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Fertiliser Strategies for Mechanical Tea Production

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Foreword

Mechanical tea production has been a stable small horticultural industry for over 30 years in north Queensland, valued at around $4m. To remain internationally competitive, producers must reduce their production costs by optimising their production practices. With the area of land planted to tea unlikely to increase greatly, growers are keen to increase their production by increasing their yields/ha to meet increasing demands. Besides climate (temperature and rainfall), the fertiliser inputs are the next most likely major factor determining yields of tea. While some work has been done on the fertiliser requirements for tea in north Queensland, this was done 25 years ago and little work has been done since.

This report investigates the nutritional status of the crop and soils, fertiliser practices and the corresponding yields across the Australian tea production area. A fertiliser programme for growers is suggested based on project findings, overseas literature, a nutrient budget model and the yearly growth cycle.

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Executive Summary

What the report is about?

This report documents the results of research into the effect of nutrition on the productivity of tea. The tea industry currently uses fertiliser recommendations developed over 25 years ago and these are being reviewed in this project. Over the last several years increased demand for Australian tea and increasing cost pressures have prompted growers to seek out better production techniques including fertiliser practices to increase yields and reduce their costs of production. The research findings are important because they will help growers to better understand the nutritional requirements of tea and improve their yields. This will reduce their costs of production and increase the economic viability of the tea industry.

Who is the report targeted at?

The research project was developed in conjunction with a group of Australian tea growers' who harvest greater than 90% of Australia's total production. They identified nutrition management as a high priority for the industry. The report and findings are targeted primarily at the Australian tea producers to help improve their production through better nutritional management of their crops. The report is also useful for tea researchers, extension officers and potential new and existing tea growers.

Background

The Australian Tea Industry has been able to compete with low cost overseas producers because of the use of mechanical harvesters, low costs of production and the high quality produced. To remain internationally competitive, producers must optimise their production systems including fertiliser practices. With the area of land planted to tea unlikely to increase greatly, growers are keen to increase their production by increasing their yields/ha to meet increasing demands. Besides climate (temperature and rainfall), the fertilizer inputs are the next most likely major factor determining yields of tea. While some work has been done on the fertiliser requirements for tea in North Queensland, this was done 25 years ago and little work has been done since. In North Queensland yields have varied from 1.5 t/ha to 4.7 t/ha and the highest yields have usually been associated with higher nutritional inputs, suggesting that nutritional research work could significantly improve production.

Aims/Objectives

The aims of the project were to monitor changes in leaf and soil nutrient status over three years in blocks of tea receiving different fertiliser inputs and to assess the effect of nutrient status and fertiliser inputs on crop productivity. The information from this work was used to develop a fertiliser program based on a nutrient budget and the yearly growth cycle.

Through this project, tea researchers, extension officers and growers have an increased knowledge of the nutritional requirements of tea.

This research will directly benefit the Australian Tea Growers. Their success will in turn benefit the rural communities in which they are located with employment opportunities and financial contributions.

Methods Used

Information on fertilising practices including rates, timing and frequency; leaf and soil nutrient levels and yields were collected from different paddocks over several years from three farms across the Australian production area. Climatic information (including rainfall, evaporation, temperature and humidity) was also collected. The relationships between fertilising practices, climatic data and yield were studied.

Results and Key Findings

The current nutritional status (leaf and soil) and fertiliser inputs of the tea growing in North Queensland has been documented. Results indicate that the climate (rainfall, temperature), pruning cycle and fertiliser inputs all interact to determine the yield of tea. The overall pattern of growth was generally influenced by the climate while the amount of growth and the length of the growing season were determined by the fertiliser inputs. Only in years where annual rainfall was less than 1500mm was yield reduced. The pruning cycle as expected reduced yields during that year and the recovery in yield was delayed by poor fertilising practices.

The fertiliser records, leaf and soil nutrient levels and yield data suggest that higher levels of a broader mix of nutrients and smaller more frequent applications than currently being used by the industry could improve the nutrient availability and yields. Smaller more frequent fertiliser applications are also likely to reduce losses and wastage of nutrients through leaching and runoff, reducing costs and reduce environmental impacts. A suggested fertiliser program has been developed, based on the results of the project, the literature, a nutrient budget and the growth cycle. It is recommended this be used as a guide within a grogram that includes soil and sap/leaf testing.

A fertiliser with a mix of nutrients in the following ratios - 10 N: 1 P: 4 K: 0.5 S: 0.5 Ca: 0.5 Mg plus small amounts of Zn, Cu, Fe and B is recommended.

Depending on the expected yield the following table gives the recommended fertiliser application rates for the major nutrients.

Expected Yield	**2-2.5 t/ha**	**4-4.5 t/ha**
N	200-250 kg	400-450 kg
P	10-20 kg	15-30 kg
K	80-120 kg	150-200 kg
S	6 kg	15 kg
Cu	6 kg	15 kg
Mg	6 kg	15 kg

The poor soil availability of Zn and Cu suggest these nutrients should be added via foliar applications (1% Cu and Zn sulphate plus 1% Urea). Fe and B could be added to the soil in the overall fertiliser mix or individually using 10 kg/ha Solubor and 10 kg/ha Fe SO_4.

Fertilisers should be applied in six even applications at 6-10 week intervals during the growing season and 10-16 week intervals during winter.

Implications for Relevant Stakeholders

Industry. With the information developed in this project, growers will have a greater understanding of the nutritional requirements of tea and are likely to modify their fertilising practices to incorporate some of the findings. This is expected to lead to an overall improvement in the yields of Australian tea plantations leading to industry expansion

Communities. Industry expansion in turn will help support rural communities in which tea is grown by providing financial input and employment opportunities.

Policy Makers. Industry expansion will also contribute to the Australian economy with valuable export income and import substitution. Although this industry is small, it does contribute to the economic diversity of the horticulture industry and regional employment opportunities.

Recommendations

The recommendations from this research are targeted at the Australian Tea Growers` who can use the findings to help them improve their production.

Growers should trial the higher rates, broader mix of nutrients and smaller more frequent applications recommended in the fertiliser program developed in this project. The fertiliser program should ensure all nutrients are adequately supplied which will help to increase yields, reducing the costs of production and improve the economic viability of the industry.

Tea growers are encouraged to keep records of fertiliser inputs and yields and to conduct one leaf and soil sample each year so that the yield responses to fertiliser practices can be monitored and adjusted as necessary over time.

1 Introduction

The tea plant (*Theaceae sinensis*) is a small tree related to camellia. In its natural state, it grows to about 15m tall, however, in commercial production, it is maintained as a hedge about 1.0 – 1.5m tall by regular pruning. It has a strong tap root and branching canopy. The young shoots (comprising two or three leaves and a bud) are plucked and processed for the production of tea. Harvesting occurs throughout the year.

Tea requires a mild climate with high rainfall and relative humidity. The ideal climate would have 2 000 – 4 000mm rain per annum (at least 150mm/month), temperatures between 12^{o}C and 30^{o}C and relative humidity greater than 65% year round. It is damaged by frost and growth is reduced at temperatures greater than 30^{o}C. A well drained soil to a depth of about 1 metre is required for good production. Poor drainage leads to poor vigour and reduced yields. Tea requires acid soils with pH levels of 4.5 – 5.5.

Plants are planted out in hedges with spacing's from 1.8 – 3.6m between centres with populations of 12 000 to 25 000 plants/ha. The young plants are brought into production by regular trimming with a machine mounted mower. Harvesting can commence about 2 – 4 years after planting.

Most of the world's tea is still harvested by hand, but all commercial production of tea in Australia is machine harvested. These self propelled machines straddle the hedges and clip the young shoots from the top of the bush usually 15 – 25 times throughout the year. The leaf is then blown into a bulk bin on the harvester and must be processed within a few hours of harvest. Virtually all the tea in Australia is processed into black tea. The leaf is first withered then fed into a macerator, crushed and allowed to ferment for several hours before drying. The dried tea is then sorted to remove stem and fibre and graded according to particle size, which is then used as leaf tea or in the manufacture of tea bags.

In Australia, commercial production of tea began in the late 1950's in north Queensland on the Nerada estate. All commercial plantings have used seedling planting material rather than vegetatively propagated clones as is now the most common practice in the major overseas tea producing countries. Selected cloned material is capable of producing twice the yields of some seedling material. A central processing factory was built and the first commercial tea was produced in the 1970's under the Nerada brand. In the 1980's, the aging factory at Nerada could not handle the increasing production and a new factory was built on the Atherton Tablelands near Malanda.

The major tea production area in Australia is located in north Queensland (95%) both on the coast near Innisfail and the elevated Atherton Tablelands around Malanda. A small amount of tea is also produced in northern NSW. Today, Australia produces about 2 000 tonnes of tea/annum from 750ha which is about 8% of annual domestic consumption worth around $4m. Australia imports 25 – 30 000 tonnes of tea annually worth $50 – 60m. Demand for Australian tea is strong and increasing and indications are that the Australian industry could expand substantially to replace more of these imports.

For Australia to remain internationally competitive and to continue increasing the percentage of import replacement, all field and factory operations need to be highly mechanised and very high yields achieved to reduce the costs of production to a minimum. High yields are achieved through good pest and disease control, weed control, good harvesting management and a good fertiliser programme. Tea has a high fertiliser requirement with around 250-450 kg N applied per hectare per annum. The fertiliser programmes currently being employed by the industry were developed 25 years ago by DPI and are being reviewed in this project.

Tea is grown less intensively than many horticultural crops as it is grown on a broad acre basis. Field operations are kept to a minimum and irrigation is not used. Yields are largely determined by the planting material, soil type (texture, fertility, depth, pH), the climate (rainfall and temperature), pruning and harvesting patterns and the fertiliser inputs. As many of these variables are fixed in tea production, nutritional management is likely to be one of the major factors that can be manipulated by the grower that can influence yields. Over the last several years, increasing demand for Australian tea and increasing cost pressures have led growers to seek out better production techniques including fertiliser practices to increase yields and reduce their costs of production. In the 25 years since any nutritional studies were conducted on tea in Australia, harvesters have changed, higher yields are achieved, plantation management has improved, a lot of research has been conducted overseas on nutritional requirements of tea and there are more choices in fertilisers available. Large fluctuations in yield from 1.5 to 4.7 tonnes/ha between properties have been attributed in part, to differences in rates and timings of fertiliser applications. Also a number of micronutrient deficiency symptoms have started to become more commonly observed. Fertiliser costs can represent 20-25 % of the total production costs and therefore its efficient use is critical. These factors suggest that some nutritional research work could improve the efficiency of fertiliser use and improve production. Another factor which has become increasingly important for crops grown in the wet tropics where catchments drain onto the Great Barrier Reef, is reducing the potential for off-farm nutrient movement. As tea is a perennial crop with full canopy cover year round and not cultivated, the potential for off-farm nutrient movement is reduced.

2 Literature Review

2.1 Introduction

Plant nutrition and fertiliser management have a long history and much as been written on the relationships between soil and plant nutrient status and crop growth and yields. The bulk of literature revolves around nutritional management of annual cereal and vegetable crops that have relatively short seasons and simple production patterns compared with perennial tree crops. Literature on tea nutrition is less common and more complex due to the perennial nature of the trees and the many variables including varieties, plant densities, harvesting and pruning practices and climate (rainfall, temperature, day length and humidity) involved in determining crop yields. Plant growth and hence final yield is limited by the most limiting factor. For example, if soil moisture is limiting due to low rainfall even good nutritional levels will not be able to increase yields. Similarly, if growth is restricted because of low temperatures, humidity or day length during the winter, growth responses to fertiliser will be weak.

All living plants require a range of essential nutrients to allow them to function and grow. The essential nutrients are classified as either macronutrients (required in large amounts) or micronutrients (required in very small amounts). As a general rule, plants have basic similarities in their behaviour to nutrient disorders and the symptoms can often be related across many species.

2.2 Essential Nutrients

The following list provides information on the roles and functions of the essential plant nutrients.

2.2.1 Nitrogen

Nitrogen is used in the production of protoplasm, proteins and chlorophyll and is the primary building block for all plant parts. Nitrogen is the main nutrient requirement of tea. Yields increase with increasing use of nitrogen up to high levels with economic returns. Rates of 200 – 500 kg/ha/year are widely quoted in the literature for high yielding tea (Bonheure and Willson, 1992).Rojoa et al (1979) reported the highest yields were achieved at 375 kg N/ha in Mauritius. Lyashko (1979) found yields were higher at 300 than 450 or 600 kg N/ha. Malenga (1985) reported a linear response to nitrogen in Malawi up to 250 kg N/ha. In recent studies, Kumwend (2006), found rates between 200 and 375, and up to 575 kg N/ha optimum on high yielding (6.4 t/ha) clonal material. In Kenya, Owuor (1985), found tea responded to nitrogen levels up to 500 kg N/ha, although economic returns peaked at 200 – 300 kg N/ha. The current DPI&F recommendation is 250 kg N/ha/year.

A common rule of thumb used in many tea producing regions is to use 1 unit of nitrogen for every 10 units of tea produced. For example, if the yield is 3 tonnes/ha, many regions would recommend using 300 units of nitrogen/ha (Malenga, 1987). If deficient plants go yellow and growth is stunted, symptoms show up in older leaves first because nitrogen is very mobile in the plant.

2.2.2 Phosphorus

Phosphorus promotes strong root growth and is involved in photosynthesis, respiration, energy storage and transfer. Phosphate fertilisers are often recommended for early development of many crops. It doesn’t move easily in the soil and can get fixed to iron in the soil (especially in acid and red volcanic soils) making it unavailable to the plant. When applying phosphorus fertiliser, it is recommended to incorporate it into the soil.

Phosphorus is required in fairly low amounts by the tea plant. However, the soils in this region are often low in phosphorus and phosphorus can get locked up in acid soils so small applications are recommended. Phosphorus is generally more important during the early development phase of the plant for the formation of new wood and roots. Therefore extra applications following pruning maybe beneficial. In Malawi, Kumwend (2006) used rates of 30-100 kg P/ha with the best yields (6.4 t/ha) at 100 kg/ha. While Rahman and Jain (1985) found best yield increases with rates of 20 – 50 kg P/ha which was similar to the rates found in Sri Lanka by Sivapalan et al (1986). The current DPI&F recommended rate is 20 kg/ha. High levels of phosphorus in the soil may make zinc unavailable to the plant. Deficiency shows up as a purplish and bronze discolouration.

2.2.3 Potassium

Potassium is involved in photosynthesis and respiration and regulates water relations of plants. It promotes root growth and is required in large amounts by plants. It is often deficient in high rainfall areas, in sandy soils and where a lot of plant matter is harvested. Deficiencies in other crops have been common in much of coastal Queensland. Potassium is not generally deficient in the soils of this region. Tea has a moderate to high requirement for potassium and large amounts are removed in the leaf, thus depleting soil reserves.

In Malawi, Kumwend (2006) used rates of 50 – 350 kg K/ha/yr with best yields achieved at 300 kg/ha. Rahman and Jain (1985) found best yields were achieved with 180 kg/ha but higher rates were not used. The current DPI&F recommendation is 110 kg K/ha. Potassium has found to be important in the recovery of tea from pruning, stimulating quicker regrowth so heavy applications following pruning are recommended (Willson, 1974). Where potassium is deficient, magnesium will also often be deficient. High levels of calcium have been shown to restrict availability of K to the plant and this should be taken into account when liming the soil. Deficiency symptoms include marginal leaf necrosis, especially towards the tips, leaves become smaller.

2.2.4 Calcium

Calcium is important in the formation of cell walls and membrane construction particularly at the growing points (roots and shoots). If deficient, it can affect the use of nitrogen in the plants. Lime, dolomite or gypsum can be used (1-3 t/ha) to correct deficiencies. Calcium is often deficient in acid soils. It is not mobile in the plant and deficiencies are seen in young leaves. The acid nature of tea soils suggests that liming may be beneficial; however, some experiments have shown an adverse effect on tea (Bonheure and Willson, 1992). Although Krishnapilli and Pethiyagoda (1980) found a small amount of calcium increased the pH of the soil which increased the availability of nitrogen and growth increased. However, others have observed potassium leaf levels decline when calcium is applied, leading to reduced yields. Therefore, if liming tea soils, extra potassium should be applied as well. High calcium fertiliser should be avoided.

