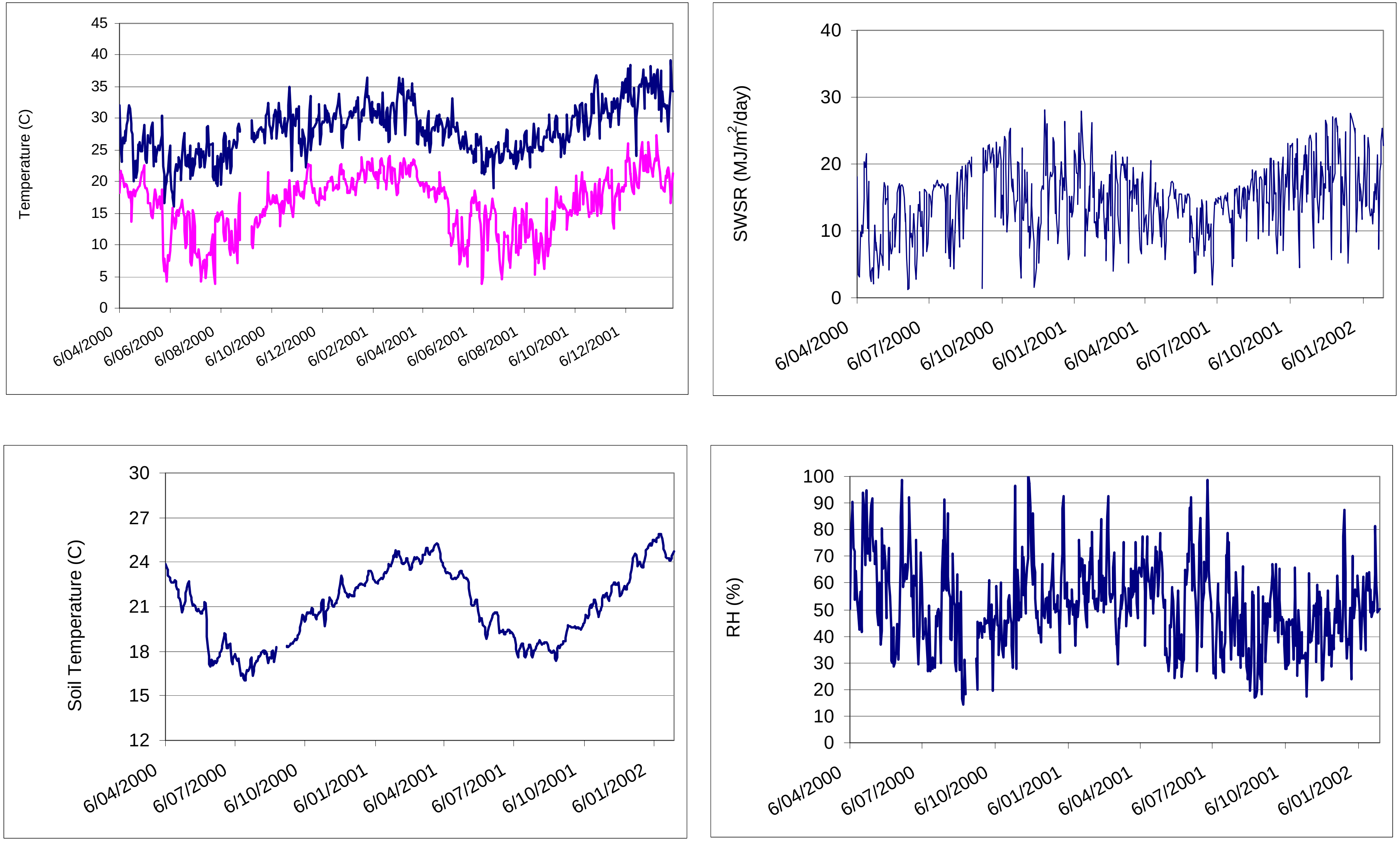

Figure 23. Daily Maximum and Minimum Temperature, Soil Temperature, Short wave solar radiation and minimum RH recorded at the Byfield site. N.B. Monitoring dates are from 6 April 2000 to 31 Jan 2002.