2.2.5 Magnesium

Magnesium is important in the formation of chlorophyll and is involved in CO2 assimilation and carbohydrate partitioning. Deficiencies are common in acid soils. Magnesium sulphate (50 kg/ha) or dolomite are used to correct deficiencies. The quantity required by tea is relatively small and deficiencies have rarely been found to effect crop yields (Bonheure and Willson, 1992). Magnesium is easily moved from the older leaves to the new leaves and even when older leaves show a deficiency, no yield responses have been observed (Willson, 1974). Rates of 125 kg of dolomite/ha are used in Sri Lanka to supply magnesium. Deficiency symptoms include interveinal and marginal chlorosis; older leaves turn yellow and can become reddish.

2.2.6 Sulphur

Sulphur is involved in the formation of protein and chlorophyll and important for photosynthesis. It can become deficient with water logging because sulphur precipitates out with Iron or Manganese. Sulphur deficiencies are well documented in many tea growing areas. The current DPI&F recommendation is to apply 25 kg S/ha/year. Deficiency symptoms include interveinal yellowing and shortening of leaves and internodes and reduced leaf size.

2.2.7 Copper

Copper is involved in chloroplast and protein formation and also photosynthesis, respiration and carbohydrate metabolism. It is often deficient at high pH and on sandy leached soils. If deficient it causes deformed and stunted growth and cupped leaves. Deficiencies are corrected by applying Copper Sulphate 10-20 kg/ha or foliar sprays of Copper chelate (1%). Copper deficiencies are common and have been reported in the literature (Bonheure and Willson, 1992). Copper is very important because it plays a vital role in fermentation during processing – therefore deficiencies can lead to reduced cupping quality.

2.2.8 Zinc

Zinc is used in chlorophyll formation, nitrogen metabolism and is involved in plant hormone synthesis. It is not very mobile in the soil and is therefore often present in soil tests, but unavailable to the plant. Deficiencies are common in many crops especially where soils have a high pH and are sandy. Organic matter is an important source of Zn. Zinc Sulphate (20 kg/ha) and Zn Chelate (1%) as a foliar spray are used to correct deficiencies. Foliar sprays are important because Zn is very immobile. Restricted root growth can lead to deficiencies and it is common to see localised deficiencies within a field.

Responses to zinc have been widely reported from overseas and are likely to be needed in north Queensland soils. Zinc is not readily absorbed by tea from the soil and can become unavailable when soil phosphorus is high. Foliar applications have found to be very effective with 2 – 3 applications in the growing season, (Ishigaki, 1984). Hartley (1973) and Malenga, (1979), have also observed good responses to foliar zinc oxide and zinc sulphate (22 kg/ha/year) applications. Deficiency symptoms occur on young growth and include shortening of the internodes, multiple budding and small sickle shaped leaves.

2.2.9 Manganese

Manganese is used in the formation of sugars and chlorophyll and in enzyme activities. It is essential for plant uptake of phosphorus and potassium. It is rarely deficient and only so at high pH. Deficiencies occur on young leaves first. Manganese Sulphate is used to correct deficiencies (50 kg/ha). Manganese is absorbed in large quantities by tea and the plant can tolerate very high levels. Manganese uptake can be stimulated by phosphate application.

2.2.10 Iron

Iron is used in chlorophyll synthesis, and many biochemical processes (oxidation, reduction). It is needed in small amounts continuously. Generally deficiencies are rare unless pH is high. Deficiencies are corrected by using either foliar (1% Iron chelate) or ground (2-5 kg/ha) applications. Restricted root growth following harvest/pruning and very rapid growth can lead to deficiencies, often localised within a field. With foliar application repeated sprays are necessary. The levels of Iron in the plant can be reduced when Mn levels are high. High phosphorus levels can lock up Iron. Iron and manganese are usually freely available in acid soils, so deficiencies are rare. When deficient, young leaves go yellow, pale yellow then eventually white in severe cases, the veins remaining green.

2.2.11 Boron

Boron is used in protein synthesis, regulates metabolism of carbohydrates, is involved in root formation and is important in growing points. Deficiencies are corrected by using foliar sprays of Boric acid (0.1%) or borax applied to the soil (2-4 kg/ha). Adequate boron is available in most tea soils for the very small quantity required by the tea plant, so deficiencies are rarely seen. Too much boron can induce zinc deficiency as well as becoming toxic itself. Deficiency symptoms include deformed growth successive dieback of the growing point and development of auxiliary shoots and brown spots can develop along the midrib of the leaves.

2.2.12 Aluminium

Aluminium influences the assimilation of phosphorus and potassium. It is freely available in acid soils and absorbed in large quantities by tea. High levels can decrease potassium uptake which should be corrected with additional potassium fertilisers.

2.3 Soil pH

Soil pH in tea plantations is often very low. High rates of fertiliser application (particularly nitrogen) and high rainfall in a tropical environment leading to a decline in pH over time. It is not uncommon for soils to have pH values of 4.5 – 5.5. These low pH levels can lead to nutrient availability problems if excessively low. However, liming is not recommended unless the pH falls below 4.0. High calcium levels can interfere with potassium uptake. In high rainfall environments, sulphate forms of nitrogen should be avoided as they will accelerate acidification of the soil.

2.4 Nutrient Mobility

Essential nutrients have been divided into mobile, variably mobile and non-mobile. The mobile nutrients, once deposited in leaf or other plant parts, can at a later stage, be remobilised to other plant parts. Nutrients that are considered mobile are nitrogen, phosphorus, potassium. These nutrients are recycled with young growth gaining nutrients at the expense of older leaves when in short supply. Non-mobile nutrients include calcium, boron, manganese and iron. These elements do not move from where they were originally deposited to new growth even if they are in short supply. Adequate levels can only be maintained by a continuous supply either from the soil or as foliar sprays. Zinc, copper and sulphur are variably mobile, only moving once leaf senescence commences.

Young new growth is most sensitive to deficiencies of immobile or variably mobile nutrients while older leaves are the most sensitive to deficiencies of the mobile nutrients.

2.5 Critical Nutrient Levels

In modern agriculture, plant nutrition management is of interest to researchers, farm advisers, plant and soil analysis laboratories and fertiliser manufacturers and suppliers. The aim of all these groups is to optimise the productivity of the crop in a sustainable and economic way.

Plant and soil analysis is done to provide information on the nutrient status of plants which can be used as a guide to nutrient (fertiliser) management. Plant and soil analysis data are used in several ways. The four most common are:

- Diagnose nutrient problems (deficiencies or toxicities)
- Predict nutrient problems likely to occur
- Monitor crop nutrition status with a view to optimising production
- Develop a fertiliser programme

To be able to carry out these functions, the researcher must compare actual leaf and soil levels collected in the field with the critical levels established for that crop. These critical levels are generally gathered through a process of surveying commercial orchards and fertiliser trials where nutrients are added at varying levels and the differences in yields measured.

Research work conducted overseas with tea grown intensively has provided the following guide to optimum levels of nutrients in the soil and leaf (Table 1).

Table 1: Critical leaf and soil nutrient levels for Tea. (Willson and Gunther (1981), Gilbert (1983)).

Nutrient	Soil	Leaf
pH	4.5-5.5	
N	50+ mg/kg	3.5-4.5%
P	50 mg/kg	0.3-0.4%
K	1.0 meq/kg	1.6-2.2%
S	30 mg/kg	0.2-0.3%
Ca	4.0 meq/kg	0.4-0.5%
Mg	1.5 meq/kg	0.18-0.25%
Al	Up to 50% Al saturation	400 mg/kg
Cu	3-10 mg/kg	>15 mg/kg
Zn	2-15 mg/kg	>30 mg/kg
Mn	4-50 mg/kg	350-1200 mg/kg
Fe	>2.0 mg/kg	60-150 mg/kg
B	>1.0 mg/kg	30 mg/kg

2.6 Fertiliser Recommendations

Fertiliser recommendations for tea grown intensively in similar conditions to those in Australia are given below.

India: N:P:K 10:2:4 at 200 kg N/ha/year or 5-10 kgN per kg of made tea, and 45 kg P/ha every second year. (Bonheure and Willson, 1992).

Sri Lanka: N:P:K 10:2.5:4 at 360 kg N/ha/year in tea yielding 3.5 t/ha in 2 – 3 applications but up to 5. (Balasuriya et al 2000.) Zinc and copper sulphate is also applied at 22 kg/ha and 10kg/ha as 4 foliar sprays. (Wickremasinghe and Krishnapillai, 1986.)

Malawi: N:P:K 10:2:6 at 245 – 375 kg N/ha/year split into 2 even applications for varieties yielding 4.5 tonnes/ha. Sulphur is also added every 5 years. Zinc oxide is applied as 4 foliar sprays each year at 1.25 kg ZnO/ha. Copper is also used regularly. (Grice, et. al., 1988 and Kumwend, 2006.)

Kenya: N:P:K:S 10:2.5:2.5:2.5 at 250 – 400 kg N/ha/year for high yielding varieties (3.5 – 4.0 t/ha). Zinc oxide is applied twice a year at 3 kg/ha as a foliar spray or zinc sulphate at 10 kg/ha (Othieno, 1988). They have found an N:K ratio of 5:1 is too low in potassium.

Malaysia: N:P:K:S 10:3:3:3 at 270 – 396 kg N/ha/year split into 2 applications (Sivaram, 1982). On lower yielding blocks (2 t/ha) 100 – 200 kg N/ha/year is used.

Indonesia: N:P:K: 10:1.7:3 at a nitrogen rate of 1 kg N for every 8 – 10 kg of made tea. For example, 300 kg N/ha/year for a yield of 3 t/ha, split into 3 – 6 applications (Darmawijaya, 1985).

Australia: N:P:K:S 10:1:4:1 at 250 kg N/ha/year split into 3 even applications once in spring and one at the start and middle of the wet season.

3 Objectives

- Improve the understanding of tea growers on the nutritional requirements of tea.
- Monitor changes in leaf and soil nutrient status across farms and fertiliser programmes and measure grower nutrient inputs.
- Assess the effect of nutrient status on productivity.
- Develop a fertiliser programme.
- Identify micronutrient deficiencies and the best methods to alleviate.

4 Methodology

4.1 Site Description

The project was conducted on three farms located on the Atherton Tablelands (West of Cairns, 17^{o}S), close to Malanda and Topaz. The soils across the farms were reasonably uniform being a red brown structured uniform clay (Kraznozen or Pingin Soil type). This soil has good moisture and nutrient holding capacity and is well drained.

On farm one, two uniform paddocks (block 1 & 2) were chosen and different fertilizing practices implemented over the three years of this project. Growers' records of yields and fertiliser inputs for the 4 years prior to the study commencing were also collected so that seven years of data could be analysed. On farm two, a single uniform paddock representative of the whole farm was chosen and the fertiliser inputs were varied each year of the study and yields recorded. On farm three, the fertiliser inputs and yields averaged over 3 years were collected from a uniform paddock representative of the farm.

4.2 Climate Monitoring

During the project, monthly and yearly rainfall data was collected as well as the average monthly temperatures (maximum and minimum), evaporation and relative humidity for the Malanda-Topaz area.

4.3 Fertiliser Inputs and Yields

On each farm, information on the fertilizing practices, including rates, timing and frequency of application were collected. Fertiliser inputs were converted to kg/ha of nutrients applied per annum. Monthly and yearly yield data both fresh weight (green leaf (GL)) and dry weight (made tea (MT)) was also collected.

4.4 Leaf and Soil Samples

Leaf and soil nutrient samples were collected at six – ten month intervals during the study. For each soil sample, 10 samples were taken randomly across each trial paddock with a 50mm auger to a depth of 15cm. The samples were bulked and thoroughly mixed by hand and then sub-sampled for analysis by Incitec-Pivot Laboratories. The samples were air dried, ground to < 2mm and analysed for pH (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 the Australian Laboratory Handbook of Soil and Water Chemical Methods (Rayment and Higginson, 1992).

For each leaf sample, 50 leaves (youngest, undamaged, and fully mature) were randomly selected across each trial paddock. Leaves were oven-dried at 60^{o}C and sent for analysis by Incitec-Pivot Laboratories. The samples were washed, dried and ground to <1mm. 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) was conducted using inductively coupled plasma technology (ICP) spectrometry. Leaf and soil analysis data are presented for each individual grower over the course of the trial. These are compared with the standard/critical leaf and soil nutrient levels established for tea.

4.5 Leaf nutrient deficient samples

On several occasions during the trial, additional leaf samples were taken from sections of trial paddocks which exhibited nutritient deficiency symptoms such as pale green, yellow growth or interveinal chlorosis. The leaf nutrient deficient data is presented for each individual grower as the percentage difference of the deficient nutrients to the comparative healthy samples.

5 Results and Discussion

5.1 Climate

Weather data for the trial sites is presented in Figures 1, 2 & 3. The data clearly shows summer and winter patterns, with higher temperatures, rainfalls, evaporation and relative humidity's during the summer months October-March and lower levels during the winter months.

The figures show that the climate around Malanda-Topaz is very suitable for tea production with good rainfall and humidity (>65%) throughout most of the year and average temperatures not too high (>30^{0}C) or too low (<10^{0}C) to restrict plant growth. Daily observation do however indicate that on occasions maximum temperatures of greater than 30^{0}C and minimum temperatures below 10^{0}C (with occasional light frosts) may restrict plant growth. The rainfall figures indicate that monthly evaporation may on occasions exceed rainfall from August to December which may limit plant growth, however for the rest of the year soil moisture is likely to be adequate. Year 2000 and 2006 were quite wet years while 2002 was very dry (Figure 2).

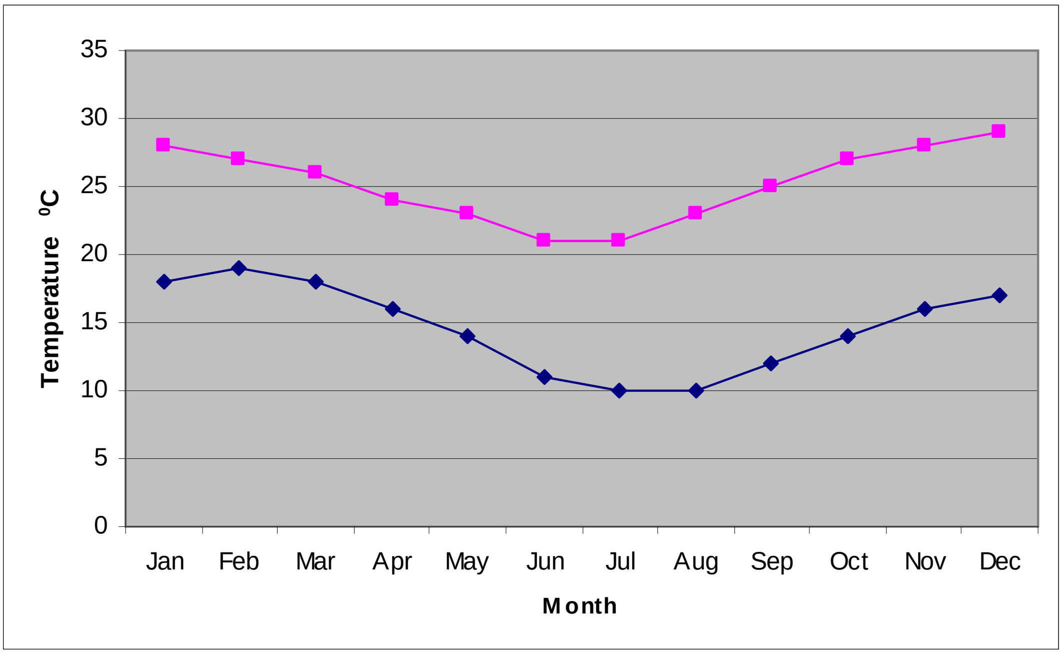
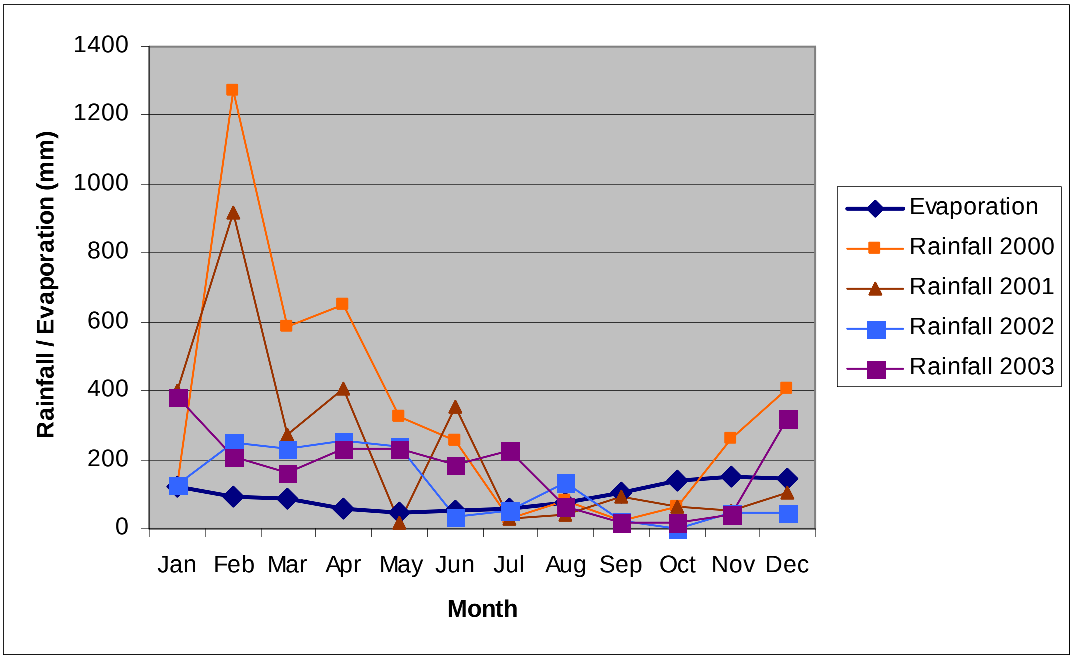


Figure 1: Average monthly maximum and minimum temperature for the trial sites



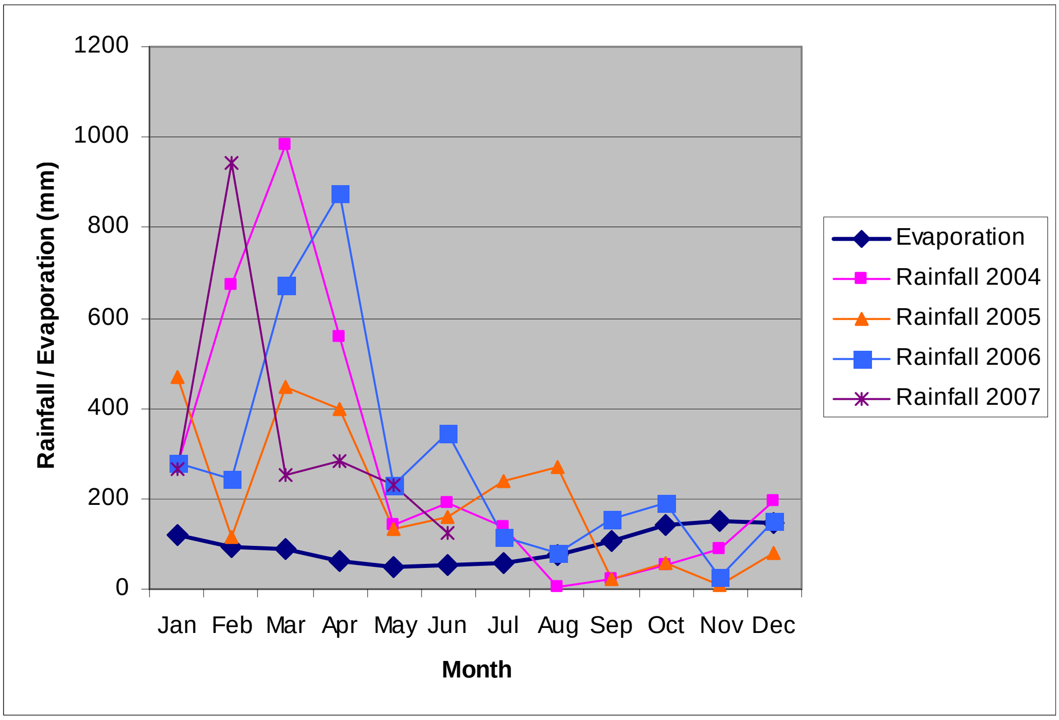


Figure 2: Monthly rainfall and evaporation for the trial sites during the project

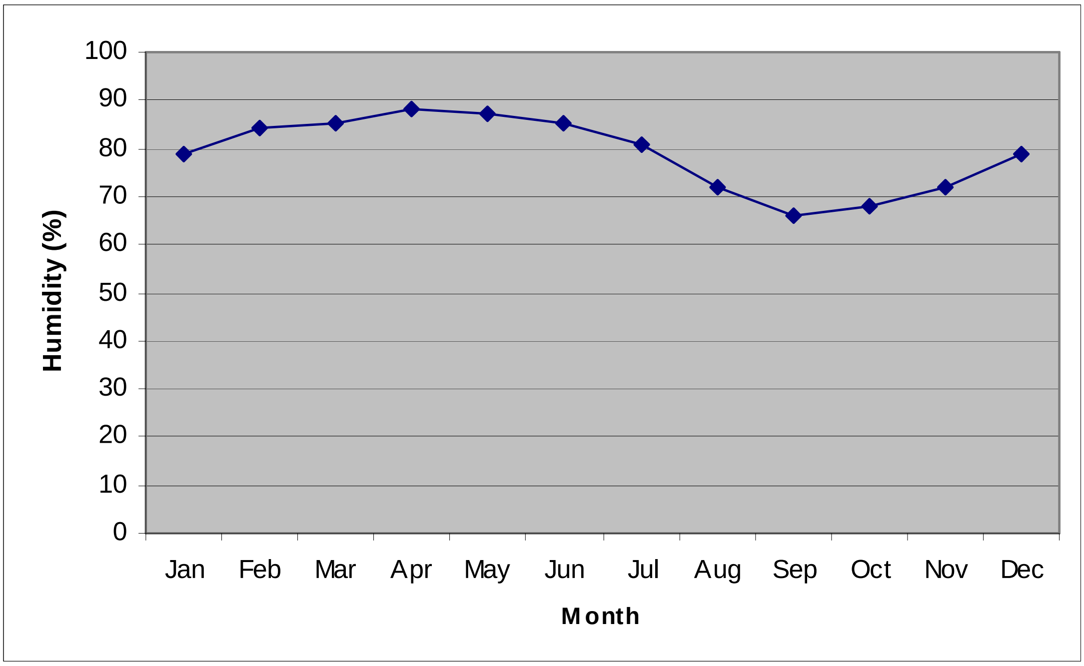


Figure 3: Average monthly relative humidity for the trial sites

5.2 Yields and Fertiliser Inputs

The yield, fertiliser inputs and costs, pruning operations and rainfall data for all three farms is presented in Tables 2 and 5.

The data initially presents a confusing picture with no strong correlation between total rainfall, fertiliser inputs or the pruning cycle and yield when considered individually. However, if these factors are considered together it is clear how each influences growth and yield.

Table 2: Yields (Green Leaf (GL) and made tea (MT)), fertiliser inputs and costs, pruning operations and climatic information for Farm 1 Block 1 and 2 during the project.

Block 1

Year	Yield		Fertiliser			Pruning Operations	Yearly Rainfall (mm)	No. of Months Evap> Rainfall (Deficit) mm
	GL/ha (t)	MT/ha (t)	Kg N/ha	No. of applications	Cost $/ha			
2000	10.4	2.19	82	1	210	prune	4088	3 (-186)
2001	13.4	2.81	358	3	936		2760	6 (-318)
2002	12.8	2.69	288	3	753		1444	5 (-449)
2003	18.1	3.66	284	5	580	prune	2089	3 (-225)
2004*	17.7	3.64	377	4	632		3325	4 (-331)
2005	23.0	4.68	435	5	737		2407	4 (-390)
2006	13.9	2.93	336	3	610	prune	3363	1 (-124)
2007+	13.0	2.59	330	3	616		2094	0 (-)

*yields adjusted for frost
+only 7 months data

Block 2

Year	Yield		Fertiliser			Pruning Operations	Yearly Rainfall (mm)	No. of Months Evap> Rainfall (Deficit) mm
	GL/ha (t)	MT/ha (t)	Kg N/ha	No. of applications	Cost $/ha			
2000	22.9	4.81	276	3	642		4088	3 (-186)
2001	23.0	4.83	303	3	793		2760	6 (-318)
2002	13.7	2.88	287	3	744		1444	5 (-449)
2003	23.5	4.78	317	5	620	prune	2089	3 (-225)
2004	19.4	4.10	236	3	555		3325	4 (-331)
2005	22.8	4.65	335	4	920		2407	4 (-390)
2006	12.7	2.64	255	3	690	prune	3363	1 (-124)
2007+	14.2	2.83	258	3	545		2094	0 (-)

+only 7 months data

5.2.1 Farm 1

In year 2000 on block 1 the pruning and low fertiliser inputs (only 82 kg N/ha in a single application) led to poor yields despite good rainfall. The poor yield then carried on into year 2001 even though trees were fertilised heavily (358 kg N/ha in three applications). It is likely the low fertiliser inputs from the previous year followed by pruning resulted in the trees being drained of nutrients and unable to regain their vigour. In block 2 in the same years (2000 and 2001) with no pruning and better fertiliser applications in 2000 yields were much better (Table 2).

In 2002 reasonable fertiliser applications (287 kg N/ha in three applications) could not overcome the effect of the very low rainfall limiting growth and yields. In this year evaporation exceeded rainfall in five months of the year and the deficit (rainfall-evaporation) in these months was 449 mm. This was the only year of the trial in which low rainfall could be associated with lower yields indicating that annual rainfalls of around 2000 mm are adequate for obtaining maximum yields. Even when rainfall was relatively low and evaporation exceeded rainfall in several months with a deficit greater than 300 mm e.g. 2001, 2004 and 2005 yields in the absence of pruning are still very good. This suggests that the trees are benefiting to a greater extent from the clearer skies and higher radiation levels in these drier years than suffering from water stress.

In 2003 yields were good on both blocks with good rainfall and fertiliser applications prior to the trees being pruned late in the year. The higher yield on block 2 may have been associated with the higher fertiliser inputs 317 kg N/ha verses 284 kg N/ha. The other likely contributing factor to the high yields achieved in this year was the more frequent fertiliser applications. The more frequent applications would help to ensure that nutrients are available to the plants more evenly throughout the year particularly in this high rainfall environment where nutrients are easily lost through runoff and leaching. Yields in 2004 and 2005 on both blocks were also high where fertiliser was applied more frequently. The total amount of fertiliser applied in these years was also generally high – 236, 335, 337 and 435 kg N/ha. The good fertilising practices in these years may have contributed to the strong recovery of the trees following pruning in 2003 (Table 2).

In 2006 yields on both blocks were low due to the trees being pruned, the lower yields on block 2 maybe attributed to the lower fertiliser inputs which were also lower in 2004 and 2005. In 2007 trees recovered strongly from the pruning in the previous year because of good fertilising in 2006 and 2007.

From 2004-2007 the yields of block 2 have been similar to those of block 1 even though the nitrogen inputs have been much lower and there were fewer applications. In Table 3 and 4 the mix of nutrients applied in each application is shown. This table indicates that a much broader range of nutrients were added to block 2, and that except for nitrogen greater amounts of all other nutrients applied. The fertiliser applied to block 2 was also of a slower release nature given that it was based on Nitrofosca Blue®. These findings could be interpreted in a few ways. Either tea is not responding to the higher nitrogen inputs being applied to block 1, this may be due to the lack of other nutrients being applied although the yields in these years were good when compared to historical averages; or the yields in block 2 have been increased by the application of the other nutrients and the slow release nature of the fertiliser sufficiently to compensate for the lower nitrogen rates and fewer applications. It would appear both these factors could be occurring so that yields could be increased further by adding extra nitrogen to block 2 or adding a mix of other nutrients to block 1. The costs involved in these fertilising practices indicates applying the broad mix of nutrients (as in Block 2) is generally 15-20% dearer but this may be compensated for by the need for fewer applications and/or higher yields.

Table 3 and 4 also shows how responsive tea is to the fertiliser applications especially in the summer growing season when high rainfall and temperatures favour fast growth. There is usually a flush of growth during the month or the following month after fertiliser is applied (the amount of fertiliser does not seem to matter) eg. Jan and Feb 2004, Feb, April and Oct 2005, Dec 2006 and Jan 2007. During these times fertiliser applications led to a large increase in the harvested yield in that month. The response is good with rates of 60-90 kg N/ha and is usually short lived (1-3 months) indicating that small frequent applications especially in the growing season are likely to be beneficial. The frequent applications may also help to extend the growing season into winter eg 2005. The response to fertilise applications are less obvious when rainfall is low eg December 2005.

Table 3: Yields and fertiliser inputs on Block I during the course of the project. Fertiliser inputs have been converted to kg/ha of each element at each application.

Year	Month	Yield GL/ha (kg)	MT/ha (kg)	Prune	N	P	K	S	Zn	Rainfall (mm)
2004	Jan	2604	482		69					274
	Feb	2218	430							674
	Mar	1401	276							983
	Apr	2282	475							560
	May	1812	382		82		30			143
	Jun	1723	339		82		30			190
	Jul	0	0							137
	Aug	642	131							5
	Sep	954	221							22
	Oct	950	239							54
	Nov	1123	246		144		44			90
	Dec	1014	208							193
	TOTAL	**16723**	**3429**		**377**		**104**			**3325**
2005	Jan	2394	448							470
	Feb	4610	890		79		30			114
	Mar	1258	230							448
	Apr	2413	408		80		30			400
	May	1482	286							135
	Jun	1197	230							161
	Jul	1312	274		76		28			239
	Aug	1107	231							269
	Sep	1685	378							24
	Oct	2397	532		92		34			56
	Nov	1689	422							10
	Dec	1418	346		108		40			81
	TOTAL	**22962**	**4675**		**435**		**162**			**2407**
2006	Jan	943	201							281
	Feb	4215	906		90		28			244
	Mar	2338	472							675
	Apr	1519	295							876
	May	1278	258		90		28			232
	Jun	585	118							344
	Jul	1192	280							113
	Aug	0	0	Prune						78
	Sep	0	0							153
	Oct	0	0							189
	Nov	447	97							27
	Dec	1428	306		156	12	47		1.4	151
	TOTAL	**13945**	**2933**		**336**	**12**	**103**		**1.4**	**3363**
2007	Jan	2979	579		156	12	47	1.5		264
	Feb	1009	199							941
	Mar	3330	629		83	7	26	1		253
	Apr	1612	337							284
	May	2653	555							229
	Jun	1445	289		91		25			123
	Jul									
	Aug									
	Sep									
	Oct									
	Nov									
	Dec									
	TOTAL	**13028**	**2588**		**330**	**19**	**98**	**2.5**		**2094**

Table 4: Yields and fertiliser inputs on Block II during the course of the project. Fertiliser inputs have been converted to kg/ha of each element at each application.