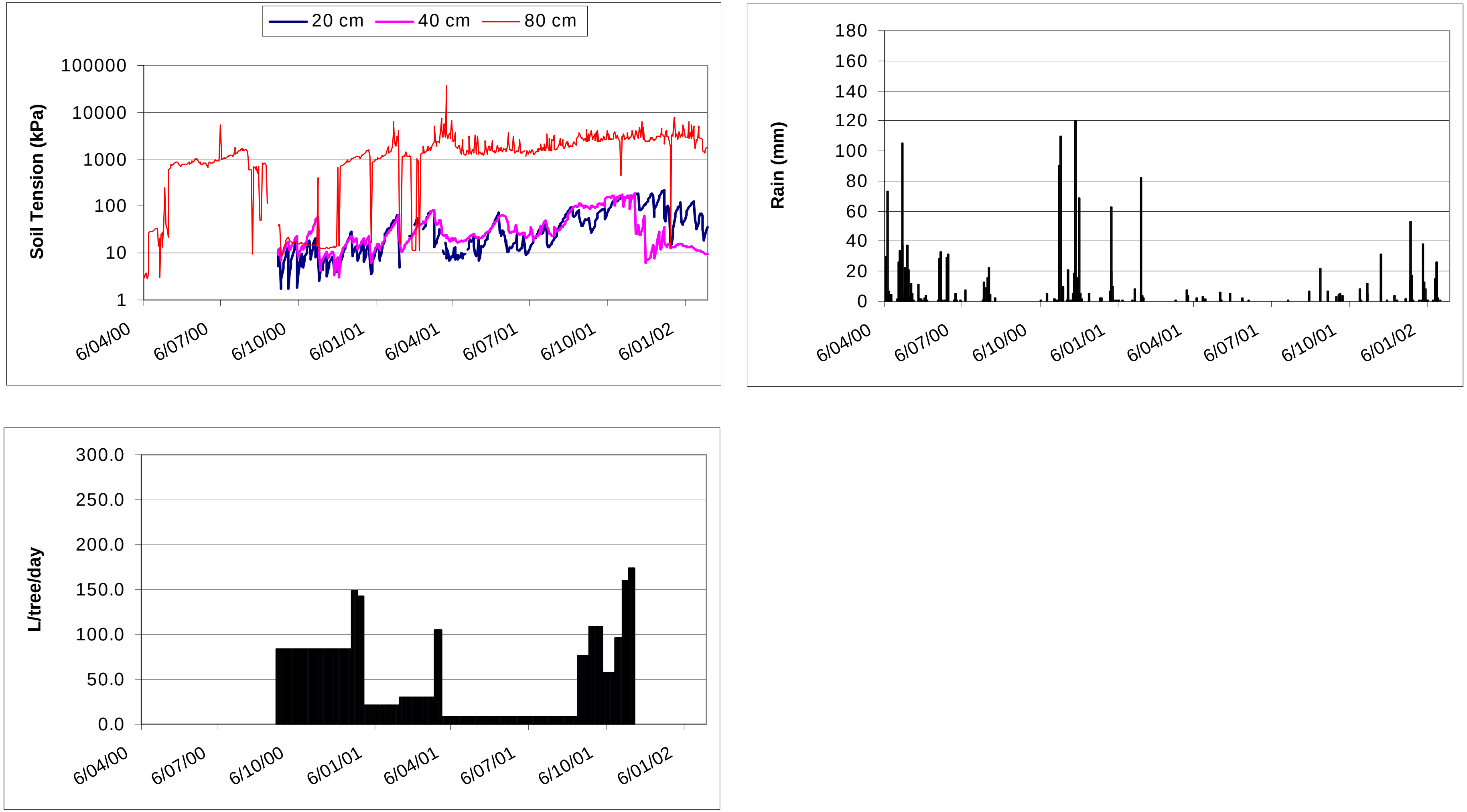

Figure 24. Daily rainfall, soil tension at 20, 40 and 80 c cm, irrigation input for the Byfield site. N.B. Monitoring dates are from 6 April 2000 to 31 Jan 2000