Year	Month	Yield GL/ha (kg)	MT/ha (kg)	Prune	N	P	K	S	Ca	Mg	Zn	B	Fe	Rainfall (mm)
2004	Jan	906	168											274
	Feb	3720	722		70									674
	Mar	1786	352											983
	Apr	2550	530											560
	May	2118	447		82	8	45	10	6	2	1.2	0.6	0.2	143
	Jun	1428	281											190
	Jul	0	0	frost										137
	Aug	1479	353											5
	Sep	2055	477											22
	Oct	1333	235											54
	Nov	1176	258		84	8	46	10	6	2	1.2	0.6	0.2	90
	Dec	871	179											193
	TOTAL	**19422**	**4002**		**236**	**16**	**91**	**20**	**12**	**4**	**2.4**	**1.2**	**0.4**	**3325**
2005	Jan	2995	560											470
	Feb	3957	764		82	8	45	9	6	2	1.1	0.5	0.2	114
	Mar	1752	321											448
	Apr	1459	247											400
	May	1765	341											135
	Jun	1212	233											161
	Jul	1408	294		83	8	45	10	6	2	1.2	0.5	0.1	239
	Aug	1434	300											269
	Sep	2078	466											24
	Oct	2155	478		85	8	45	10	6	2	1.2	0.5	0.2	56
	Nov	1888	472											10
	Dec	719	175		85	8	45	10	6	2	1.2	0.5	0.2	81
	TOTAL	**22822**	**4651**		**335**	**32**	**180**	**39**	**24**	**8**	**4.7**	**2**	**0.7**	**2407**
2006	Jan	1913	408											281
	Feb	2081	447		85	8	45	10	4	2	0.1	0.2	0.2	244
	Mar	1634	330	cyclone										675
	Apr	2996	581											876
	May	959	199		85	8	45	10	6	2	1.2	0.5	0.2	232
	Jun	897	180											344
	Jul	1104	248											113
	Aug	0	0	prune										78
	Sep	0	0											153
	Oct	0	0											189
	Nov	253	55											27
	Dec	872	187		85	8	45	10	4	2	0.1	0.2	0.2	151
	TOTAL	**12709**	**2635**		**255**	**24**	**135**	**30**	**14**	**6**	**1.4**	**0.9**	**0.6**	**3363**
2007	Jan	2843	553		85	8	45	9	6	2	1.2	0.6	0.2	264
	Feb	3507	692											941
	Mar	2186	413		83	7	26	1						253
	Apr	2715	567											284
	May	1744	362											229
	Jun	1175	243		91		25							123
	Jul	0	0	frost										
	Aug													
	Sep													
	Oct													
	Nov													
	Dec													
	TOTAL	**14170**	**2830**		**259**	**15**	**96**	**10**	**6**	**2**	**1.2**	**0.6**	**0.2**	**2094**

5.2.2 Farms 2 & 3

At farm 2 and 3 (Table 5) the yields were generally much lower than at farm 1. This may have been partly attributable to the lower fertiliser inputs 90-250 kg N/ha versus rates of up to 350-435 kg N/ha and the fewer application times 1-2 versus 3-5 at farm 1. The other factors contributing to the lower yields on these farms is the density and row spacing of the trees and the harvesters used and harvesting management. The harvesters used on these farms are narrower and have less adjustable height therefore there is more wasted inter-row space and the cutting height is not raised sufficiently at each harvest to allow the hedges to grow to their maximum potential.

At farm 2 the yields were similar between years except during 2004 when trees were pruned. In the other years the better yields corresponded to higher rates of nitrogen and more frequent applications. At farm 3 fertiliser inputs were again quite low and yields were also low. Under these less intensive management conditions with lower yield potential, high fertiliser rates and frequent applications may not be economic.

Table 5: Yields (Green Leaf (GL) and made tea (MT)), fertiliser inputs and costs, pruning operations and climatic information for Farm 2 & 3 during the project.

Year	Yield		Fertiliser			Pruning Operations	Yearly Rainfall (mm)	No. of Months Evap> Rainfall (Deficit) mm
	GL/ha (t)	MT/ha (t)	Kg N/ha	No. of applications	Cost $/ha			
Farm 2								
2003	12.8	2.7	148	2	320		2089	3 (-225)
2004	3.2	0.66	148	1	320	prune	3325	4 (-331)
2005	10.3	2.17	94	1	230		2407	4 (-390)
2006	13.1	2.74	254	2	625		3363	1 (-124)
Farm 3								
2004-2006	9.0	1.89	148	2	320		3032	3 (-282)

5.3 Patterns of Growth

Even though the yields vary significantly between farms and between years the overall patterns of growth are quite similar (Figure 4) with the most growth from October to April with a peak in January to March and the least growth from June to September. The slow growth in the winter is also due to pruning in some years. The temperature, radiation, day length, humidity and rainfall patterns provide the main drivers to the cycle of growth with the best growth rates corresponding to the highest temperatures and radiation, day length, humidity and rainfall; and the least growth corresponding to when these climatic factors are lowest.

Some of the big fluctuations in growth from month to month within individual years (Figure 5) may be related to the flushing patterns of tea and the timing of mechanical harvesting rather than growth stopping and starting. Although some resting/dormancy maybe expected after flushing and harvesting.

The fertiliser inputs (amounts, timing and frequency) provide additional stimulus to growth and may extend the length of the growing season e.g. Farm 1 (Figure 4) but they do not change the patterns of growth. In the years where yields were high at Farm 1 e.g. 2003, 2004 and 2005 (Figure 5) growth rates are higher in the summer months and the period of growth extends for longer, this appears to be related to the higher fertiliser inputs and more frequent applications. Big fluctuations in growth (0 to over 2000 tonnes GL/ha) observed in October, November and December, are related to the fertiliser and rainfall inputs with temperature, radiation and humidity all ideal for fast growth at this time e.g. 2000, 2001 and 2005. In 2002 low rainfall reduced the growth during this period even though trees were fertilised.

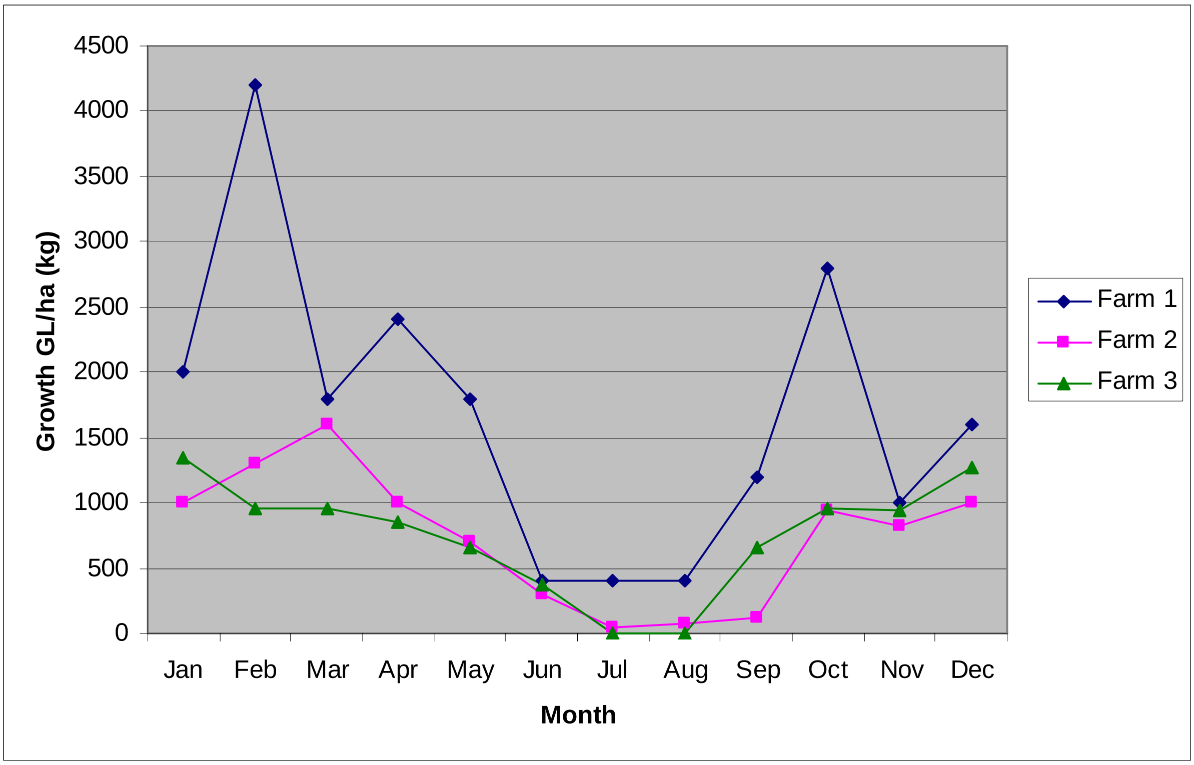
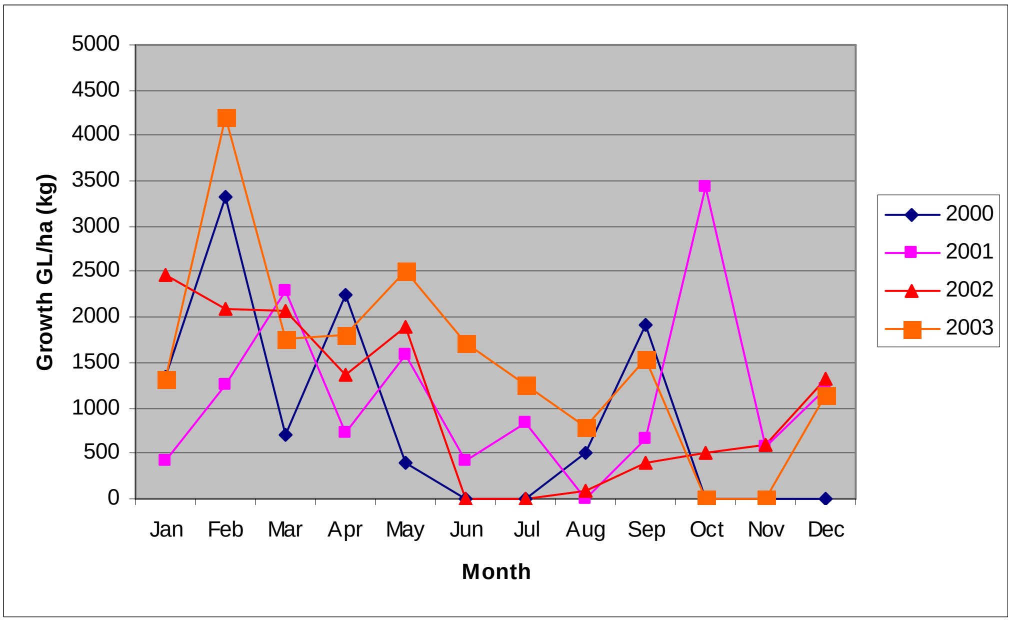


Figure 4: Average monthly growth rates on Farm 1, 2 & 3



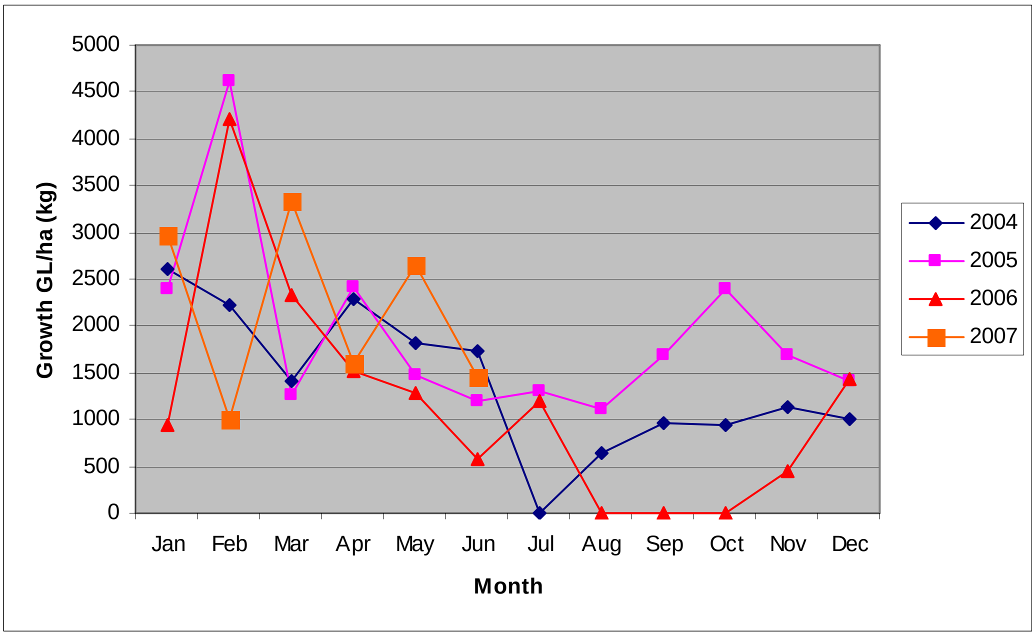


Figure 5: Monthly growth rates for Block 1 at Farm 1 during each of the years of the project.

5.4 Leaf and Soil Nutrient Levels

Leaf and soil nutrient levels over the course of the project for the three farms are shown in Figures 6-9.

5.4.1 Leaf Nutrient Levels

The leaf nutrient sampling conducted during this project allows comparisons of actual leaf levels on the three farms with the optimum or critical levels established for tea. Generally the leaf levels reflected differences in fertiliser inputs. At Farm 1 (Figure 6) the levels of N, S, Ca, Mg, Mn, Fe and B were either at or close to the optimum levels. Only P, K and Cu were lower than optimum and Zn levels much lower than optimum. Block 2 at Farm 1 generally had slightly lower N levels but higher levels of most other nutrients which reflected the lower N applications but higher applications of the other nutrients.

The good yields achieved on this farm indicate that even with sub-optimal leaf levels of P, K, Cu and Zn good yields can be achieved. This indicates that either these levels are sufficient for good yields in this environment or yields could be further improved by improving the levels of these nutrients. Similar yields on Block 2 despite lower nitrogen inputs suggest yield improvements with applications of a broad mix of nutrients may be possible.

Similar levels of leaf nutrients to Farm 1 were measured at Farms 2 and 3 (Figure 7) which was a little unexpected given the lower fertiliser inputs. Lower yields at these blocks would however have reduced the demand for nutrients. As with Farm 1 the N, S, Ca, Mg, Mn, Fe and B levels were close to the optimum levels, except the B levels at Farm 2 and the N levels at Farm 3 were a bit low. Again as with Farm 1 the leaf P, K and Cu levels were low and the Zn levels very low.

5.4.2 Soil Nutrient Levels

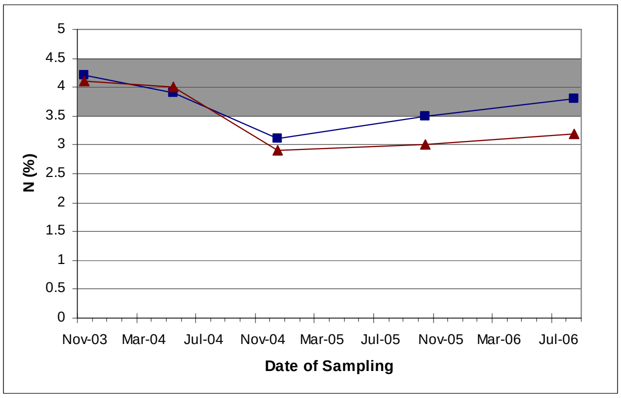
The soil nutrient sampling conducted during the project allows comparisons of the actual soil levels on the three farms with the ideal or optimum levels which have been established for tea (Figure 8 & 9). Generally the soil levels were similar between farms and seemed to reflect the geology, mineral content and soil type to more extent than the fertiliser inputs.

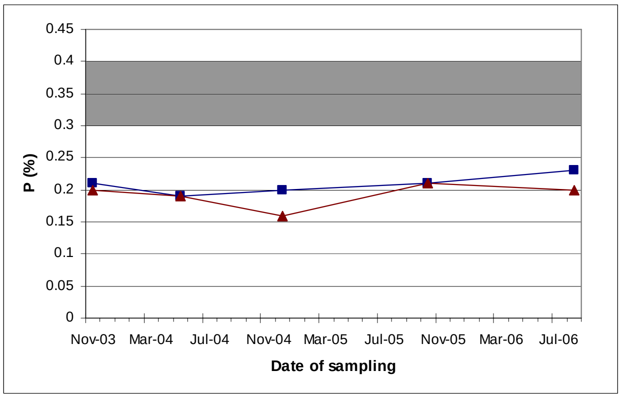
Soil pH was low on all farms 4.6-5.3 (Figure 8 & 9) although within the range considered optimum for tea production. The nutrients P, S, Mn, Fe and B were generally close to the optimum levels although B was a little low on Farm 2. These soil levels were generally reflected in the leaf levels for these nutrients at each farm. The leaf P levels are lower than expected from the soil levels and this maybe related to the P being bound with the Fe in the soil restricting its availability to the plant.

The nutrients N, K, Ca, Mg, Cu and Zn were generally quite low in the soils across the farms except for Zn at Farm 1 which is accounted for by the application of Zn SO_4 to the soil during the project. Again these low soil levels are generally reflected in the low leaf levels for some of these nutrients (K, Cu and Zn). The soil measure of Ca and Mg is likely to be under-estimated because in these acidic leached soils the Ca and Mg is sometimes not attached to the colloids in the soil (being replaced by Mn and Al) and as such are under-estimated in measurement. The good leaf levels suggest Ca and Mg are adequately supplied from these soils. The soil nitrogen is measured by measuring the NO_3 levels which are quite variable in the soil and therefore an unreliable indicator of available N. The low soil and leaf K, Cu and Zn suggest trees may benefit from additional applications of these nutrients; Ca and Al are known to interfere with the uptake of K in acid soils. On Farm 1 where additional Zn was added soil levels increased however this did not significantly improve the leaf levels suggesting that this nutrient may need to be applied as a foliar spray. High soil Mn levels associated with the low pH and high soil P are known to interfere with the uptake of Zn. In the same way Mn can interfere with the uptake of Cu. Even where the soil Cu level was reasonable leaf levels were low therefore foliar sprays of Cu may also be warranted.

The recommendation for these nutrients would be to apply a 1% Zn/Cu So_4 solution mixed with 1% urea and a wetter as a foliar spray to new actively growing flush 2-3 times a year during the growing season.

Again the reasonable yields achieved at Farm 1 indicate that even with sub-optimal levels of the soil nutrients K, Cu and Zn good yields can be achieved. This indicates that either these levels are sufficient for good yields in this environment or yields could be improved by improving the levels of these nutrients.


N (%)
Date of Sampling
Nov-03 Mar-04 Jul-04 Nov-04 Mar-05 Jul-05 Nov-05 Mar-06 Jul-06


P (%)
Date of sampling
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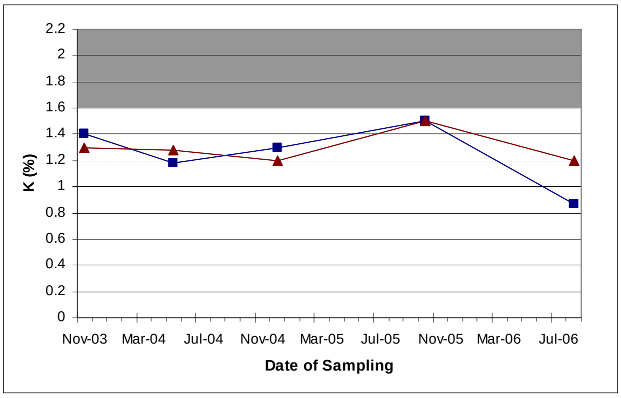
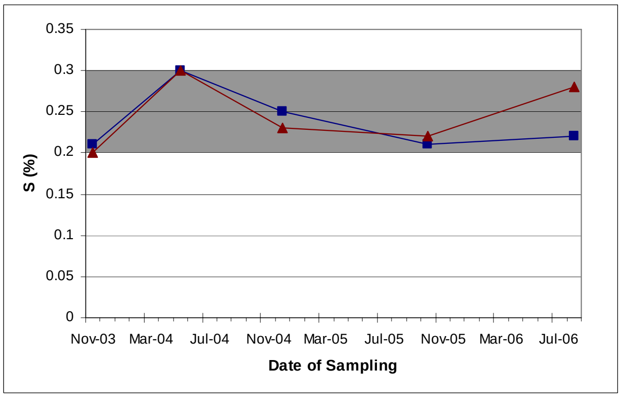
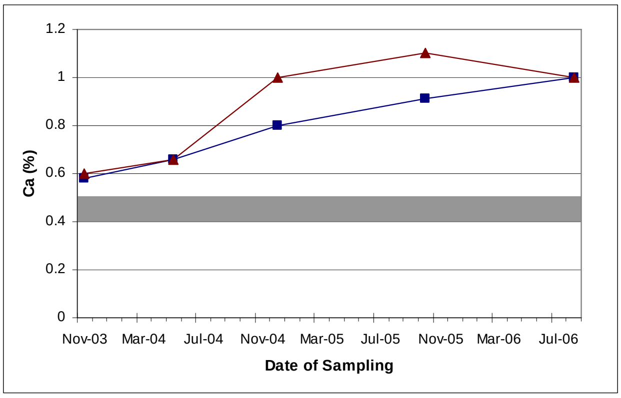
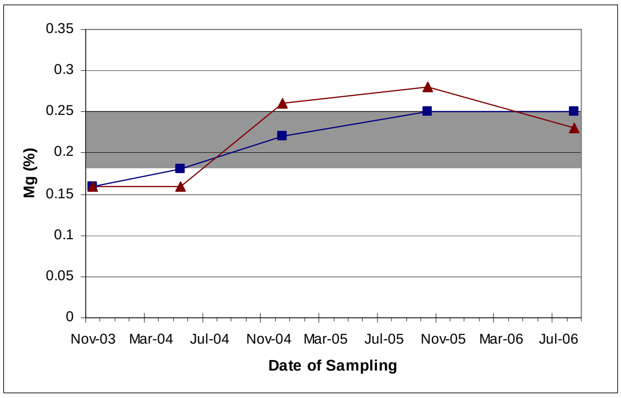
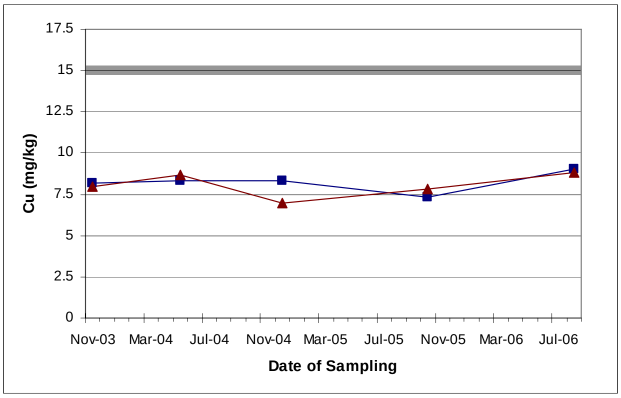
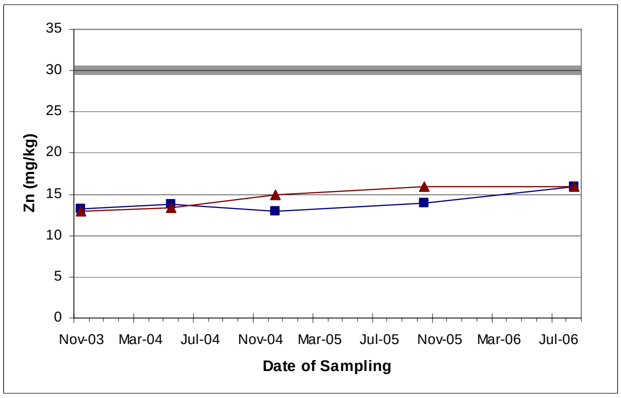

K (%)
Date of Sampling
Nov-03 Mar-04 Jul-04 Nov-04 Mar-05 Jul-05 Nov-05 Mar-06 Jul-06


S (%)
Date of Sampling
Nov-03 Mar-04 Jul-04 Nov-04 Mar-05 Jul-05 Nov-05 Mar-06 Jul-06


Ca (%)
Date of Sampling
Nov-03 Mar-04 Jul-04 Nov-04 Mar-05 Jul-05 Nov-05 Mar-06 Jul-06


Mg (%)
Date of Sampling
Nov-03 Mar-04 Jul-04 Nov-04 Mar-05 Jul-05 Nov-05 Mar-06 Jul-06


Cu (mg/kg)
Date of Sampling
Nov-03 Mar-04 Jul-04 Nov-04 Mar-05 Jul-05 Nov-05 Mar-06 Jul-06


Zn (mg/kg)
Date of Sampling
Nov-03 Mar-04 Jul-04 Nov-04 Mar-05 Jul-05 Nov-05 Mar-06 Jul-06

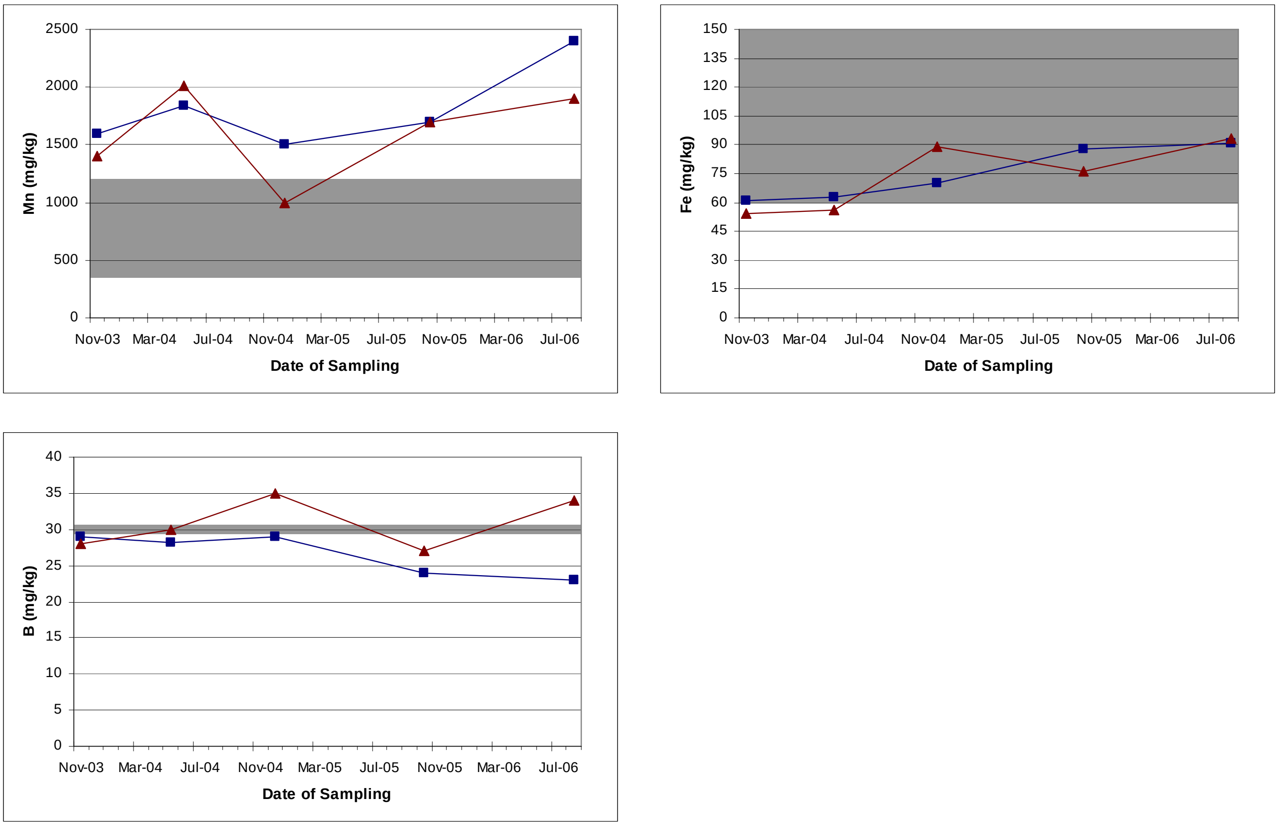
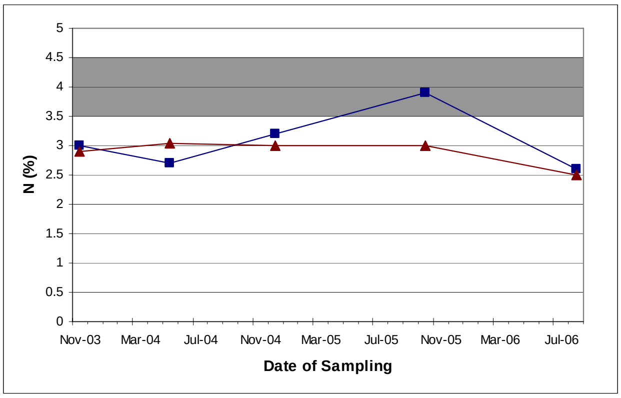
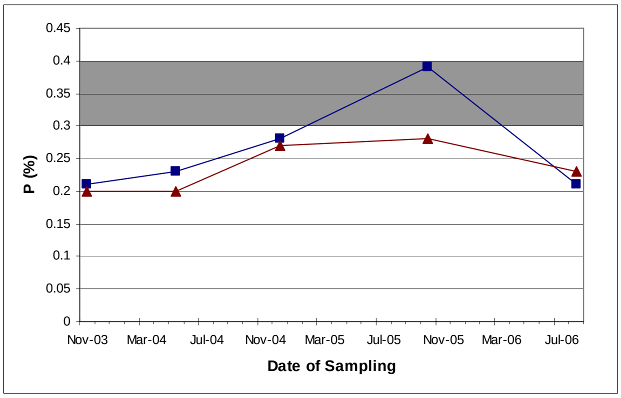
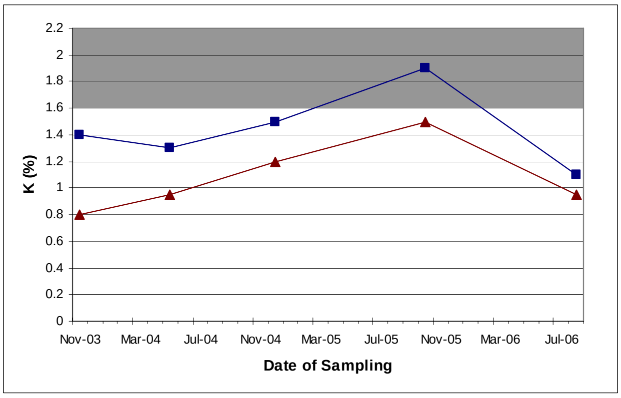
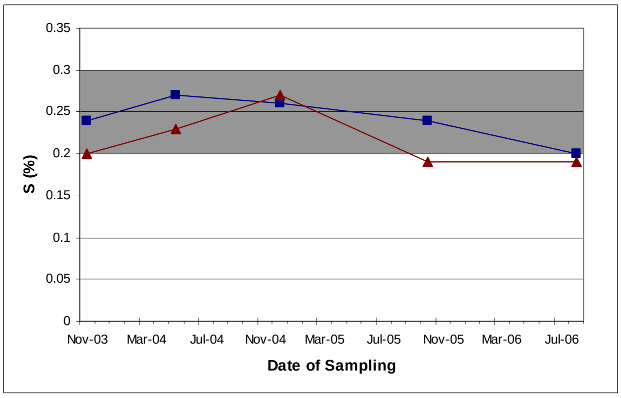


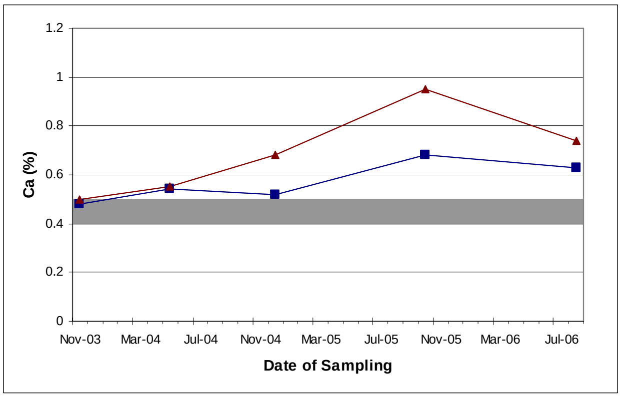
Figure 6: Leaf nutrient levels for Block 1 (■) and Block 2 (▲) at Farm 1 during the project. The shaded area is the optimum/critical leaf level for tea.

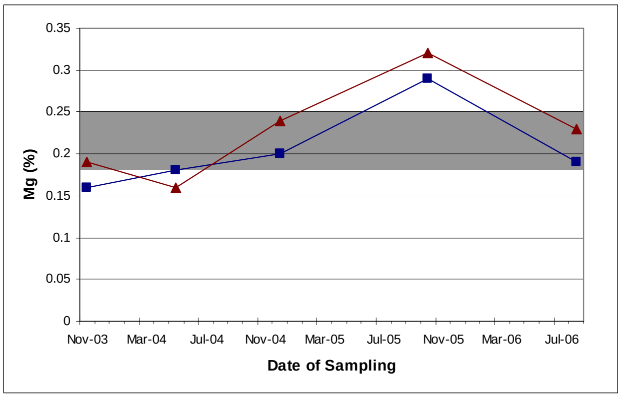

N (%)
Date of Sampling
Nov-03
Mar-04
Jul-04
Nov-04
Mar-05
Jul-05
Nov-05
Mar-06
Jul-06

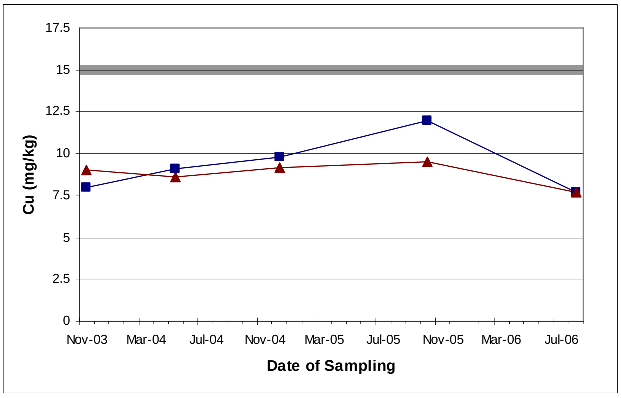

P (%)
Date of Sampling
Nov-03
Mar-04
Jul-04
Nov-04
Mar-05
Jul-05
Nov-05
Mar-06
Jul-06

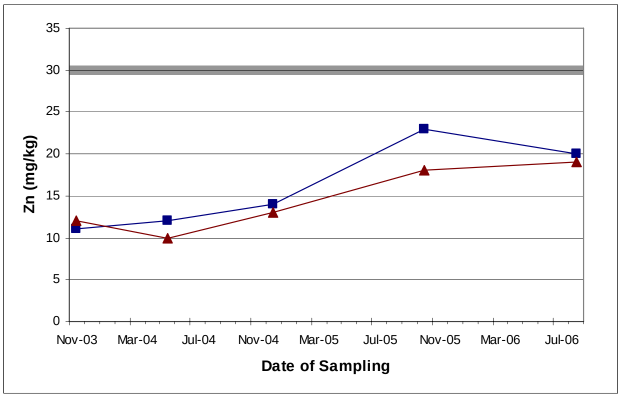

K (%)
Date of Sampling
Nov-03
Mar-04
Jul-04
Nov-04
Mar-05
Jul-05
Nov-05
Mar-06
Jul-06


S (%)
Date of Sampling
Nov-03
Mar-04
Jul-04
Nov-04
Mar-05
Jul-05
Nov-05
Mar-06
Jul-06


Ca (%)
Date of Sampling
Nov-03
Mar-04
Jul-04
Nov-04
Mar-05
Jul-05
Nov-05
Mar-06
Jul-06


Mg (%)
Date of Sampling
Nov-03
Mar-04
Jul-04
Nov-04
Mar-05
Jul-05
Nov-05
Mar-06
Jul-06


Cu (mg/kg)
Date of Sampling
Nov-03
Mar-04
Jul-04
Nov-04
Mar-05
Jul-05
Nov-05
Mar-06
Jul-06


Zn (mg/kg)
Date of Sampling
Nov-03
Mar-04
Jul-04
Nov-04
Mar-05
Jul-05
Nov-05
Mar-06
Jul-06

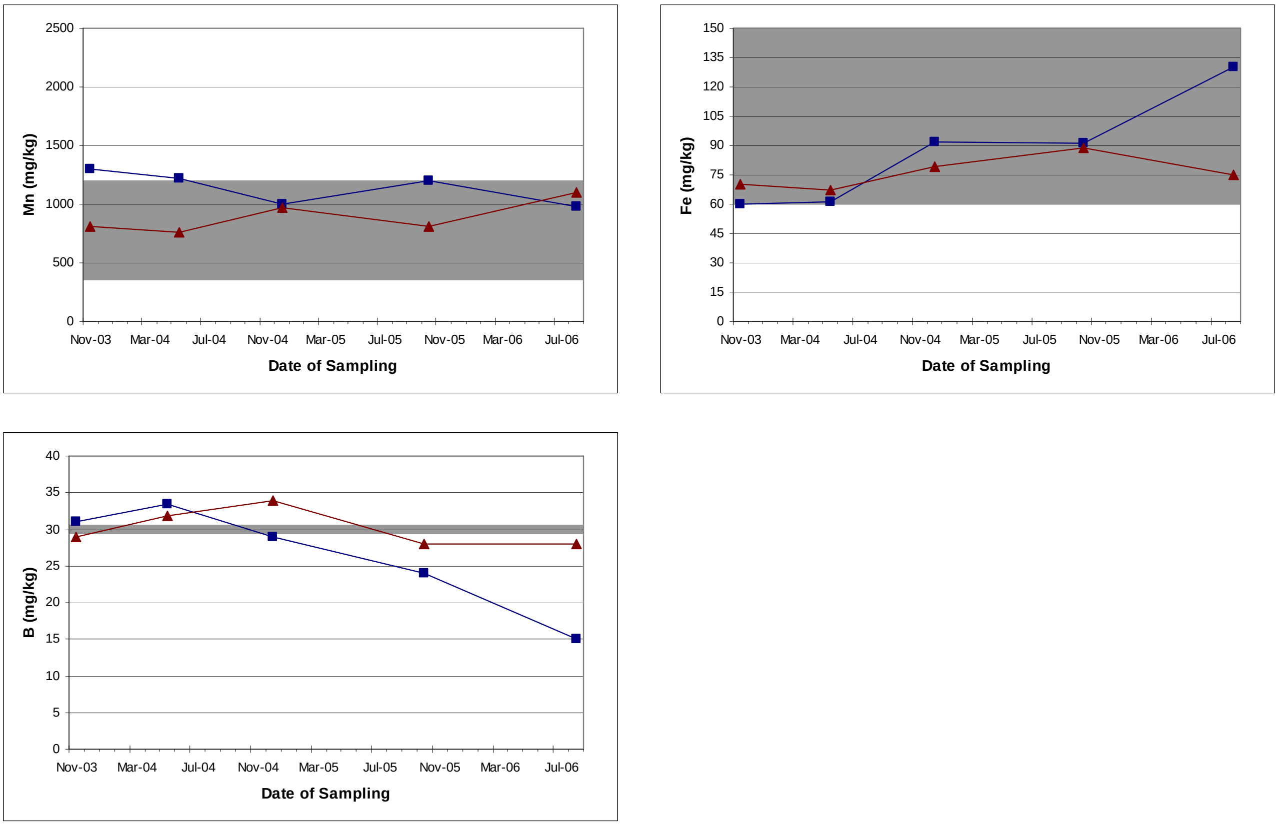
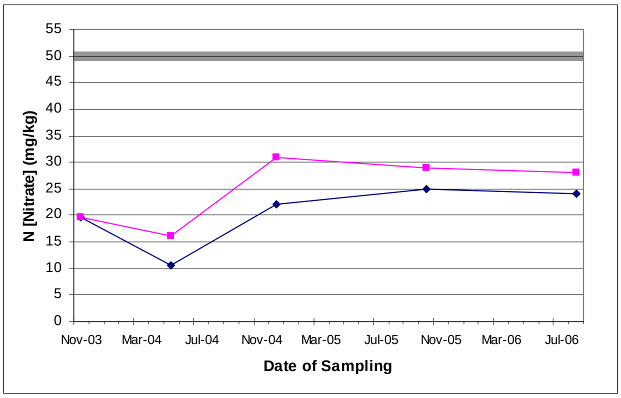
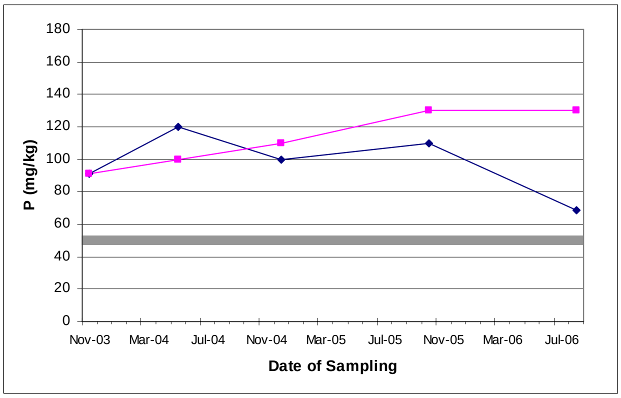
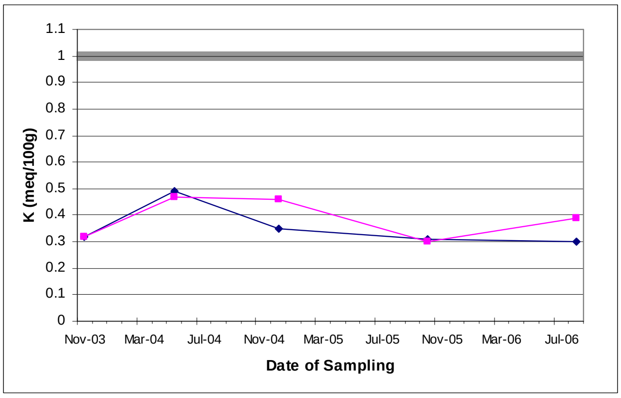
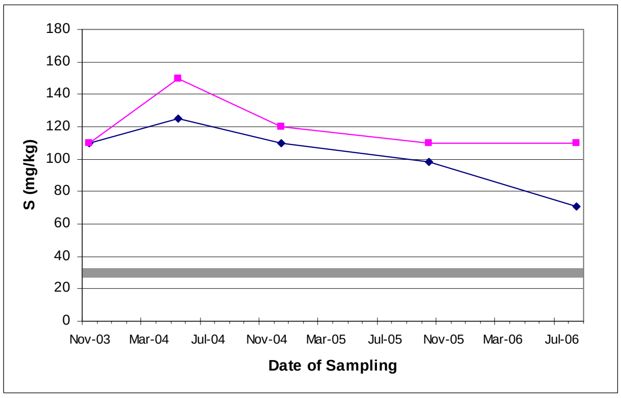


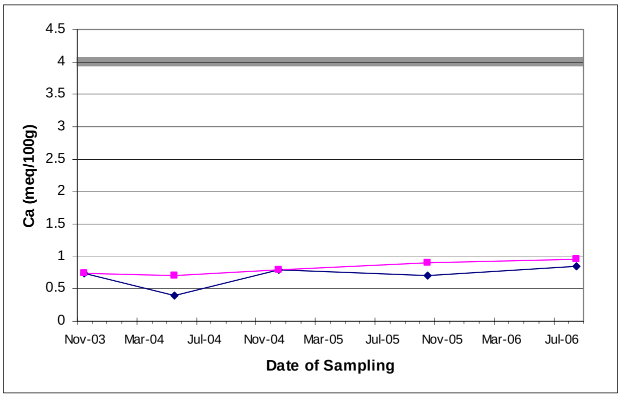
Figure 7: Leaf nutrient levels for Farm 2 (■) and Farm 3 (▲) during the project. The shaded area is the optimum/critical leaf level for tea.

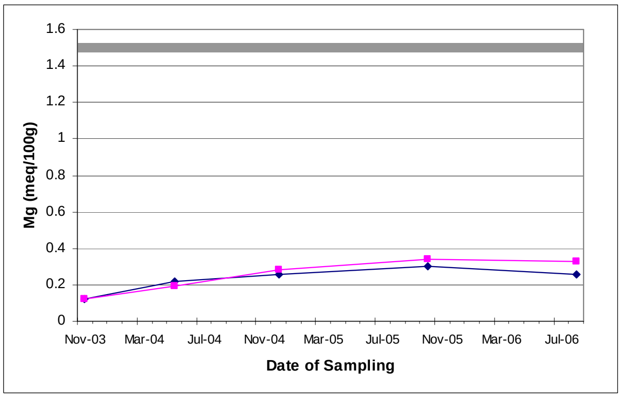

N [Nitrate] (mg/kg)
Date of Sampling
Nov-03
Mar-04
Jul-04
Nov-04
Mar-05
Jul-05
Nov-05
Mar-06
Jul-06

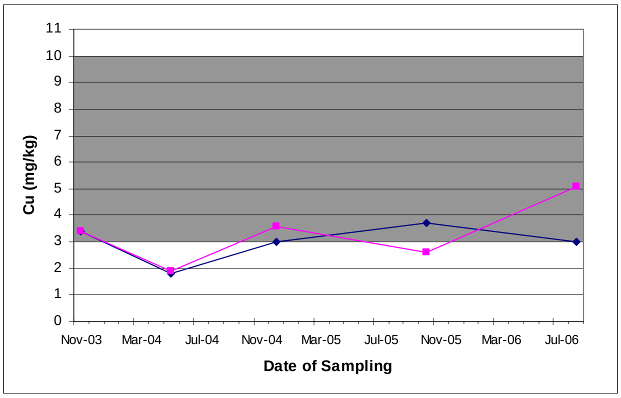

P (mg/kg)
Date of Sampling

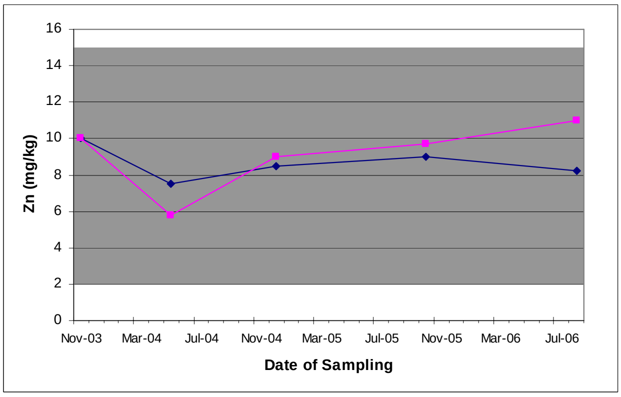

K (meq/100g)
Date of Sampling


S (mg/kg)
Date of Sampling


Ca (meq/100g)
Date of Sampling


Mg (meq/100g)
Date of Sampling


Cu (mg/kg)
Date of Sampling


Zn (mg/kg)
Date of Sampling

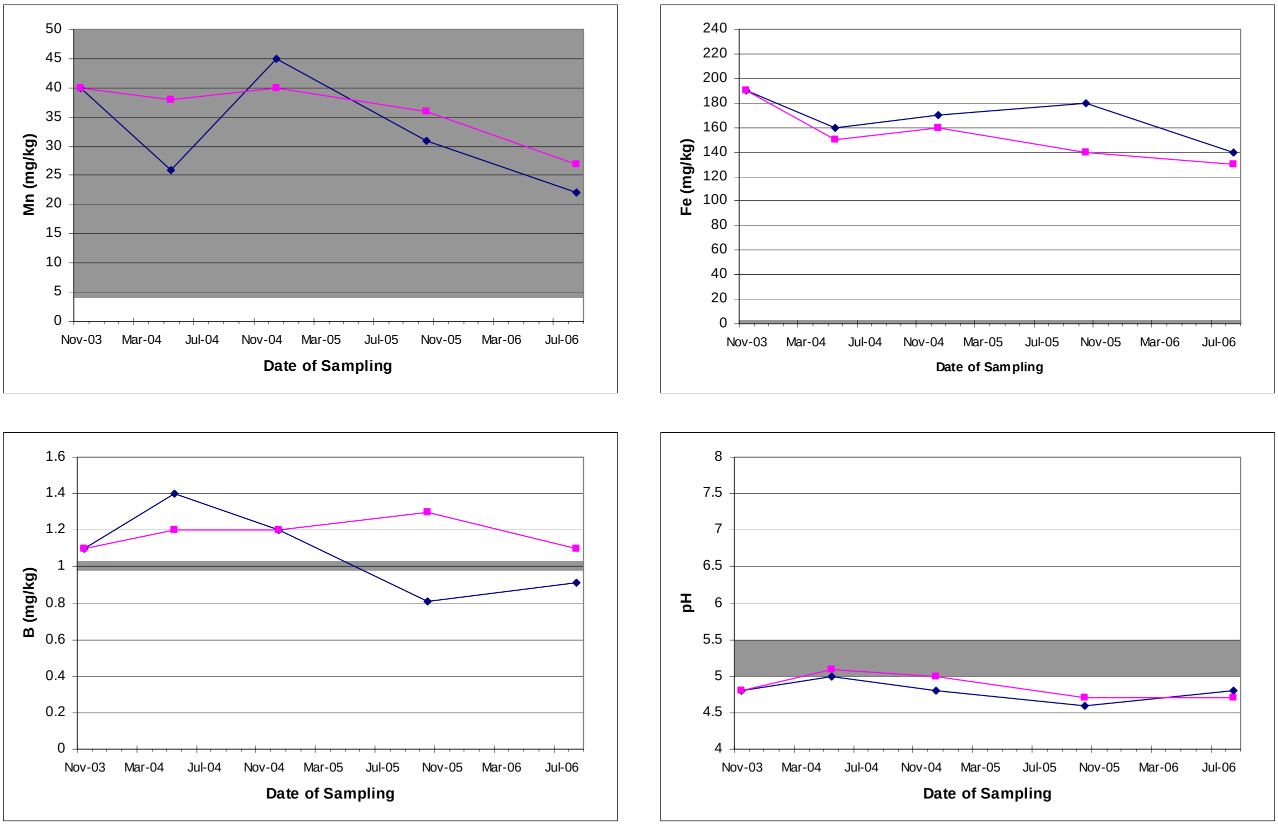
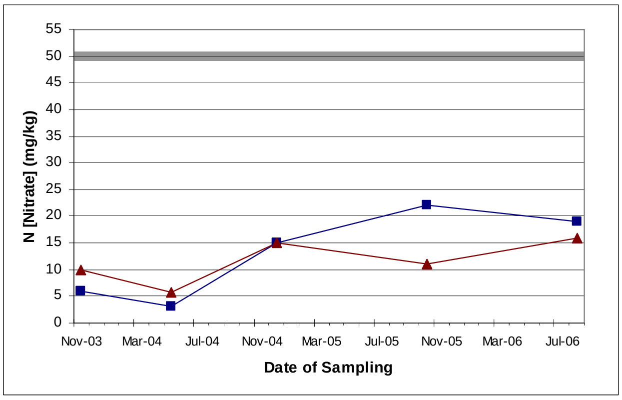
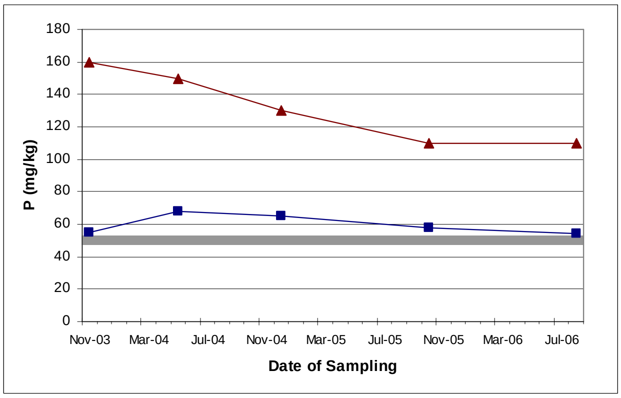
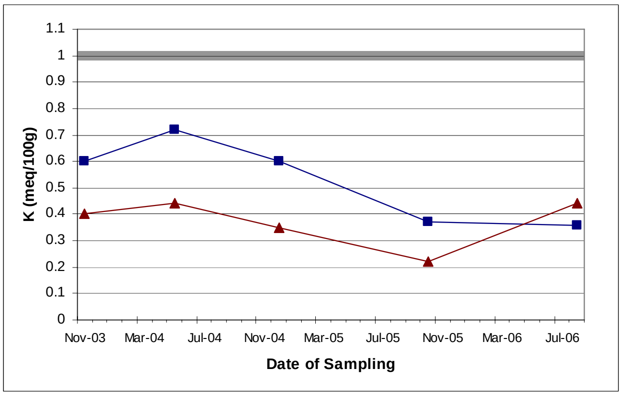
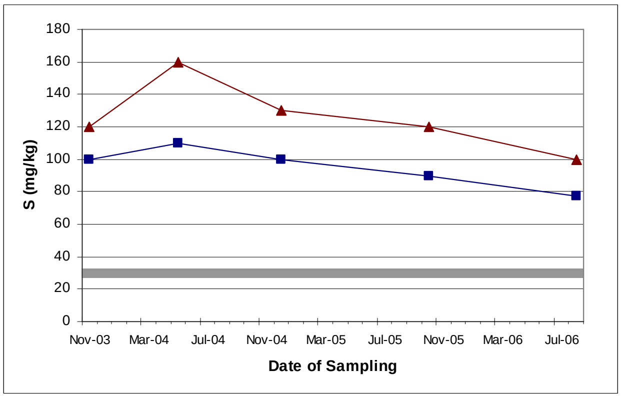


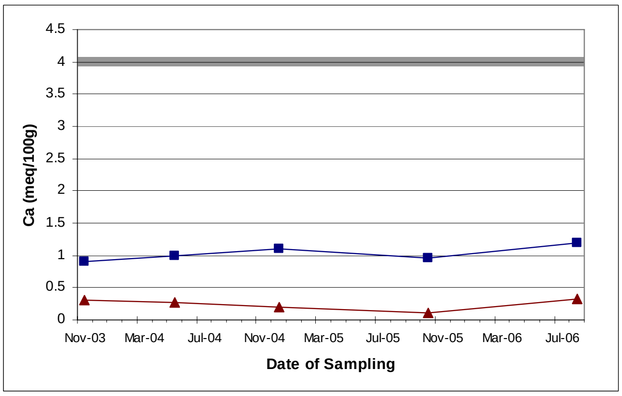
Figure 8: Soil nutrient levels for Block 1 (▲) and Block 2 (■) during the project. The shaded area is the optimum/critical soil level for tea.

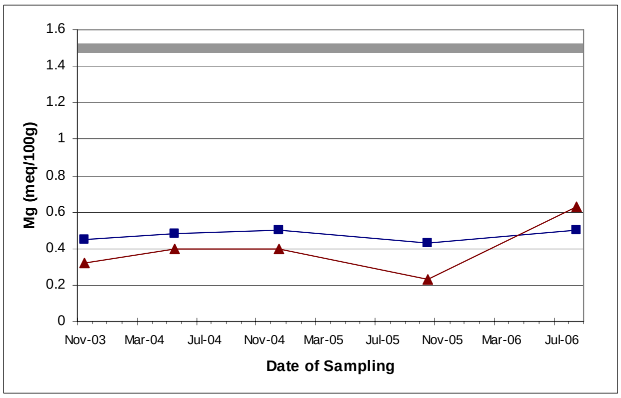

N [Nitrate] (mg/kg)
55
50
45
40
35
30
25
20
15
10
5
0
Nov-03
Mar-04
Jul-04
Nov-04
Mar-05
Jul-05
Nov-05
Mar-06
Jul-06
Date of Sampling

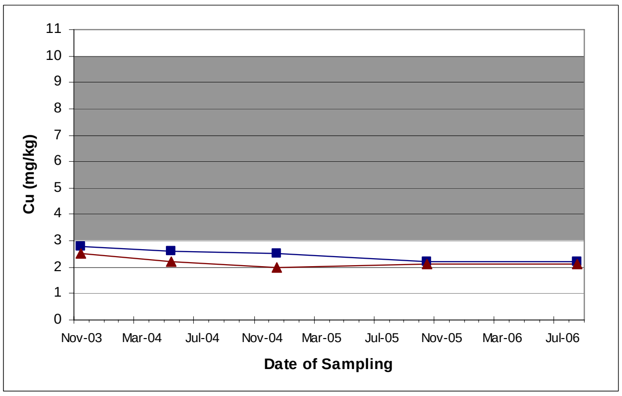

P (mg/kg)
180
160
140
120
100
80
60
40
20
0
Nov-03
Mar-04
Jul-04
Nov-04
Mar-05
Jul-05
Nov-05
Mar-06
Jul-06
Date of Sampling

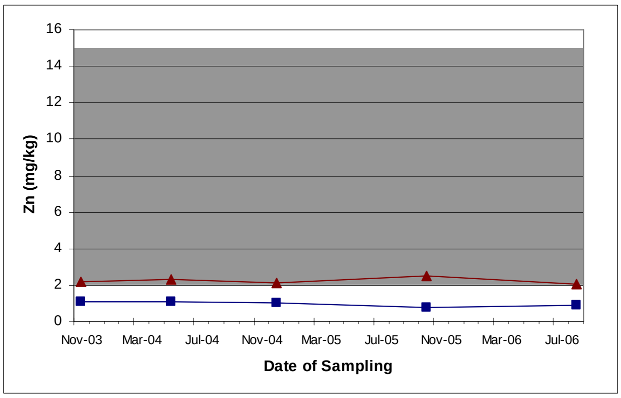

K (meq/100g)
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Nov-03
Mar-04
Jul-04
Nov-04
Mar-05
Jul-05
Nov-05
Mar-06
Jul-06
Date of Sampling


S (mg/kg)
180
160
140
120
100
80
60
40
20
0
Nov-03
Mar-04
Jul-04
Nov-04
Mar-05
Jul-05
Nov-05
Mar-06
Jul-06
Date of Sampling


Ca (meq/100g)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Nov-03
Mar-04
Jul-04
Nov-04
Mar-05
Jul-05
Nov-05
Mar-06
Jul-06
Date of Sampling


Mg (meq/100g)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Nov-03
Mar-04
Jul-04
Nov-04
Mar-05
Jul-05
Nov-05
Mar-06
Jul-06
Date of Sampling


Cu (mg/kg)
11
10
9
8
7
6
5
4
3
2
1
0
Nov-03
Mar-04
Jul-04
Nov-04
Mar-05
Jul-05
Nov-05
Mar-06
Jul-06
Date of Sampling


Zn (mg/kg)
16
14
12
10
8
6
4
2
0
Nov-03
Mar-04
Jul-04
Nov-04
Mar-05
Jul-05
Nov-05
Mar-06
Jul-06
Date of Sampling

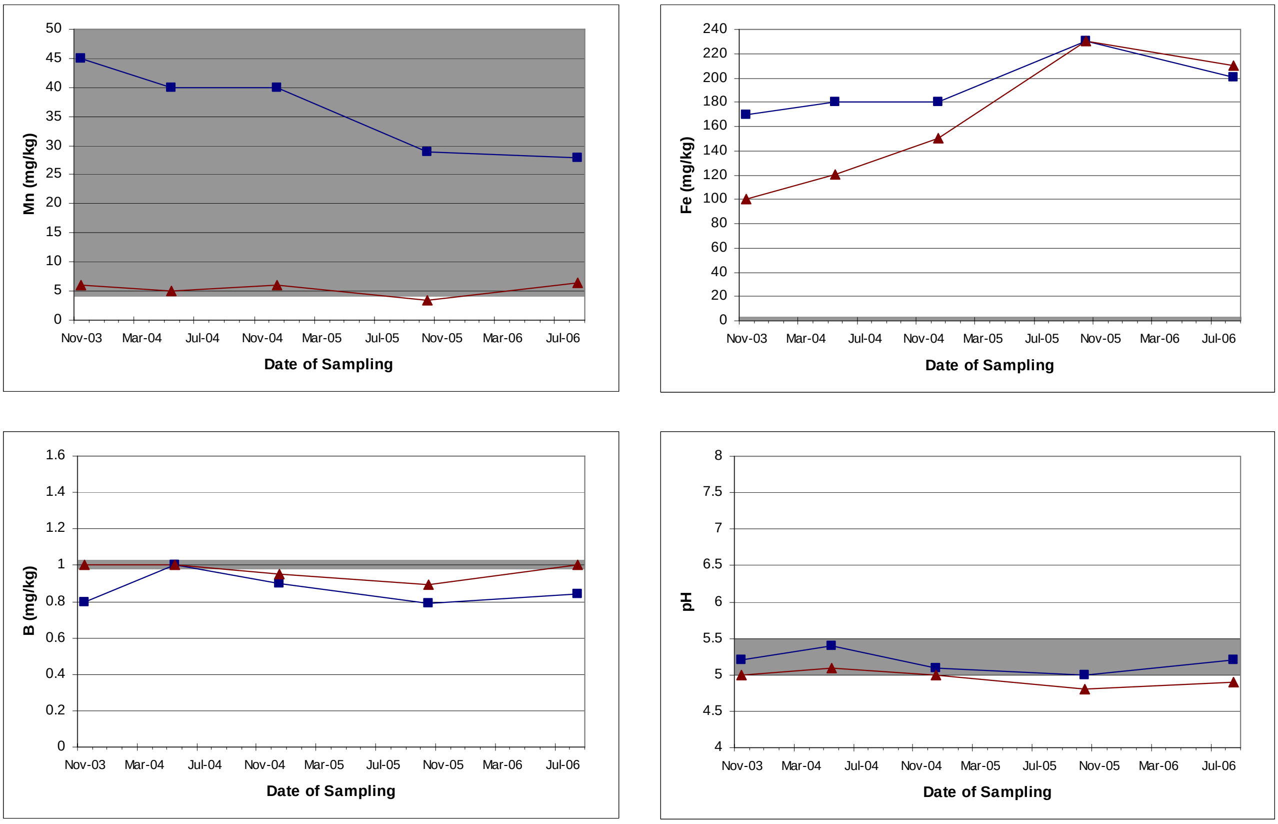


Figure 9: Soil nutrient levels for Farm 2 (■) and Farm 3 (▲) during the project. The shaded area is the optimum/critical soil level for tea.

5.5 Deficiency Symptoms

To help identify which nutrients may be inducing deficiency symptoms and possible losses in yield, a series of paired comparison of nutrient levels were conducted. Samples were taken from the same field at the same time from dark green plants exhibiting strong growth and from plants exhibiting nutrient deficiency symptoms such as yellow or pale green leaves, small or deformed leaves or leaves with intervienal chlorosis. Samples were taken at various times throughout the project from each of the farms. The results are presented in the following figures. Only the differences in the levels of the deficient nutrients are shown (Figure 10).

The samples indicated that nutrient deficiency symptoms sometimes exhibited by tea could not always be attributed to nutrient deficiencies and maybe due to other factors. Where nutrient deficiencies could be implicated nitrogen was the nutrient most consistently lower in the yellow samples, followed by Fe and B. The levels of Cu and Zn were also deficient in the yellow samples however interestingly the levels were often higher in the yellow samples than the dark green leaf green samples. When growth is restricted as maybe the case in these yellow samples where nitrogen and potassium are deficient the levels of some micro-nutrients may rise as a percentage of the dry matter.

The cause of the deficiency symptom sometimes exhibited by individual plants therefore cannot be attributed to a single nutrient but maybe due to several nutrients including N, Fe, B, Cu or Zn. Deficiencies in B, Fe, Cu and Zn may be corrected by applying foliar sprays of Boric Acid (0.1%) or 1% Iron, Copper, Zinc Sulphate or applying solubor at 5-10 kg/ha or Fe, Cu or Zn sulphate at 5-10 kg/ha to the soil.

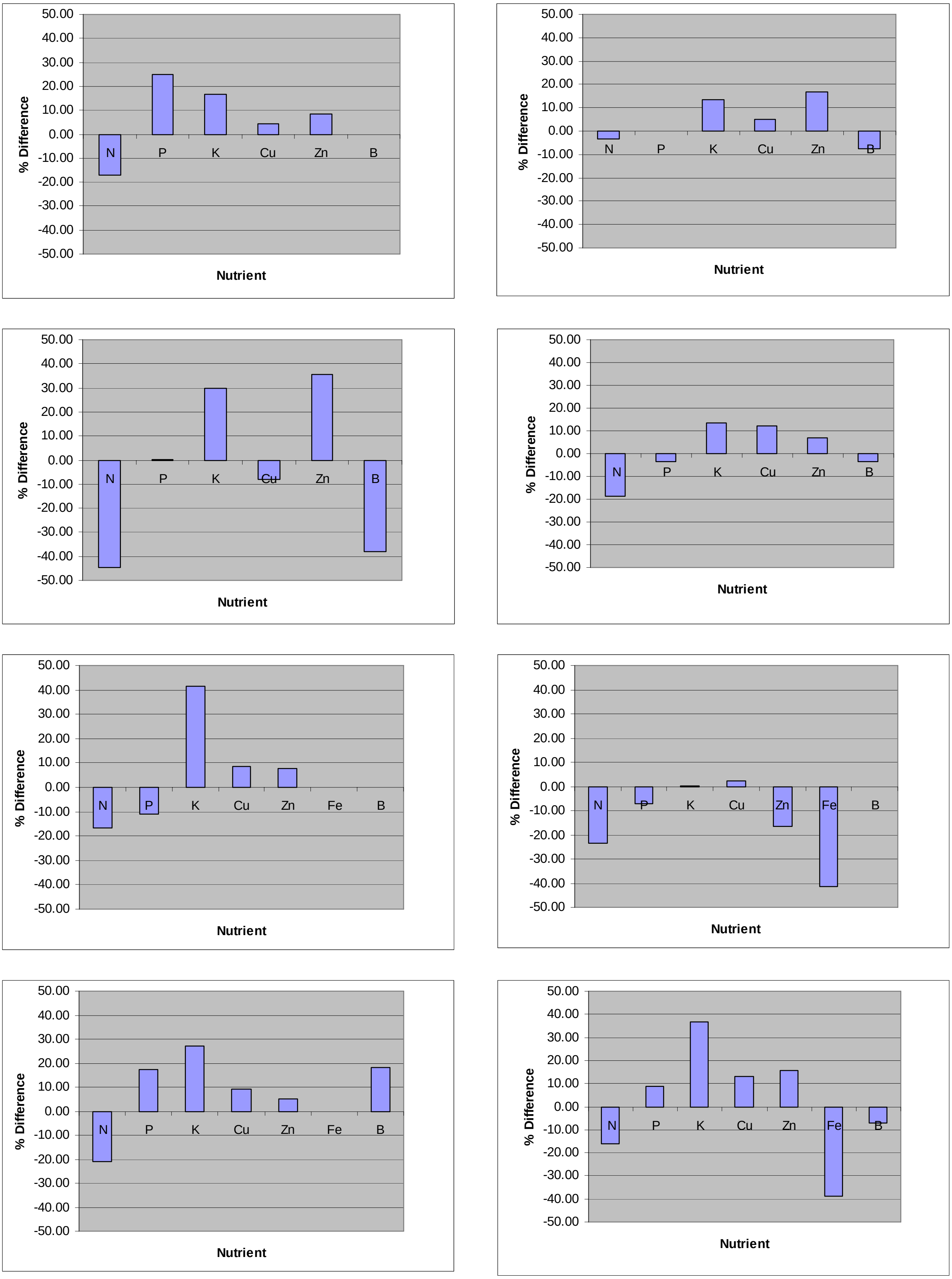


Figure 10: Differences in the levels of the deficient nutrients between healthy dark green leaf samples and unhealthy yellow leaf samples.

5.6 Developing a Fertiliser Program

Developing a fertiliser programme for tea ought to be fairly straight forward being a perennial crop whose production is based on vegetative growth. Unlike many horticultural crops where considerations of dormancy, floral initiation, flowering, cropping and fruit quality have to be factored in. For tea, a fertiliser programme which promotes strong vegetative growth over the entire year is likely to produce the best yields. In developing a fertiliser program three things need to be determined, the amount of each nutrient that should be applied, how frequently and at what times.

5.6.1 Amount

The amount of each nutrient required can be determined by collecting yield responses to various fertiliser inputs (as in this project), from the literature on fertiliser recommendations from other countries or by conducting a nutrient budget where the nutrient inputs are matched to the nutrient outputs (crop removal).

The results from this project indicate that on Farm 1 where high yields (3.6 – 4.7 t/ha) are being achieved nitrogen rates around 350-450 kg/ha, phosphorus rates around 15-30 kg/ha and potassium rates around 100-180 kg/ha seem adequate. While on Farm 2 & 3 where due to different plant spacing, densities and harvester management the yields are lower (1.9 – 2.7 t/ha) nitrogen rates around 150-250 kg/ha, phosphorous rates around 10-20 kg/ha and potassium levels around 65-126 kg/ha seem adequate.

In the literature rates of fertiliser inputs vary greatly depending on the planting material, level of management and yields being achieved. In situations similar to North Queensland nitrogen rates of 300-500 kg/ha, phosphorous rates of 30-100 kg/ha and potassium rates of 180-300 kg/ha have been used. In determining nitrogen rates quite often a ratio of 1 unit of N for every 10 units of made tea produced is used i.e. 300 kgN for 3 tonnes of made tea.

The other approach to determining the nutrient requirements is to conduct a nutrient budget where the nutrient inputs are matched to the nutrients removed by the crop plus an adjustment for other losses such as leaching, runoff, volatilisation and fixation. These factors can be minimised by careful management particularly by avoiding fertiliser application during periods of intense rainfall. These losses have been estimated at 30-50% for N, 50-100% for P, 30% for K, 10% for Ca and 25% for Mg. (Slack, et. al., 1996, Armour (pers. com.)). Losses for the other nutrients could be estimated to be similar. A nutrient budget method does not take into account the soils existing nutritional status however it is still a good estimate of fertiliser requirements and highlights any major discrepancies between fertiliser inputs and crop removal. Additional nutrient demand would occur following pruning to re-establish the hedge however this is assumed to be balanced by nutrients recycled through decomposition of prunings.

The amount of nutrients removed by tea is a function of the biomass yield multiplied by the nutrient level in the biomass. For a sustainable production system the nutrients removed should be at the very least be replaced. If nutrients are not replaced the soil reserves are slowly depleted and soil fertility declines. This can lead to nutrient deficiencies and reduced growth.

In the following table the amount of nutrients removed by a crop yielding 2 and 5 t/ha is given. Figures have been inflated for estimated losses from leaching, runoff, volatilisation and fixation.

Nutrient	Levels found in leaf	Nutrient Removed (kg)		Estimated losses
		2t/ha	5t/ha	
N	4%	120	300	50%
P	0.35%	14	35	100%
K	2%	45	110	30%
S	0.25%	6	15	25%
Ca	0.4%	9	22	10%
Mg	0.2%	5	13	25%
Cu	20 mg/kg	0.05	0.13	25%
Zn	40 mg/kg	0.1	0.25	25%
Fe	100 mg/kg	0.25	0.65	25%
B	30 mg/kg	0.075	0.19	25%

This data indicates that tea uses large amounts of nutrients especially when high yields are being achieved. A fertiliser with a nutrient ratio of 10 N: 1 P: 4 K: 0.5 S: 0.5 Ca: 0.5 Mg should provide these nutrients in roughly the right proportions. Small amounts of Cu, Zn, Fe and B should also be added.

The levels of nutrients required indicated by the nutrient budget are lower than the levels recommended in the literature and the levels being indicated by this project. This maybe due to greater losses occurring in the system than being estimated in the nutrient budget. By splitting the fertiliser used into smaller more frequent applications these losses maybe able to be reduced and hence application rates reduced. It is suggested growers use the rates developed from the nutrient budget for all nutrients except nitrogen and potassium as a minimum and gradually experiment with higher levels if yield increases can be demonstrated. For nitrogen and potassium data from the project and the literature suggest growers use 400 - 450 kg N/ha and 150-200 kg K/ha where yields of 4-4.5 t/ha are being targeted and 200-250 kg N/ha and 80-120 kg K/ha where yields of 2-2.5 t/ha are being targeted.

The micronutrients Cu, Zn, Fe and Boron can be added either to the ground or as foliar sprays. Foliar application is recommended for Cu and Zn as these nutrients are often unavailable to the plant from the soil because of interactions with other nutrients as observed in this project. Two to three applications of 1% Cu and Zn Sulphate during the growing season is recommended. Urea (1%) and a wetter can also be added to aid absorption. Foliar applications are best applied to new flush as the young leaves readily absorb nutrients. If applied to the ground the nutrients can be added to the fertiliser mix or they can be added individually. For Cu, 10 kg/ha of Cu So_4 and for Zn, 10 kg/ha of Zn So_4 is recommended.

For B and Fe ground application should be sufficient. They can be added as part of a fertiliser mix or they can be added individually. For B, 10 kg/ha of Solubor and for Fe, 10 kg/ha of Fe SO_4 is recommended.

5.6.2 Frequency

In determining the ideal frequency of fertiliser applications there are a number of considerations:

1. The cost of application. Fertiliser application on a broad acre crop such as tea is relatively expensive $20/ha. Therefore, in order to keep costs to a minimum the number of applications should be kept to a minimum.
2. The nutrient holding capacity of the soil. Even these rich red Kraznozen soils are limited in the amount of nutrients which can be held to the clay particles. If more nutrients are added than can be held by the clay particles they remain in the soil solutions and can be lost by leaching. Therefore the quantity of fertiliser added at one time should be kept to a minimum. It has been estimated from work on pastures on similar soils in this environment that single Nitrogen applications should not exceed 50-80 kg N/ha.
3. The climate. In a heavy rainfall environment where the potential for extreme rainfall events is great it is wise to split fertiliser applications up so that the risks of losses from leaching, runoff or erosion are minimised.
4. The growth response. Tea is very responsive to fertiliser applications, flushing each time fertiliser is applied and yields have been greatest with frequent applications.

Taking into account these considerations four to six even applications would appear to be the best compromise between minimising the costs of application, minimising possible losses and wastage from leaching, runoff, erosion etc. and maximising production.

5.6.3 Timing

The best timing of applications will be determined by the growth cycle. Most of the fertiliser should be applied in the summer months when growth is the fastest and the least during the winter months when growth is the slowest (Figure 4). The applications should aim to increase the growth rates through summer and extend the length of the growing season into winter.

Figure 4 shows that 80% of the yearly growth occurs from October to April and 20% from May to September, therefore fertiliser applications should be timed to apply 80% of the fertiliser from October to April and 20% from May to September. With the first application starting in September or October coinciding with the first storms the following intervals between applications is given depending on the number of applications being used (Table 6).

Table 6: Suggested intervals between fertiliser applications depending on the number of annual applications.

	1st Application (Sept-Oct)	2nd Application	3rd Application	4th Application	5th Application	6th Application	% of total annual fertiliser applied
6 yearly applications	↑ 8 weeks	↑ 6 weeks	↑ 6 weeks	↑ 6 weeks	↑ 10 weeks	↑ 16 weeks	16
5 yearly applications	↑ 8 weeks	↑ 8 weeks	↑ 8 weeks	↑ 14 weeks	↑ 14 weeks		20
4 yearly applications	↑ 12 weeks	↑ 10 weeks	↑ 10 weeks	↑ 20 weeks			25

The intervals are timed so that the % of the annual fertiliser applied matches the % of the annual growth expected. The middle applications are closest together coinciding with the summer growth flush when temperatures, rainfall and humidity are all favourable for fast growth. The applications then become less frequent leading into winter when growth is slow.

6 Implications

This project has increased the knowledge base of Tea Researchers, Extension Officers and Australian Tea Growers on the nutritional requirements of tea. The current nutritional status (leaf and soil) and fertiliser inputs of the tea growing in North Queensland has been documented. Results indicate that the climate (rainfall, temperature), pruning cycle and fertiliser inputs all interact to determine the yield of tea. The overall pattern of growth was generally influenced by the climate whilst the amount of growth and the length of the growing season were determined by the fertiliser inputs. Only in years where annual rainfall was less than 1500mm, was yield reduced. The pruning cycle, as expected, reduced yields during that year and the recovery in yield was delayed by poor fertilising practices.

The fertiliser records, leaf and soil nutrient levels and yield data suggest that higher levels of a broader mix of nutrients and smaller more frequent applications than currently being used by the industry, could improve the nutrient availability and improve yields. A suggested fertiliser program has been developed based on the results of the project, the literature, a nutrient budget and the growth cycle. Smaller more frequent fertiliser applications are also likely to reduce losses and wastage of nutrients through leaching and runoff reducing costs and environmental impacts.

Improved yields are likely to lead to reduced costs of production and improved economic viability of the tea industry. This in turn will lead to expansion of the tea industry and an increase in the economic and social contribution to the regional economies of Malanda and the Atherton Tablelands, as well as contributing more to the Queensland and Australian economy through increased exports and import substitution.

7 Recommendation

The results from this project have allowed a fertiliser program to be developed. The timing and frequency of fertiliser applications is shown in Figure 11. Four to six applications at intervals of 6 to 20 weeks is recommended. Most of the fertiliser should be applied during the growing season and least, during the winter dormant period.

Growers are advised to use a fertiliser mix with the following ratio of nutrients as this is likely to supply the nutrients in the right proportions for good plant growth. It is also advisable to work with a soil and sap or leaf testing program

10 N: 1 P: 4 K: 0.5 S: 0.5 Ca: 0.5 Mg plus small amounts of Cu, Zn, Fe and B.

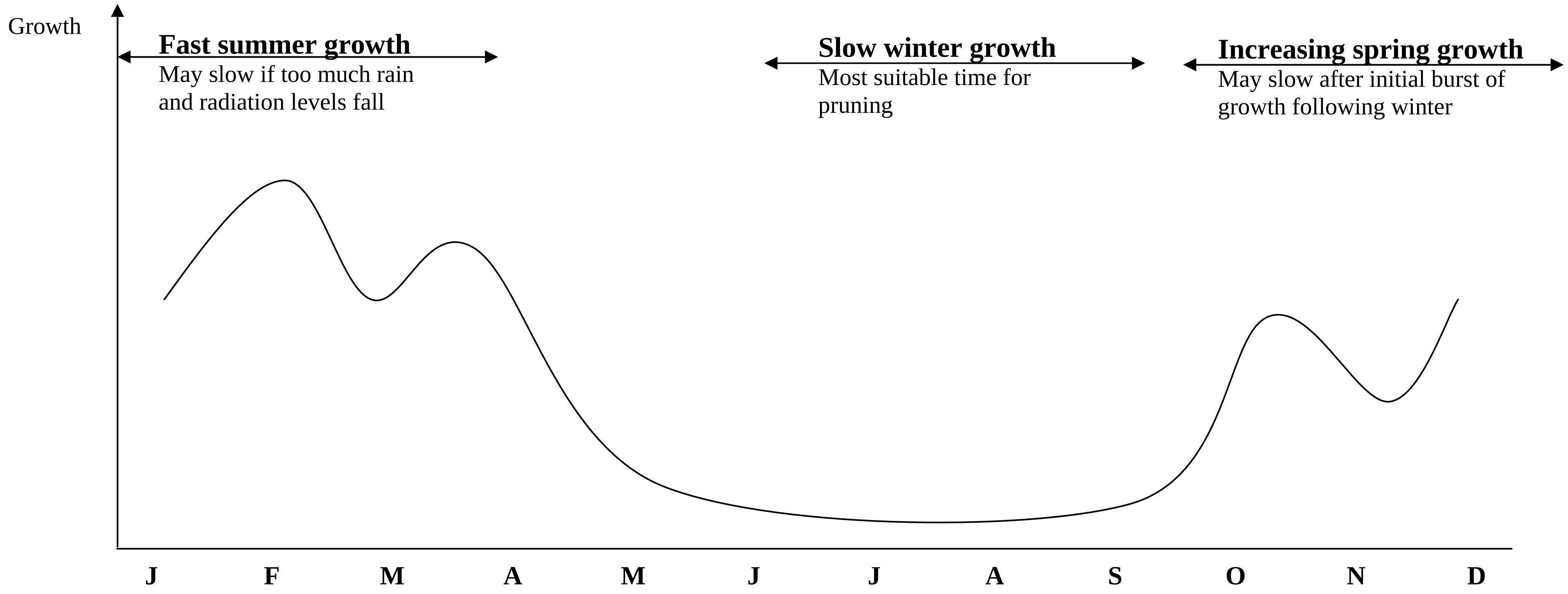
For the major nutrients the following table gives the recommended rates depending on the expected yield.

Expected Yield	2-2.5 t/ha	4-4.5 t/ha
N	200-250 kg	400-450 kg
P	10-20 kg	15-30 kg
K	80-120 kg	150-200 kg
S	6 kg	15 kg
Cu	6 kg	15 kg
Mg	6 kg	15 kg

The micronutrients could be added to the soil in the overall fertiliser mix or individually using 10 kg/ha Cu or Zn SO_4, 10 kg/ha Solubor or 10 kg/ha Fe SO_4.The poor soil availability of Zn and Cu suggest these nutrients should be added via foliar applications, 1% Cu and Zn Sulphate plus 1% Urea and a wetter is recommended.

Tea growers are encouraged to keep records of fertiliser inputs and yields and to conduct one leaf and soil sample each year so that the yield responses to fertiliser practices can be monitored and adjusted as necessary over time.

Tea Growth Pattern



CLIMATE

Temperature Radiation Humidity Rainfall Day length	High	Decreasing	Low	Increasing

FERTILISER

Amounts
(% of annual total)

6 applications	16%	16%	16%	16%	16%	16%
5 applications	20%	20%	20%	20%	20%	
4 applications	25%	25%	25%	25%		

Times

Increase growth rates with frequent small applications through the growing season. This will reduce losses through leaching & erosion and minimise environmental impacts.

Extend growing season with late summer application. Add extra K and P to aid recovery from pruning.

Ensure strong early growth by applying fertiliser with the first storms.

Increase growth rates with frequent small applications through the growing season (≈ every 6 weeks). Consider foliar Zn & Cu applications.

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